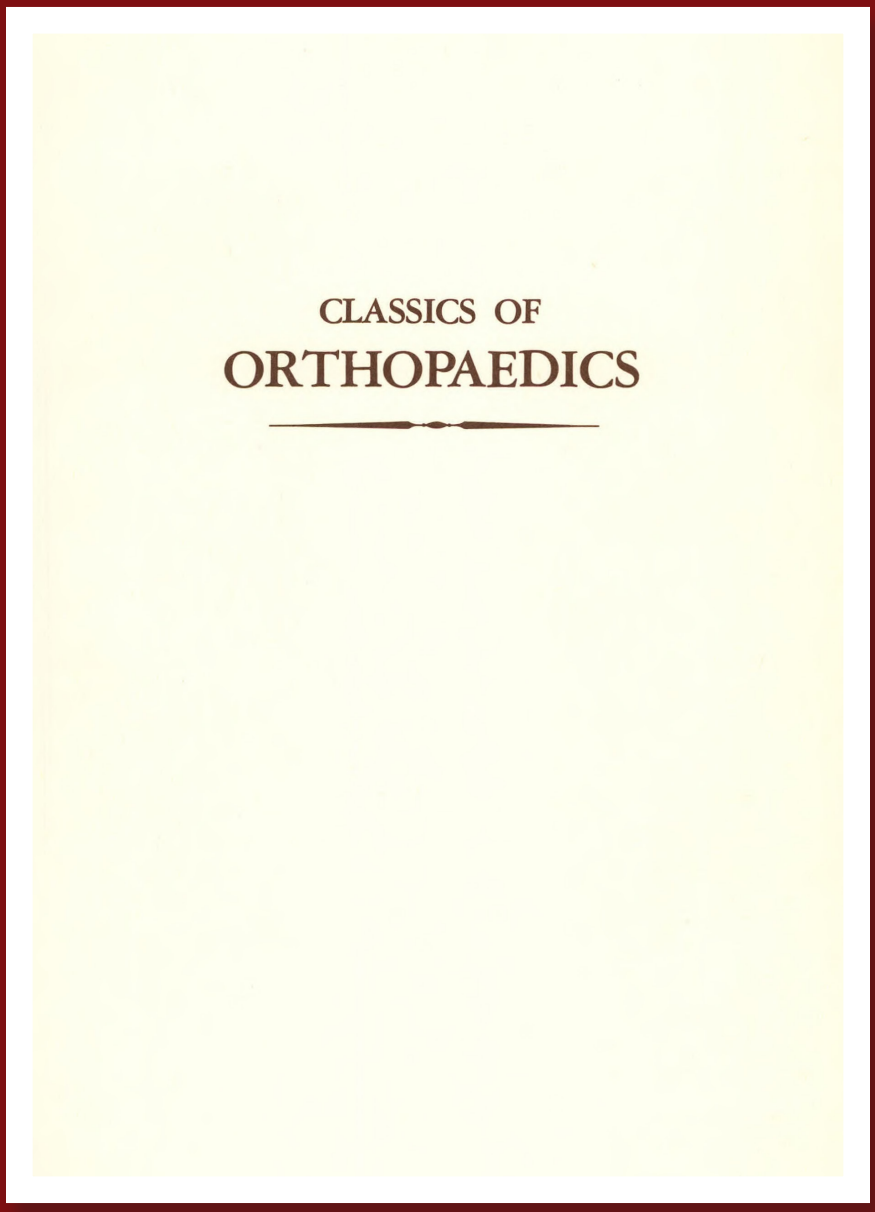
Classics Of Orthopaedics



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CLASSICS OF ORTHOPAEDICS

Edited with bibliographic notes by

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Marshall R. Urist, Editor-in-Chief

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To Dale and Anne

PREFACE

Starting with volume No. 26, 1963 and continuing with few exceptions in all subsequent issues, each number of *Clinical Orthopaedics and Related Research* has been introduced with a reprint in English, either complete or edited, of a classic publication related to the subject of its symposium. These have been chosen from the historically modern era, that is, no earlier than the late 17th century. A number of the foreign language writings are appearing for the first time in English.

Since the choice of the Classic was related to the subjects of the Symposia, this book is not a freely chosen anthology. It is hoped the Classics will continue to be published and at proper intervals be issued in book form. If so it be, then as in earlier transitional periods, the best of our immediate past and present will be preserved easily available for future readers, and perhaps many research hours and reams of paper saved.

The intellectual difference between the humanities and the sciences lies in the immutable essence that a Plato may be born tomorrow and create a philosophy or literature from his or her personal cerebration, whereas the sciences advance at times with striking originality but always developed or varied from the accumulation of preceding and available observations.

Most of the material in this volume comes from the Library of the New York Academy of Medicine and its famous portrait collection. I have been grateful to its most efficient and dedicated staff for many years.

The preparation of the material for publication both in *Clinical Orthopaedics and Related Research* and in this volume owes much to Miss Helen L. Kleinwechter, O.N.A., who for some years has been my indefatigable editorial assistant.

To Marshall R. Urist, my Editor in Chief, I might add that if in the field of the printed word all Associates enjoyed the same encouragement and co-operation which has existed between us, we might be living in a less contentious world.

EDGAR M. BICK, M.D.
Associate Editor
Clinical Orthopaedics
and Related Research

INTRODUCTION

Marking articles of orthopedic history has been the avocation of Edgar Bick for nearly a half century. He has abridged books and condensed monographs by deleting only such illustrations or embellishments as are too numerous to reproduce in one volume. As the object is to select epochal articles and make them conveniently available in one place, this volume is bound to become an instrument for teaching residents as well as for continuing education programs for practicing surgeons. Some readers will find the time reading this one book better spent than perusing hundreds of current articles in the library.

The realization that all the best brains in orthopedic surgery are not now alive will come to the reader at once. Some of the most creative and inventive surgeons that ever lived are known now only by their progeny or by some scientific article. Many of the most productive orthopedic surgeons of all time walked the wards of antiquated hospitals, now long since demolished and replaced by new ones. In some instances, the names of the medical schools and hospitals survive, but while the patients, the doctors, and the old buildings are gone, their contributions to medical science are immortal.

The orthopedic professors of the yesteryear were often versed in literature and the arts as well as science, and this broad background is expressed in the quality of their writing. The subject and the writer's style are perfectly blended to communicate his views and anticipate questions raised by either protagonistic and/or antagonistic colleagues. Medical historians will refer to the original sources for the illustrations and the unabridged versions. Nothing less than direct contact with the original is necessary for some readers. For others, Bick's reproductions suffice to show that in the writer's time, the disease was something that was seen many times before by many people without really recognizing it as a special entity. With the same educational background, the same diagnostic tools, the same surgical instruments that were available to everyone, the author of a classic made an unmistakably original observation and, at the same time, a fundamental advance in orthopedic diagnosis and treatment.

Once an article becomes a classic, the words of which it is composed become working tools just as essential to everyday orthopedics as a new surgical instrument. For Edgar Bick, the Lippincott Company, and the Association of Bone and Joint Surgeons who conceived this volume, bravo!

MARSHALL R. URIST, M.D.
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Los Angeles, California

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CLASSIC 1

Injury of the Spinal Cord Due to Rupture of an Intervertebral Disc During Muscular Effort

GEORGE S. MIDDLETON, M.D. (1853–1928)

AND

JOHN H. TEACHER, M.D. (1869–1930)

The following case is of interest, because it seems to throw light upon certain cases of spinal myelitis and haemorrhage into the spinal cord arising out of strains and racks of the back in men engaged upon heavy work. So far as we are aware, the lesion is one which has not hitherto been observed, as we have been unable, after considerable search in literature and enquiry among pathologists and surgeons, to find any record of an exactly similar case.

SUMMARY

A man was lifting a heavy plate from the floor to a bench, when he felt a "crack" in the small of his back. He suffered intense pain, and was unable to straighten himself. Paraplegia soon developed, and patient died sixteen days later, principally from the effects of bedsores and septic cystitis. The cause of the paraplegia was haemorrhage and softening in the lumbar enlargement of the spinal cord, and the cause of this was found in a mass of the pulp of an intervertebral disc which had been displaced into the vertebral canal.

Read at a meeting of the Medico-Chirugical Society of Glasgow held on 3rd March, 1911.

HISTORY OF THE CASE

W. M., age 38 years, engineer's labourer, was admitted to Glasgow Royal Infirmary on the 12th February, 1910, under the care of Dr. Paterson, and transferred to Dr. Middleton's ward on 16th February. The history of the case was as follows:

At 6:30 A.M. on 8th February, while patient and another man were lifting a heavy plate from the floor to a bench, he "felt something crack in his back." He could not stand up straight, but had to go bent on account of pain and a feeling of weakness in his back. He remained for about a quarter of an hour at the works trying to "straighten himself," and then walked home —two or three minutes walk—without assistance, unable to straighten his back, but not conscious of any loss of power in his legs. The metal plate was to be placed on a bench, about 3 feet in height, so that he had not to raise his arms to any height. He was assisted by another man, who apparently has not suffered in any way, and M. himself said he had lifted heavier weights many a time without injury.

When he reached home he sat in a chair, fairly comfortable, except when he moved;

movement causing intense pain from the back around both sides, evidently not a girdle character. He was seen about 1 o'clock by his doctor, who ordered him to bed. He was able, with assistance, to walk over to his bed, but it is probable that he had even then lost some power in his legs, as he said he could not stand, and his legs gave way under him; he himself attributed the difficulty to the "excruciating pain in the back."

In bed he lay most uncomfortably, turning and twisting in his efforts to find a comfortable position, and suffering much pain in his vain endeavours to do so. He evidently had no great difficulty in turning in bed or moving his legs. He was sick, but did not vomit. He took some supper on the night of the 8th, but no solid food thereafter. That night he passed water normally for the last time. Between 2 and 3 o'clock in the morning of the 9th he felt a sudden agonizing pain shoot down "from his chest to his feet," with peculiar sensations as if the limbs were "sleeping." This feeling passed away in a short time, and he then found he could not move either limb. Prior to this he was not aware of any paralysis. His arms were not at all affected. He thought the condition grew worse instead of better as the night wore on, but from his statement there must have been almost complete paralysis immediately after the sudden pain. His bladder and bowels now became paralysed, and after two days his doctor was again called in. Two days later he was sent up to the surgical wards as a case of intestinal obstruction. His bowels moved in the ambulance van without his knowledge.

Condition on admission. There was great distension of intestines and bladder. The urine was ammoniacal, with some pus in it. Both legs were absolutely paralysed, and were flaccid. The knee-jerks, and all reflexes of the lower limbs and the cremasteric reflexes, were absent. There was also complete anaesthesia and analgesia of the lower limbs as high as Poupart's ligament.

Patient was rather flushed in the face, and seemed to be in pain. Both his legs were atrophied in their whole length, the gluteal muscles sharing in the atrophy. Both sides were affected equally. Rigidity was beginning to set in.

On his back, at the upper part of his buttocks, there were two bedsores, or rather "acute decubital" sores—that on the left was the more advanced, and its centre was black and sloughing. The heart and lungs appeared to be normal. Temperature, 98·8°; pulse, 80; respiration, 24. He had always been healthy; not a drinker; a light smoker; and there was no history of syphilis.

Patient grew steadily weaker, the signs of septic infection of the urinary tract more pronounced, the temperature rose, and rigors occurred. He died on 24th February, sixteen days after the accident.

Post-mortem examination (20th February, 1910, No. 6,253).

External appearances: A small, strongly-built man, somewhat emaciated. No external signs of injury. Bedsores in the sacral region. No irregularity of the vertebral column could be made out either externally or internally after opening the canal. It was noted that the backs of the vertebral bodies seen through the vertebral canal appeared rather more porous than usual. There was no blood clot outside the dura mater.

Spinal cord: The spinal cord was removed, and the dura mater opened very carefully from behind. There was marked softening of the lumbar enlargement with brown staining, indicative of some haemorrhage into the cord, but there were no blood clots. From about the upper end of the lumbar enlargement the cord appeared to be normal. After a cursory inspection it was placed in a 5 per cent solution to harden.

The brain appeared perfectly healthy.

The internal organs showed early hypostatic pneumonia at the base of the left lung, and septic cystitis, pyelitis and abscesses in the kidneys.

Further examination of the spinal cord after hardening. The cord contained no distinct large haemorrhage, but there was much blood in streaks through several segments of the lumbar enlargement. There was also a segment of cord, about a quarter of an inch in length, well down in the lumbar enlargement, which was thinner than the rest, and appeared to have been crushed. Opposite this, entangled in the loose fibrous tissue, on the exterior of the dura mater, there was an irregular, roughly circular flat mass of firm white tissue, which looked rather like the pulp in the centre of the intervertebral discs. Microscopic sections showed the structure characteristic of the pulp of the intervertebral discs. The mass measured about 15 mm. in diameter by 5 mm. in thickness. Its margins were ragged, with a few red blood corpuscles clinging to them and entangled in the shreds. There was no sign of inflammatory reaction about it. It lay on the front of the theca of the cord, somewhat to the right of the middle line, and extended as far back as the line of exit of the nerve roots.

Microscopically, the spinal cord showed advanced softening, with degeneration amounting almost to necrosis in the central parts, and much diffuse blood infiltration. This condition extended some distance above and below the crushed segment. There was early secondary degeneration of the various tracts of the cord. The softened parts were full of compound granular corpuscles. A Thrombosed vessel was found in the section of the cord which showed most haemorrhage.

The nature of the injury was quite clear. The cord had been compressed, and softening (myelitis) of considerably wider extent than the area actually injured had followed. Probably the injury to the cord was increased by the movements of the patient during the twenty hours following the accident, and the sharp pain which then occurred and the paralysis which ensued were due to the occurrence of haemorrhage into the cord.

The body which caused the injury, and its nature and source, are also clear. The position which it occupied is that to which it would be directed by the powerful ligament which lies on the posterior surface of the vertebral bodies in the middle line. Unfortunately the portion of intervertebral disc was not noticed until the day after the examination, and it was impossible to obtain another examination of the body; but injury or displacement of the vertebrae of the common types had been searched for, and can be excluded.

From the position of the injury to the cord it is probable that the disc which gave way was that between the twelfth dorsal and the first lumbar vertebrae.

With regard to the mechanism of the injury, it can be inferred from the history of the case that the man, at the moment at which he felt the "crack" in his back, must have had his back more or less bent forward, with the lumbar and abdominal muscles in full action. This would cause powerful compression of the intervertebal discs, with the anterior margins of the vertebrae approximated to one another, and, therefore, in a favorable position for displacement of the pulp of the intervertebral disc backwards, if that were possible.

To test this theory of the injury experiments were made to see whether the pulp of the intervertebral disc could be squeezed out through the strong surrounding liagments, and the direction which it would take.

In one a successful result was obtained. The first three lumbar vertebrae from the body of a well developed man with no disease of the column were placed in a car-

penter's wooden vice, and pressure made rather more to the front than to the back. The cord and nerves had been cut out, leaving the dura in situ. It was noted before pressure that the position of the intervertebral discs was shown by slight bulging inwards. After pressure had been applied a definite rounded prominence could be seen opposite the disc between the first and second lumbar vertebrae, close to the side of the posterior longitudinal ligament.

The pressure had not been very powerful—certainly not enough to crush the bones at all. Repeating the experiment with more powerful pressure the swelling was seen to increase slightly.

The arches were then cut out and the dura mater raised. The rounded swelling was found with the fibrous outer layer of the disc intact. Pressure with an iron vice to crushing of the bone failed to produce any further swelling.

On cutting through the disc with a sharp knife it was found that the swelling actually was due to displacement of the soft pulp, which had forced its way through the inner fibrous layers of the disc as far as the outer sheath. The corresponding area on the other side was unchanged. The pulp of the disc had, therefore, been displaced, and it had travelled in the direction which it must have followed in the victim of the accident.

A case which presents a similarity to the present one in respect to the injury of the intervertebral disc without injury of the vertebral bodies has been recorded by Kocher. The cause of the condition was however, entirely different.

CASE OF JOH, MESSERLI*

A man, act. 26, fell 100 feet upon a stone pavement on his feet and walked 20 to 30 steps thereafter. He complained of burning sensation in the scrotum and penis and lower part of abdomen, and girdle pain in the horizontal navel line, and pain on sitting up in the region of the first lumbar vertebra. The spine of the first lumbar vertebra projected strongly and was painful to pressure. He had some difficulty in moving his lower limbs. Sensation was normal. There were many other injuries, including rupture of the bowel, from which he died in some hours. *Post-Mortem* examination showed fracture of the sternum and ulna, laceration of the jejunum, and peritonitis. There was complete smashing of the intervertebral disc between first and second lumbar vertebrae, and it had been squeezed out from between the vertebral bodies. The bodies themselves and the spinal cord appeared to be undamaged. There was a definite curvature at the level of the crushed disc. There is no information as to the direction in which the crushed out portions of the disc had travelled.

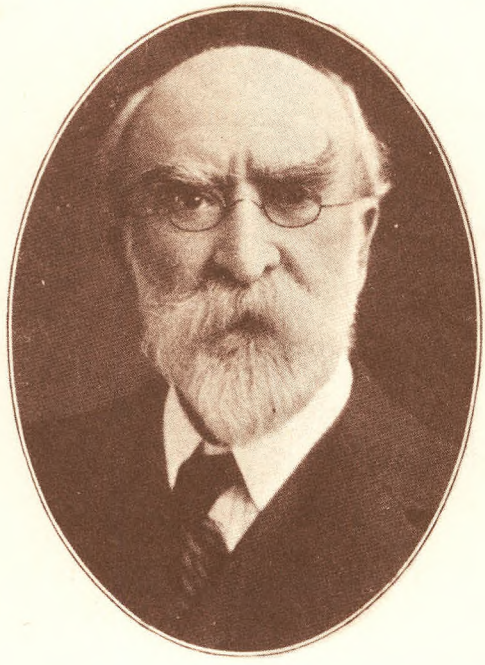
While this case is different in many respects from that now recorded, it shows that the intervertebral disc may be injured without visible injury of the vertebrae themselves, and this is confirmed by experiment. The rupture of an intervertebral disc during muscular effort may prove to be a very rare injury, but it may prove to be the explanation of certain cases the nature of which has been regarded as quite obscure, or which have been ascribed to the rupture of a vessel in the cord during exertion.

The opening paper in the July issue of the *Glasgow Medical Journal* in 1911 was a detailed report of the signs and symptoms of a severe intervertebral disk injury, including its postmortem findings. The authors were George S. Middleton and John H. Teacher of Glasgow. In the same year Joel E. Goldthwait published a paper of monographic proportions as an original article in the *Boston Medical and Surgical Journal* which was also based on a severely traumatized trisacral area. One full section of this long report dealt especially with the effect and the appearances of the lumbosacral disk herniation into the medullary canal. The

* *Mittheilungen aus den Grenzgebieten der Medizin und Chirurgie*, vol. 1, p. 420, *Jena, 1896.*

first of these papers is reprinted in full. Excerpts, especially the section dealing with the disk, are taken from Goldthwait's broader study of the lumbosacral area.

Pathologists had described the disk previously, and 2 years earlier, Goldthwait had suggested the possibility of a slipped disk causing sciatic symptoms, but the two reports published here formed the basis of those subsequent clinical and surgical studies by Barr, Beadle, Keyes and Compere, Mixter, and Naffziger, during the 1930's which defined our present concepts of this common lesion.



GEORGE STEVENSON MIDDLETON

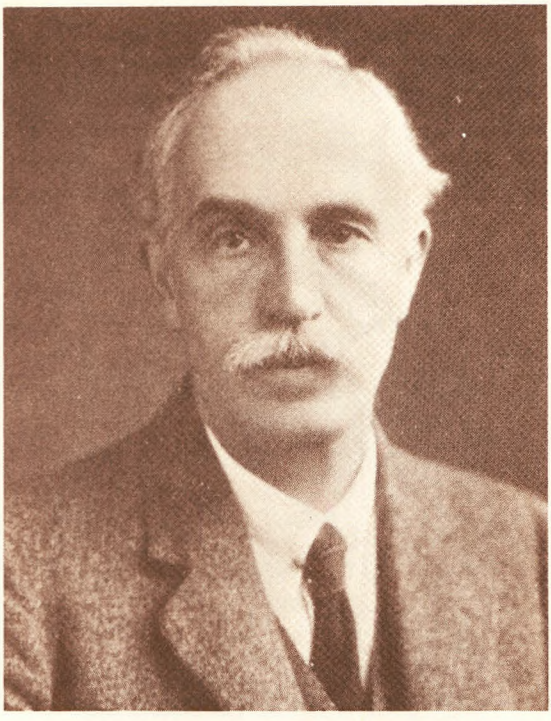
George Stevenson Middleton, M.A., M.D., LL.D., F.R.F.P.S.G., was born at Aberdeen on January 14, 1853. He received his early education at the Grammar School and later at the University of Aberdeen. He was graduated M.A., with honors, in 1873.

After his father's death the family moved to Glasgow where he entered the Faculty of Medicine at Glasgow University, and after a brilliant career was graduated M.B., C.M., with honors, in 1876. He worked with Sir Hector C. Cameron and Sir William Tennant Gairdner and eventually became assistant to the latter Professor.

In 1892, he was appointed visiting physician to Glasgow Royal Infirmary and there taught medicine with great acceptance. He instituted a Sunday class in medicine for postgraduate students—possibly the beginning of postgraduate education in Glasgow.

He was granted the honorary degree of LL.D. by the University of Glasgow in 1915 and was made an Honorary Fellow by the Glasgow Royal Faculty of Physicians and Surgeons in 1926.

His writings were mainly descriptions of unusual and interesting cases; they reveal his unusual powers of observation to the full. His thesis for the M.D., which he received in 1884, was pseudohypertrophic muscular paralysis. He gave an early account of the disease known as rat-bite fever. He died on March 21, 1928.



JOHN HAMMOND TEACHER

John Hammond Teacher, M.A., M.D., C.M., F.R.F.P.S.G., was born in 1869 and was graduated at Glasgow Academy and at the University of Glasgow, graduating M.B., C.M., in 1893.

He became one of the early specialists in the subject of Pathology, being assistant to Professor Coats at the Pathology Department at the Western Infirmary, Glasgow. Later he assisted Sir Robert Muir and became a lecturer on Pathology in the University of Glasgow.

His main interest was in gynecologic pathology, and his thesis was on chorionepithelioma. His first international fame came as a result of the "Teacher-Bryce ovum No. 1," the earliest ovum known at that time (1908):

In 1909 he became Professor of Pathology in the Royal Infirmary, and in 1911 he became St. Mungo Professor of Pathology of the University of Glasgow and Pathologist to the Royal Infirmary.

In 1924 he discovered the "Teacher-Bryce ovum No. 2." His textbook of gynecologic pathology was published posthumously in 1935.

In his early days he compiled the "Catalogue of the Anatomical and Pathological Preparations of Dr. William Hunter," and it is fitting that most of these are now housed in the Department of Pathology which he founded, in the Royal Infirmary. He died on November 21, 1930.

Biographical notes on Middleton and Teacher were graciously supplied by Mr. A. L. Goodall, Hon. Librarian, Royal Faculty of Physicians and Surgeons of Glasgow.

CLASSIC 2

The Lumbo-sacral Articulation

An Explanation of Many Cases of "Lumbago," "Sciatica" and Paraplegia

JOEL ERNEST GOLDTHWAIT (1866–1961)

An experience of the writer within the past year in connection with the treatment of a patient with a spinal lesion was so disastrous to the patient and so distressing to the writer that a series of investigations were started in the hope of bringing some relief to the patient and at the same time of preventing such happenings in the future. It is this study which represents the basis of this communication, and in order that it may be fully understood the case that led to it is first reported.

INTERVERTEBRAL DISK

Another element which was not at first appreciated, but which is undoubtedly of much importance as a direct cause of the paralysis, consists in the formation and possible displacement of the intervertebral disk, lying between the body of the vertebra and the sacrum. This structure, as is peculiar to the same structures in the rest of the spine, is made of two parts, one the peripheral or outer portion, called the "annulus fibrosus," the other the central portion, called the "nucleus pulposus." Histologically, the two parts are quite unlike, the outer part being made up of concentric layers of connective tissue fibers, and serves to assist partly in holding the vertebrae together, but probably the more important function is to hold the central or pulpous portion confined so that its shape can be preserved. The central portion is an oval mass of fibro-cartilage which exists under high pressure.

This is placed a little back of the center of the disk and practically represents the point upon which the weight of the body is balanced, motions of the body in bending being made upon this as a center. The pressure under which this pulpous portion exists and upon which its importance as the pivotal point in the body motion must depend is at once apparent if a sagittal section of the spine is made. In this, this "pulpous" or central portion bulges markedly, while the remaining or outer portion does not alter its position. At the same time, in such a section, the histological differences between the two portions of the disk is easily apparent.

If, now, with such a condition existing the spine is bent in any direction so far that the attachment of the outer or annular part of this cartilage is separated from the bone, the result must be that since the confining element of this central or pulpous portion is removed, it forces the detached outer portion outward and projects beyond the edge of the vertebra. If, now, this separation of the outer portion of the disk occur at the back, as might easily occur if the

articular process had been separated or displaced as has been described, the result must be that the detached portion of the disk is crowded backward and must narrow the spinal canal. If the articular processes have been separated upon one side, naturally the separation of the intervertebral disk will occur chiefly upon the side of the separation or away from the side toward which the body is bent. This would naturally result in there being more paralysis or irritation of the cauda equina upon one side. The projection of the disk into the canal when the posterior part is separated is shown in Figure 22. That which shows of the disk projecting backward in this drawing is schematic, since if the sagittal section were made the projection would naturally be toward the center, that being the direction of least resistance. To demonstrate actually the backward projection into the canal, the body of the vertebra must not be disturbed, but simply with the spinal canal exposed the attachment of the disk be loosened, in which case the projection of the disk is apparent. This can easily be demonstrated in any reasonably fresh subject, but is suggested in this manner as being more easily presented and more strikingly suggestive.

The projection of the central portion if the sagittal section of the body is made is so often seen and so easily demonstrated that illustration is not considered necessary.

Because of the structure of the disk if such separation occurred the projection of the disk and the possible paralysis would be gradual in development since the dense annular portion must be stretched by the central portion and would require some hours or possibly days for the full extent of the displacement to develop.

In the case here presented, probably this condition, as well as the displacement of the bones, existed or was produced. The patient had been very tired, so that he drooped the body as one does at such times, with strain and weakening of the posterior spinal ligaments. When in this condition in lifting, the sacro-iliac joint was slipped, this naturally leading to a temporary still greater weakening of the ligaments. This was followed, before he was fully well, and when the body was still used drooped, and with the back flat, by the strain in carrying the heavy suitcase as a one-sided load. In this weakened condition, in turning over in bed, the sacro-iliac joint was again displaced. With this displacement present, so that the muscles of the back could not work naturally for protection, and with the two sides of the sacrum changed as well as the relations of the crests of the ilia to the transverse process also changed, the body was drawn forward in trying to get out of the tub, with the result that the articular processes upon the side of the displaced sacro-iliac joint were drawn apart and the body was held drawn forward and to the left by the tip of the process of the fifth which had slipped forward over the oppossing process of the sacrum. This naturally led to the separation of the intevertebral disk, as has been described, and to strain or irritation of the nerves in this region, both inside and outside of the canal, explaining his great pain. The replacement of the bones at the sacro-iliac joint gave little if any relief because this was not the chief trouble. In placing the patient upon the frame the back of the body was straightened, but at the same time the already displaced articular process was still further displaced while the other process was drawn away from its normal position toward the center of the body and crowded against the cauda equina, causing the paralysis. The temporary relief by changing the position to the left side (this side was used simply because it was more comfortable than the other) is at once apparent, as is also the intense "rectal" pain which was located directly at the lumbo-sacral articulation, and any strain for voiding the urine or moving the bowels naturally not only aggravated the pain by causing motion of the spine, but because with the attachment of the rectum

at the side of the spine at this very articulation, the strained and damaged anterior ligaments were irritated. The effect of such displacement at the back upon the anterior part of the spine is well shown in Fig. 23, and easily explains the anterior or rectal pain.

The fact that the pain was increased whenever the patient was put upon the back with the legs straight is also understandable, the same explanation holding for the sensations which developed when the x-ray was taken and also when the jacket was applied after the operation. It also explains the relief of this sensation instantly obtained by raising the buttocks. In such position not only would the articular process be forced more firmly into the canal, but naturally anything which tends to hyperextend the body must compress the posterior portion of the intervertebral disk, with the result that the movable or unattached portion would be crowded outward still farther into the canal. This would naturally be corrected by flexing the body slightly so that the space at the back of the vertebra would be increased, and into this the disk would naturally retract.

The fact that the pain was not relieved by the operation is also understandable, because at this time the vertebra was not replaced nor was the probably displaced intervertebral disk confined: and while it is probable that with the increased space given for the cauda equina in removing the spinous process, sufficient room has been given so that the ultimate adjustment of the parts to their natural function will take place, the immediate relief under such circumstances could hardly be expected.

The actual paraplegia ensuing from such cases is probably not as rare as would at first be supposed is shown by the fact that during the preparation of this paper the writer has seen a patient in frequent consultation with Dr. A. H. Crosbie, in which paraplegia existed, due, not to actual displacement of the bones, as was demonstrated by operation, but in which the intervertebral disk undoubtedly caused the compression of the cord. In this case the compression should have been chiefly upon the right side; and the patient, by change of position or manipulation, could be given a paralysis of the right leg or both legs, depending upon the degree of compression of the posterior part of the intervertebral disk. This case will undoubtedly be reported fully later by Dr. Crosbie, but is here mentioned to show that probably such cases are not as rare as the first case suggested, and the writer cannot help wondering if some of the cases of so-called transverse myelitis or cases of paraplegia without bone or neoplastic disease are not due to these features.

JOEL ERNEST GOLDTHWAIT

Joel Ernest Goldthwait was born June 18, 1866, at Marblehead, Mass. He was descended from Thomas Goldthwait, an original member of the Massachusetts Bay Colony.

He was graduated from the Massachusetts State Agricultural College in 1885.

In 1890 he received his M.D. degree from Harvard and joined the staff of the Children's Hospital in Boston. Here he came into active contact with Bradford, the leading Boston orthopaedic surgeon of his day, and began working with him at Boston City Hospital.

From that time on Goldthwait practiced as an orthopaedic surgeon at the leading hospitals of his city.

In 1899 he was elected head of the first orthopaedic service at the Massachusetts General Hospital. After a long lifetime of work he died in retirement in 1961.

A biographical sketch, "Joel Ernest Goldthwait," by John G. Kuhns, M.D., was published in *Clinical Orthopaedics, No. 5,* 1955; pages 3-7.

CLASSIC 3 Rupture of the Intervertebral Disc with Involvement of the Spinal Canal

WILLIAM JASON MIXTER, M.D., (1880–1958)
AND
JOSEPH S. BARR, M.D. (1901–1964)

During the last few years there has been a good deal written and a large amount of clinical work done stimulated by Schmorl's[1] investigation of the condition of the intervertebral disc as found at autopsy. His work will stand as the most complete, painstaking and authoritative that has ever been done in this condition. This work, however, is purely pathological and it now remains for the clinician to correlate it with the clinical findings and apply it for the relief of those patients who are disabled by the lesion.

In the routine examination of spines from autopsy material he discovered that the intervertebral disc is often involved in pathological changes, the most common one being prolapse of the nucleus pulposus into an adjacent vertebral body. He found one or more such prolapses (Knorpel-knochen) in about thirty-eight per cent of the spines examined. He also discovered that in about fifteen per cent of the spines there were small posterior prolapses beneath the posterior longitudinal ligament, but concluded that they rarely, if ever, produced clinical symptoms. He attributed their presence to weakening of the annulus fibrosus by degenerative changes, with mild trauma as a second factor, producing fissures in the annulus and escape of the semifluid nuclear material.

On the other hand, for a number of years clinicians have been reporting cases of spinal cord pressure from intervertebral disc lesions. In 1911 Goldthwait[2] reported a case of sciatica and paraplegia which he attributed to a posterior displacement of the intervertebral disc at the lumbosacral junction and suggested that such displacements might be the cause of many cases of lumbago, sciatica, etc. Middleton and Teacher[3] report a similar case confirmed at autopsy. Elsberg[4] in 1916 mentions chondroma of the vertebrae as causing compression of the cauda equina and states that Oppenheim has described a similar case. Mixter[5] in 1921 mentions a similar case and numerous other reports by Elsberg[6], Stookey[7] Bucy[8], Petit-Dutaillis and Alajouanine[9], and others have come into the literature. Thus the enchondroma, chondroma or ecchondroma arising from the intervertebral disc has become, to the neurosurgeon at least, a well-recognized lesion to be treated by excision and with a distinctly favorable prognosis. Dandy[10] in 1929 reported two cases from which he had removed loose cartilaginous fragments protruding extradurally into the spinal canal. He considered them "undoubtedly traumatic" in origin.

Our interest in this group of cases was stimulated particularly by a case seen by us two

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Read at the Annual Meeting of the New England Surgical Society, September 30, 1933, at Boston.

Mixter, William Jason—Chief of Neurosurgery, Massachusetts General Hospital. Barr Joseph S.—Orthopedic Surgeon to Out-Patients, Massachusetts General Hospital. For records and addresses of authors see "This Week's Issue," page 234.

years ago in which the main symptoms were referable to root pain and in which the tumor was situated in the intervertebral foramen without cord or cauda equina compression of any moment.

Investigation of the cases of spinal cord tumor treated at the Massachusetts General Hospital and in our own private practice has shown a surprisingly large number of these lesions, classified as chondromata, to be in truth not tumors of cartilage, but prolapses of the nucleus pulposus or fracture of the annulus. We have attempted to review these cases and differentiate true neoplasm and masses caused by rupture of the disc. We find as a result of this review that nineteen of our cases are rupture of the disc and six are true cartilaginous tumor or unclassified.

Clinically these cases of disc rupture, particularly the more recent ones, are of considerable interest. Diagnosis has been made difficult and operation has been delayed in them on account of the indefinite nature of the symptoms and signs and their similarity to those found in various conditions such as back strain, arthritis, sacro-iliac disease, etc.

A summary of all cases of ruptured intervertebral disc is shown in table 1. For the purposes of this article abstracts of two cases will suffice.

CASE 4: On February 6, 1933 a white married chauffeur, aged 28, was admitted to the Massachusetts General Hospital. He gave a histoy of gradually increasing stiffness of his legs, noticed chiefly in walking, and of increasing numbness of the fourth and fifth fingers of each hand. The onset was insidious about six months before admission. He had been treated for cerebrospinal syphilis for three months.

P. H.: Essentially negative. There was no history of serious trauma.

P. E.: Showed definite hypesthesia over the ulnar distribution of each hand and very mild sensory disturbance of the trunk extending downward from the level of the nipples. There was definite spasticity of the legs with hyperactive knee and ankle jerks, bilateral ankle and patellar clonus, bilateral positive Babinski sign. Biceps and triceps reflexes were also increased.

Combined cistern and lumbar puncture was done. There was alteration in the dynamics in the lower needle indicative of a partial block. The total protein of the fluid from the cistern was 17, and of the lumbar fluid 52. If 40 milligrams be considered the upper limit of normal, then the lumbar fluid shows definite elevation in total protein. By injection of 2 cubic centimeters of iodized oil into the cisternal needle the block was localized at the level of the intervertebral disc between the fifth and sixth cervical vertebrae. Note that in the lateral view (fig. 4) the block is shown, and that the intervertebral disc is narrowed and there are hypertrophic changes present. After some delay the oil passed the point of obstruction and descended into the lower end of the dural sac. The patient was then placed on a fluoroscopic tilt table, head down. Another x-ray showed that the return of the iodized oil to the cistern was blocked at exactly the same point as on its descent.

Cervical laminectomy disclosed a spinal cord compression by an extradural encapsulated fibrocartilaginous mass 1. 5 x 0.8 x 0.3 centimeters in size. The tumor lay in the midline in front of the cord and was exposed by rotating the cord and incising the anterior dura. It was easily removed from the underlying intervertebral disc.

Microscopic examination of the mass showed a homogeneous matrix containing elastic fibers and occasional cartilage cells. There was no evidence of malignancy.

CASE 14: A twenty-five year old white man was admitted to the Massachusetts General Hospital June 15, 1932 complaining of pain and stiffness in his left leg of two years' duration. A few months before the onset the patient sustained a severe ski fall, but had no immediate disability. He noticed at first only mild discomfort in his back and the posterior portion of his left thigh, but it increased gradually until he was unable to work. The pain radiated down the posterior thigh, calf and into the heel. There was a little discomfort in the other leg. He finally consulted one of us, who treated him with adhesive strapping and corset to support his back, with a tentative diagnosis of low back strain. He spent several months in absolute recumbency on a Bradford frame without relief. On account of lack of improvement it was decided to institute a complete neurological investigation.

On admission he presented the clinical picture of a man suffering from an extremely acute back strain. He stood with his knees flexed, the

trunk listed forward and to the right. The motions of the lumbar spine were almost abolished by muscle spasm. Straight leg raising was limited to 25° on the left and 80° on the right. Neurological examination was negative except for absent ankle jerk on the left. There was tenderness along the course of the sciatic nerve, especially in the sciatic notch.

Lumbar puncture showed questionable partial block and a definite elevation in the total protein to 108 milligrams. Lipiodol examination was negative.

On June 29, 1932 an exploratory laminectomy from the second lumbar to the first sacral inclusive, was done. After prolonged search a mass one centimeter in diameter was found in the intervertebral foramen pressing on the left fifth lumbar root and displacing the cauda equina to the right. It was removed piecemeal from the intervertebral disc and the wound was closed. Recovery was complete and uneventful. He had complete relief from pain immediately after the operation and has remained well since his recovery from the operation.

Pathological examination of the specimen showed it to be composed almost wholly of dense eosin staining fibrous connective tissue characteristic of annulus fibrosus. The original report classified this specimen as a chondroma.

The symptoms and signs of these so-called chondromata, which we believe in most instances represent rupture of the intervertebral disc, have been discussed at length by Elsberg and Stookey. The symptoms depend entirely on the location and size of the lesion. There is often a history of trauma not immediately related to the present condition. Numbness and tingling, anesthesia, partial or complete loss of power of locomotion, are usually present. Bladder and rectal sphincters may be involved. The condition of the reflexes varies with the level of the lesion. If it is compressing the cauda equina the tendon reflexes may be absent; if higher, compressing the cord, the legs may be spastic and the reflexes exaggerated with positive Babinski sign. If the lesion is low in the spine, the physical examination may be suggestive of low back strain or sacro-iliac strain. X-ray examination may be entirely negative, but narrowing of the intervertebral space is often present and is of significance, as it ordinarily means escape of the nucleus pulposus, not necessarily but possibly into the spinal canal. Lumbar or combined puncture and lipiodol examinations are of real value. If the mass is large, a partial or complete block is demonstrable at the level of the lesion. The spinal fluid rarely contains more than one or two cells, but the total protein in all of our cases was elevated moderately.

It so happens that most of the cases in this group have been operated on by one of us (W. J. M.) and not by a large number of surgeons; therefore we have developed certain ideas as to the operation when we suspect this lesion to be present. Exposure of the spine and laminectomy are performed as usual except that the laminectomy is narrow and on the side where the lesion is suspected, for we believe that a ruptured disc is a weakened disc and the strength of the spine should be preserved as much as possible. The dura is opened and the spinal canal carefully explored, particular attention being given to the intervertebral discs in front of the cord and the intervertebral foramina. If the lesion is found in the midline it is approached by incising the dura over it as suggested by Elsberg. If it is lateral, the dura is closed and the dissection carried out to the side between the dura and the bone. If a lesion is suspected in the intervertebral foramen it may be necessary to carry the removal of bone well out to the side, even taking in part of the pedicle. One must always remember that the tumor may be very small and extremely difficult to find on account of its position in the intervertebral foramen. After the tumor is exposed removal is a simple matter. It frequently comes away without any dissection and if not, section across its base or removal with a curette is bloodless. Though we have done it in only two cases, we believe that it may be advisable to slip bone chips in between the stumps of the laminae before closing the wound, in order to facilitate fusion. After removal of the torn piece of the

disc one frequently finds an opening through which a probe or half length may be passed into the nucleus pulposus. An interesting point is the appearance of the specimen before and after removal. The tumor in situ usually has the appearence of a half a pea with its flat side against the intervertebral disc, but as soon as it is removed it tends to unroll and can often be flattened out like a crumpled bit of wet blotting paper or a rolled up piece of fascia. The true chondromata on the other hand are rounded or lobulated masses of almost translucent cartilaginous tissue.

The microscopic picture of these chondromata is quite at variance with that of the normal disc. The chondroma is composed wholly of well-formed cartilage cells. The extruded portions of the intervertebral discs on the other hand may have occasional normal cartilage cells, but for the most part are made up of the different elements of the annulus fibrosus and nucleus pulposus, such as very poorly differentiated atypical cartilaginous cells scattered irregularly in a very granular and loose reticulum. The compactness of a true chondroma is not seen in this group.

We conclude from this study:

That herniation of the nucleus pulposus into the spinal canal, or as we prefer to call it, rupture of the intervertebral disc, is a not uncommon cause of symptoms.

That this lesion frequently has been mistaken for cartilaginous neoplasm arising from the intervertebral disc.

That in reality rupture of the disc is more common than neoplasm; in our series in the ratio of three to one.

That this lesion should be borne in mind in the study of certain orthopedic conditions, particularly in those cases which do not respond to appropriate treatment.

That a presumptive diagnosis may be made in many instances and that operation whether for this or for supposed spinal cord tumor should always be planned with the possibility of finding this lesion.

That the treatment of this disease is surgical and that the results obtained are very satisfactory if compression has not been too prolonged.

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NOTE: Since the reading of this paper before the New England Surgical Society in September, 1933 we have obtained G. Mauric's monograph on the intervertebral disc published in Paris by Masson et Cie in 1933.

This monograph covers many of the points touched upon in this communication. It is a most complete and exhaustive study of the subject and includes a voluminous bibliography.

It is interesting to note that his deductions are drawn from exhaustive studies and review of the literature while ours are from a small group of personal cases. Notwithstanding this difference of attack, our conclusions are in substantial agreement. Anyone interested in this subject is advised to read this monograph which is too long and complete to be reviewed here.

DISCUSSION

DR. JOSEPH BARR (By invitation): *Members of the New England Surgical Society*—I appreciate the privilege of being allowed to have a part in the presentation of this paper. Dr. Mixter has operated on almost every one of the cases and I have been primarily interested in the orthopedic aspects of some of them. It is worth while to stress the anatomy of the disc, as it is almost impossible to appreciate what appears in these lesions without knowing the anatomy.

(Figure 1.) The annulus fibrosus is a fibrocartilaginous semi-elastic tissue which completely incloses the nucleus pulposus. The nucleus pulposus is composed of remnant cells from the notochord in a semi-gelatinous matrix containing elastic fibrils. In the adult the water content of the nucleus is 75 to 90 per cent, which means that it is a semi-fluid mass and if the annulus is injured, either from trauma or degeneration so as to produce a break in its continuity or weakening of the wall, the nucleus pulposus will herniate or extrude. If the extrusion takes place posteriorly into the vertebral canal or either intervertebral foramen, symptoms of spinal cord or root pressure are thus produced.

Dr. Benjamin Castleman, Resident Pathologist at the Massachusetts General Hospital, and I have compared the histology of the material removed at operation from eighteen cases with the histology of intervertebral disc and we have have found that seven of the specimens represent purely annulus tissues, four cases nucleus pulposus only and seven contained elements of both annulus ad nucleus pulposus.

It is interesting to note that in ten of the nineteen cases the lesion was either between the fourth and fifth lumbar vertebrae or the fifth lumbar and the sacrum. Every one of these cases had some clinical symptoms and signs which are associated with back strain, i.e., sciatic pain, low back pain, stiff back with limitation of straight leg raising, etc. In other words, they were cases which clinically resembled lumbosacral or sacro-iliac strain, and several of them were treated under this diagnosis for a considerable period of time. I know of no way of accurately ruling out intervertebral disc lesions in cases of low back strain with sciatica by clinical examination. If the patient fails to respond to correct orthopedic treatment, the case certainly warrants complete neurological examination and lumbar puncture. If the total protein is elevated or there are signs of block, either partial or complete, a lipiodol injection and finally a laminectomy may be the only means of settling the diagnosis.

DR. ERNEST L. HUNT, Worcester, Mass.: I think we cannot be too grateful for work like this which will help us to clear up some of the distressing back conditions which so disable people and so often are shoved into the category of neurosis.

I can't add anything to this excellent presentation from personal experience, but the importance of it is clear to all of us. The approach in removing those particles is not wholly clear to me. I want to learn a little more about the subject by asking Dr. Mixter to tell us if he is able ever to get them by displacing the dura, not going through the dura.

I should think there might be a question as to when we should consider that lesion important enough or large enough to justify the rather severe operation of laminectomy; that is to say, are there instances in which the extrusion is small and in which with the passing of time nature would take care of it without the necessity of operation with its attendant risk, which apparently was five per cent in this group?

Clearly, to be able to get down and do something for this distressing result of back injury is very worth while. The newer methods of neurological investigation afford valuable help in the diagnosis of these conditions and I think we may draw from this paper a stimulation to make more careful and more thorough investigations before we decide we can't help very much.

DR. PHILIP D. WILSON, Boston, Mass.: I believe the paper by Drs. Mixter and Barr represents an important contribution and I am only sorry that the limitation of time did not permit them to present some of the aspects of the subject in greater detail. Naturally I am interested in the orthopedic aspects of the subject, and it is from this angle that I shall discuss it.

One of the common problems of orthopedic practice is the treatment of patients with so-called sciatic pain. We make an investigation of such cases, and in some we find extraspinal or intrapelvic causes, while in others we find evidence of disturbances of the sacro-iliac joints of a type sufficient to account for the symptoms. But there remains a group of cases in which we

are in great doubt as to the cause, and the management of which represents a problem. We have turned to our neurological friends for help, and they have generally been able to assure us there was no evidence of intraspinal tumor.

The work of Drs. Mixter and Barr has, however, begun to shed new light on this problem. Gradually with the accumulation of cases in which spinal punctures have been performed, one finding has assumed increasing importance, namely, a high total protein. Combined cistern and lumbar puncture has shown the high protein concentrated at the lower lumbar level. In some of these cases a rupture of the intervertebral disc between the fifth lumbar and the sacrum has been demonstrated at operation with sufficient protrusion of the disc to cause pressure on the spinal curve.

I believe these lesions are more common than we have supposed and now that we know how to look for them we will find them more often. A narrowing of the intervertebral disc can generally be demonstrated by x-ray, and a history of traumatic onset of the symptoms is also suggestive together with signs of impaired mobility of this segment of the spine.

DR. JOHN HOMANS, Boston, Mass.: I should like to ask in my ignorance why protrusion of an intervertebral disc should cause pain upon one side and, if it does, why operation should be of any value whatever. I can't get that through my head.

DR. DONALD MUNRO, Boston, Mass.: I should like to add my voice to the chorus of praise for Dr. Mixter's and Dr. Barr's work in presenting adequate information so that somebody else can get a chance to make new diagnoses.

I have had no personal experience with this matter. There are one or two points that I believe have been covered in their full paper and in which I am particularly interested. One is how frequently abnormal protein is found in the spinal fluid below the level of these tumors. Another is whether any attempt to relieve the pain by the injection of alcohol has been made. It would also seem to me from what little I know about it, that there must be a good many of the cases where the protrusion is small, it is not perhaps in direct contact with the nerve roots, and where perhaps some less radical procedure than the laminectomy might be expected to give some possible relief.

DR. WILLIAM JASON MIXTER: I am going to attempt to answer Dr. Homans' question first. A tumor far out to the side of the intravertebral disc will compress the nerve roots as they leave the spinal canal, causing severe root pain. The sheath containing the roots arches over such a tumor in the notch. There is no evidence of block in such a case, but there is increase in protein in the spinal fluid. I do not know why these patients have tenderness along the sciatic nerve. Does that answer your question?

DR. HOMANS: Absolutely! Thank you very much.

DR. MIXTER: There have been two or three cases which I have operated on expecting to find the lesions and in which I have had a negative exploration, and those we have not included in this presentation to-day because it seemed to us to confuse the picture. It is a difficult diagnosis to make and we have been wrong several times.

I think in the early cases where diagnosis is uncertain, as it is in many of these cases, adequate orthopedic treatment should certainly be tried out before laminectomy is done. They should be given adequate orthopedic treatment because we are distinctly uncertain as to the diagnosis and only the therapeutic test will tell the story.

I believe that if you give a patient adequate orthopedic treatment short of operative fixation by fusion, you have probably given him a sufficient test to know that a fusion operation will not cure the disability. I may be wrong, but it seems to me if you have given such cases fixation and they still have pain, then you have a right to go ahead and do a laminectomy.

I think fusion should be combined with operation where there is any question of an unstable spine, and I believe that a ruptured disc may be unstable.

Joseph Seaton Barr (1901–1964), born Wellsville, Ohio, Harvard 1926, became Orthopaedic Surgeon to the Massachusetts General Hospital; Chief of Service 1947, and Professor of Orthopaedic Surgery at Harvard Medical School in 1948.

William Jason Mixter (1880–1958), was Chief of Neurosurgery at Massachusetts General Hospital, and Professor of Neurosurgery at Harvard Medical School.

CLASSIC 4 A Treatise on the Blood, Inflammation, and Gun-Shot Wounds

JOHN HUNTER, M.D. (1728–1793)

III. OF THE STRUCTURE OF ARTERIES

THE arteries in an animal, as far as we can examine them, are endowed with the property of elasticity, the use of which we perceive in the action of those parts; and this power is at all times demonstrable, while the muscular has been by some overlooked, by others denied, and has only been asserted by others as appearing necessary by reasoning from analogy.

The quantity of elasticity in any artery, on which an experiment can be made, is easily ascertained, as it only requires the application of an opposing force, to prove both its power and extent. But it will appear from experiment, that the power varies according to the distance from the heart, being greatest at the heart; while probably the extent may be the same in every artery.

To endeavour to ascertain the elasticity of arteries, I made comparative experiments on the aorta and pulmonary artery. Having cut off a portion of about an inch in length from the ascending aorta, at half an inch above the valves, and having slit it up, it measured, transversely, two inches and three quarters, but when stretched to its full length, three inches and three quarters, having gained rather more than one third, and having required a force equal to the weight of one pound ten ounces to produce this effect. A similar section was made of the pulmonary artery in the same subject, which measured two inches one half, transversely; and when subjected to trial in the same manner, was stretched to three inches and an half, being rather more in proportion than the aorta; so that the pulmonary artery appears to have rather more elasticity than the aorta. It is not impossible that this difference might arise from the aorta having lost some of its elasticity by use; for although I chose for my experiment the arteries of a young man, where I conceived them to be perfectly sound, yet if there could have been any diminution of the elasticity from use, it would be most considerable in the aorta.

These experiments were made on different arteries with nearly the same result, and seemed to prove that there was almost the same extent of elasticity, though not the same powers.

An artery being composed of an elastic and inelastic substance, its elasticity is not altogether similar to that of a body which is wholly elastic. There is an effect produced from stretching it that is expressive of the nature of both these substances, till it gives way or breaks; for an artery has a check to its yielding to so great a degree, and is stopt at once, when stretched to a certain point*, which check is occasioned probably by the muscular, together with the internal inelastic coat.

To prove the muscularity of an artery, it is only necessary to compare its action with that of elastic substances.

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* This gives a determined size to an artery.

Action in an elastic body can only be produced by a mechanical power; but muscles acting upon another principle, can act quickly or slowly, much or little, according to the stimulus applied; though all muscles do not act alike in this respect.

If an artery is cut through or laid bare, it will be found that it contracts by degrees till the whole cavity is closed; but if it be allowed to remain in this contracted state til after the death of the animal, and be then dilated beyond the state of rest of elastic substances, it will only contract to the degree of that state; this it will do immediately, but the contraction will not be equal to that of which it was capable while alive.

The posterior tibial artery of a dog being laid bare, and its size attended to, it was observed to be so much contracted in a short time as almost to prevent the blood from passing through it, and when divided, the blood only oozed out from the orifice.

On laying bare the carotid and crural arteries, and observing what took place in them while the animal was allowed to bleed to death, these arteries very evidently became smaller and smaller.

When the various uses of arteries is considered, such as their forming different parts of the body out of the blood, their performing the different secretions, their allowing at one time the blood to pass readily into the smaller branches, as in blushing, and at another preventing it altogether, as in paleness from fear; and if to these we add the power of producing a diseased increase of any or every part of the body, we cannot but conclude that they are possessed of muscular powers.

The influence of the heart in the body, like that of the sun in the planetary system, we know extends to every part; all the parts of the vascular system being supplied according to the necessity it has, though every part is not equally endowed with power, or disposition to make use of that power.

The arteries, upon the whole, may be said to possess considerable living powers, and to retain them for a long time. This is evident when we observe what must happen in transplanting a living part of one body with an intention that it should unite with another body and become a part of it: the part transplanted must retain life till it can unite so as receive its nourishment from that into which it has been inserted. It is however to be supposed, that in such situations, life can be retained longer than in others, although it is well known that it is preserved in the vascular system, even when there is no colateral assistance. I found in the uterus of a cow, which had been separated from the animal above twenty-four hours, that after its having been injected and allowed to stand another day, the larger vessels were become much more turgid than when I first injected them, and that the smaller arteries had contracted so as to force the injection back into the larger. This contraction was so obvious that it could not but be observed at the time, which was forty-eight hours after the separation from the body of the animal.

This shews too the muscular power of the smaller arteries to be superior to that of the larger, and that it is probably continued longer after the separation from the body; a property which the involuntary muscles possess to a degree greater than the voluntary, in the former of which classes the muscular structure of the arteries is to be considered.

To ascertain how long the living power existed in an artery after separation from the body, perhaps, to speak more properly, after that communication with the body was cut off, by which we have reason to suppose life to be continued in a part, I made the following experiments, for which I chose the umbilical arteries, because I could confine the blood in them, and keep them distended for any length of time. In a woman delivered on the Thursday afternoon, the naval string was separated from the foetus; if was first tied in two places and cut between, so that the

blood contained in the chord and placenta was confined in them.

The placenta came away full of blood; and on Friday morning, the day after, I tied a string round the chord about an inch below the other ligature, that the blood might still be confined in the placenta and remaining chord. Having cut off this piece, the blood immediately gushed out, and by examining the cut ends of the chord, I attentively observed to what degree the ends of the arteries were open; and the blood having now all escaped from this portion, the vessels were left to contract with the whole of their elastic power, the effect of which is immediate.

Saturday morning, the day after this last part of the experiment, having examined the mouths of the arteries, I found them closed up, so that the muscular coat had contracted in the twenty-four hours to such a degree as to close entirely the area of the artery. That same morning I repeated the experiment of Friday, and on Sunday morning observed the result of this second experiment to be similar to that of the former.

On this morning, Sunday, I repeated this experiment the third time, and on Monday observed that the result had not been the same as before, the mouths of the arteries remaining open; which shewed that the artery was become dead.

There was but little alteration perceived in the orifices of the veins in all the experiments.

These experiments shew that the vessels of the chord have the power of contraction above two days after separation from the body.

Having given a general idea of muscular action, including muscular relaxation, together with the union of the muscular and elastic power in an animal, I shall now apply them to the arteries.

There are three states in which an artery is found, viz. the natural previous state, the stretched, and the contracted state which may or may not be previous.

The natural previous state is that to which the elastic power naturally brings a vessel which has been stretched beyond or contracted within the extent which it held in a state of rest.

The stretched is that state produced by the impulse of the blood in consequence of the contraction of the heart; from which it is again brought back to the natural state by the elastic power, perhaps assisted by the muscular.

The contracted state of an artery arises from the action of the muscular power, and is again restored to the natural state by the elastic. It has been shewn that certain muscles have both a voluntary and involuntary contraction, and that in some of these the involuntary action having brought the part to a necessary position, supports it in that state till it be either necessary for the muscle to relax, or for the voluntary action to take place; instances of which I have given in the sphincter muscles.

I shall now endeavour to shew that the arteries have a middle state; but that in them the power of bringing the coats into a certain position and sustaining them in it, is not the effect of a muscular but of an elastic power; and that the muscular action, both in contraction and relaxation, is involuntary.

In parts endowed with considerable elastic powers, although not apparently muscular, as many arteries, but which we yet know from other modes of information to be possessed of muscular power, elasticity is so combined as to produce a middle or natural state, by acting to a certain degree only as an elongater of the muscular part of some of its actions*.

These two powers, muscular and elastic, are probably introduced into the vascular system of all animals, the parts themselves being composed of substances of this description, together with a fine inner membrane, which

* We can hardly suppose that the muscular coat of the artery assists the elastic in bringing it to the middle state when already contracted within it.

I believe to be but little elastic, and this membrane is more apparent in the larger than in the smaller ramifications; although when we consider the construction and use of the arteries, we must at once see the necessity of their having these two powers; yet in the greatest number it is impossible to give clear occular demonstration of the existence of distinct muscular fibres. But still, as arteries are evidently composed of two distinct substances, one of which is demonstrably elastic, and we know them likewise to be certainly endowed with the power of contraction peculiar to a muscle, it is reasonable to suppose the other substance to be muscular; I shall endeavour also to prove its existence in such vessels, from their having a power of contraction in the action of death.

As the human body is always alluded to in this account, I shall found my experiments and observations on such animals only as have a similar structure, as in other animals, as the turtle, alligator, &c. we can plainly discern muscular fibres, the insides of the arteries and veins being evidently fasciculated with them.

Every part of the vascular system is not equally furnished with muscular fibres, some parts being almost wholly composed of the elastic substance; such as the larger vessels, especially the arteries, in which, were they equally muscular with the smaller vessels, the existence of muscular fibres might be more easily proved. Neither does the elastic substance equally prevail in every part; for many, especially the smaller arteries, or what have been called, the capillary vessels, appear to be almost entirely muscular; at least I am led to think so by my observations and experiments on that subject. From these I have discovered that the larger arteries possess little muscular powers, but that as they recede from the heart towards the extremities, the muscular power is gradually increased, and the elastic diminished. Hence I imagine there may exist a size of vessels totally void of elasticity; but this I should conceive to be in the very extremities only. For it is to be observed, that every portion of an artery, of a considerable length, is capable of assuming the middle state, which must be referred to the elastic power.

The greatest part of the arterial system evidently appears to be composed of two substance, which structure is most remarkable in the middle sized arteries, where the two substances are more equally divided, and where the size admits a visible distinction of parts. The best method to see this is to cut the vessels either across or longitudinally, and to look upon the edges that have been cut.

If the aorta be treated in this way, we shall find that though it appears to be composed of one substance, yet towards the inner surface it is darker in colour, and of a structure which differs, although but in a small degree, from that of the outer surface.

If we proceed by this mode of investigation, following the course of the circulation, we shall find that the internal and external parts become evidently more distinguishable from each other: the internal part which is darker, but with a degree of transparency, begins almost insensibly in the larger vessels, and increases proportionably in thickness, as the arteries divide, and of course become smaller, while the external, being of a white colour, is gradually diminishing, but in a greater degree, according to the diminution of size in the artery, and of the increased thickness of the other coat, so that the two do not bear the same proportion to each other in the small arteries, as in the larger.

The disproportion, however, between them appears greater than it really is, some deception arising from the greater muscular power, possessed by the smaller arteries, in consequence of which the inner coat will be more contracted, and therefore seem thicker. This circumstance alone makes the difference of thickness between the whole coats of a large artery, and those of a small one, appear less than it really is; accordingly we

find the coats of the humeral artery in the horse apparently thicker than the coats of the auxillary, the coats of the radial as thick as those of the humeral, and the artery near the hoof as thick in its coats as any of the others. There is yet another circumstance which also deserves attention in comparing the two coats, namely, that in many places, but especially at the surfaces of contact in the elastic and muscular substances of the middle sized arteries, the fibres of the muscular and elastic are very much blended or intermixed. I mention this, because otherwise we might be led to draw false conclusions, with regard to the comparative quantity of each substance; and, because it explains by what means both these coats are made elastic.

The external coat, however, is more so than the internal, being composed almost entirely of elastic substance, while the internal has a mixture of muscular with its elastic fibres. As there is, therefore, a difference in the elastic power of the two coats, there must be a difference in their powers of contraction after death; for instance, the external coat contracting more than the internal, and also, as there is a difference between the muscular and elastic powers of contraction, the muscular having the greatest, there must have been a difference between the contracting powers of these two coats during life, but contrary to that which takes place after death.

In those arteries, which are evidently composed of two distinct substances, especially in the smaller, we may observe two very opposite appearances, according as the elastic or muscular coats have contracted most. In the one, when we make a transverse section, and look upon the cut end, we may observe that the inner surface has been thrown into rugæ, so as to fill up the whole cavity; and if such an artery be slit up longitudinally, so as to expose its inner surface, we shall find that inner surface forming wrinkles, which are principally longitudinal. If the finger is passed over that surface, it feels hard, while the external is soft; but if the artery be stretched, and allowed to recover itself by its elasticity, which is the only power it now has, it will be felt equally soft on both surfaces, and its coats will be found to have become thinner than before. On the contrary, I have observed in many of the smaller arteries, when the muscular contraction has been considerable, the external or elastic coat to be thrown into longitudinal inequalities, from not having an equal power of contraction with the muscular, an artery under such circumstances being to the touch as hard as a cord. But if the muscular contraction be destroyed by stretching, or passing something through the artery, then it becomes very soft and pliant, and the muscular coat having once been stretched, without having the power of contracting again, is thrown into irregularities by the action of the elastic.

The elastic coat of an artery is fibrous, and the direction of its fibres is principally transverse or circular; but where a branch is going off, or at the division of an artery into two, the direction of the fibres is very irregular. I cannot say that I have found any fibres which are to a great degree oblique or longitudinal, a circumstance that shews their simple elasticity to be equal to the intention or use, a transverse or circular direction of fibres not being the most advantageous for producing the greatest effect*. They are also elastic laterally, from the direction of their fibres, which property shortens the artery when elongated by the blood; and I believe the muscles have little share in this action; the whole of which tends to shew that the elastic power is equal to the task of producing, and really does produce the natural state of the artery. What the direction of the mus-

* This is a principle in mechanics so well known, that it need not here be explained; we find it happily introduced in the disposition of muscles in various parts of the body.

cular fibres may be, I never could discover, but should suppose them oblique, because the degree of contraction appears greater than a straight muscle could produce, in which light a circular muscle is to be considered, as its effects are in the direction of its fibres; for either the diameter or the circumference of the artery will decrease in the same proportion, but not the area, which will decrease in proportion to the square of the diameter.

We should naturally suppose that where the action of the heart is strong, elasticity is the best property to sustain its force; and that where the force and elasticity are well proportioned, no mischief can ensue. Where the force, therefore, of the heart is greatest there is a degree of elasticity, which yields with reluctance, and constantly endeavours to oppose and counteract that force.

From these active powers of an artery, together with a foreign power, viz. the blood acting upon them in a manner somewhat similar to the common action of fluids in canals, protruding their contents, we may perceive that there are three actions which take place, all of them, operating in concert with each other, and producing one ultimate effect.

As the filling of the cavity of an artery produces an extension of its coats in every direction, the arteries are endowed with the elastic power, which, by contracting in all directions, may bring the vessels back again to their natural state.

The action of the muscular power being principally in a transverse direction, tends, when the artery is extended, to lessen its diameter, and assist the elastic power; but as its quantity of contraction is superior to that of the elastic power, it does or may contract the artery within what the latter could effect. When the muscular action ceases, elasticity will be exerted to dilate the vessel and restore it to a middle state again, becoming the elongater or antagonist of the muscular coat, and by that means fitting it for a new action as described in other parts of the body. This will be most evident in the middle sized vessels; for in the smaller, the proportion of elastic substance is not so considerable, and therefore it will contribute less to the dilatation of the vessel, when the muscular coat relaxes. Yet we must suppose that no vessel, even to its very extremity, is ever entirely collapsed; but that it possess an elastic power sufficient to give it a middle state. Although these differences do not in all cases bear the same proportion to the size of the artery, yet we must conclude there is in the arteries themselves a certain regular proportion preserved; and I am inclined to believe, that this is in some degree in an inverse proportion to the decrease of size, presuming at the same time that the muscular power increases in the same proportion. A vessel is stretched beyond its natural state, first by the force of the heart, and in succession by the first order of vessels; then it is that the elastic power is exerted to contract the vessel, and restore it to the natural size; and in the performance of this it will be more or less assisted by the muscular power, according to the size of the vessels; least in the larger, and most in the smaller vessels, as was observed above.

There appears to be no muscular power capable of contracting an artery in its length, the whole of that contraction being produced by the elasticity. For in a transverse section of an artery, made when the muscles of the vessel are in a contracted state, it may always be observed, that the external or elastic coat, immediately contracts longitudinally, and leaves the internal or muscular projecting; which would not be the case if there was a longitudinal muscular contraction, equal to the elastic; and were not the quantity of muscular contraction greater than the elastic there would be no occasion for muscles.

Another proof of this is, that if a piece of contracted artery be stretched transversly, or have its area increased and be allowed to

recover itself, it loses a part of its length. To understand this it will be necessary to know that muscular fibers, by contraction, become thicker, and in proportion corresponding with the degree of contraction in the muscle.

The thickening in the muscle of a horse was found to be an increase of one fourth part of thickness to one third of a contraction*; from which it follows, that the more the muscular fibres of any vessel contract, the more the vessel is lengthened; but destroy the muscular contraction by dilating the artery, and the elastic power, which acts in all directions, will immediately take place and restore the vessel to its proper size; which is a proof that the effect of the lateral swell, produced by the muscular contraction, is greater than that of the longitudinal elasticity of the artery.

If we examine how much the vessel has lost of its length in this trial, we shall find it will amount to about one twelfth of the whole; a proof that the internal coat does not contract so much longitudinally by its muscular power, as the external does by its elasticity. By multiplying such experiments we have further proofs that the power of muscular contraction acts chiefly in a circular direction; for in a longitudinal section of an artery in its contracted state, the internal coat does not project as in a transverse section, both coats remaining equal, or rather indeed the elastic coat projects beyond the other, from the internal muscular coat having contracted most. But if this section be stretched transversely, the external coat then contracts and leaves the internal most projecting; because the internal or muscular has now no power of contraction. If the transverse extention be repeated, and to a greater degree, the artery, when allowed to recover itself, will have its inside turned outwards, as well as bent longitudinally, having the inside of the artery on the outside of the curve, and often bringing the two ends together; but this is easily accounted for, as by the transverse extention of the artery its muscular contraction is destroyed, it becomes pliant, and the only resistance to the elastic power on this side being removed, it is allowed to exert itself to its utmost extent. In doing this it bends the section in a longitudinal direction, which also inclines us to believe, that the external part of the elastic coat, is the most elastic.

These experiments not only prove that the muscular power of an artery, acts chiefly in a transverse direction; but also, that the elastic power exists almost entirely in the external coat, and therefore that the internal coat must be the seat of the muscular power.

EXPERIMENTS on the arteries of a horse bled to death.

To ascertain the muscular power of contraction in the arteries, and determine the proportions which it bears to their elasticity, I made the following experiments upon the aorta, iliac, axillary, carotid, crural, humeral, and radial arteries of a horse.

In this animal the muscles were all allowed equally to contract, and therefore we might reasonably presume that the vessels (at least such of them as were furnished with muscles) would also be contracted, the stimulus of death acting equally upon muscles in every form, and every situation. The animal had also been bled to death, so that the vessels had an additional stimulus to produce contraction in them; as we know that all vessels in animals endeavour as much as possible to adapt themselves to the quantity of fluid circulating through them.

As I supposed the larger arteries had less of this power than the smaller, and that perhaps in an inverse proportion to their size, in order to ascertain that fact, and also to contrast the two powers, I made my first experiments upon the aorta and its nearest branches; continuing them on the other

* This calculation is not accurate; for in the experiments made to discover if the muscle lost of its size in the whole when contracted, I found it hardly did; therefore what it lost in length, it must have acquired in thickness.

branches as these became smaller and smaller.

The arteries were taken out of the body with great care, so as not in the least to alter their texture, or state of contraction.

The experiments were made in the following manner: I took short sections of the different arteries, slit them up in a longitudinal direction, and in that state measured the breadth of each, by which means as I conceived, I could ascertain their muscular contraction; then taking the same sections and stretching them transversely, I measured them in that state, which gave me the greatest elongation their muscular, and elastic powers were capable of. As by this extention I had entirely destroyed their muscular contraction; whatever degree of contraction they exerted afterwards must, I believe, have been owing to elasticity. Having allowed them to contract, I again measured them a third time in that state, and thus ascertained three different states of vessels, between which I could compare the difference either in the same or different sections, so as from the result to deduce with some degree of certainty the extent of these powers in every size of vessel. I say only with some degree of certainty; for I do not pretend to affirm that these experiments will always be exact; circumstances often happening in the body which prevent the stimulus of death from taking place with equal effect in every part. I have accordingly seen in the same artery some parts wider than others, even when the more contracted parts were nearest the heart, and this merely from a difference of action in the muscular power; for when that was destroyed by stretching, the parts contracted equally in both.

Experiment I. A circular section of the aorta ascendens when slit up and opened into a plane, measured five inches and a half; on being stretched, it lengthened to ten inches and a half; the stretching power being removed, it contracted again to six inches, which we must suppose to be the middle state of the vessel. Hence the vessel appeared to have gained by stretching half an inch in width or rather circumference, which may be attributed to the relaxation of its muscular fibres, whose contraction must have been equal to one-eleventh part; six inches being the natural size, or most contracted state of the elastic power.

Experiment II. A circular section of the aorta at the origin of the first intercostal artery, measuring four inches one-fourth, extended by stretching to seven inches and one-half; it contracted again to four inches and one half, and therefore gained one-seventeenth part.

Experiment III. A circular section of the aorta at the lower part of the thorax, on being stretched, and being allowed to contract again gained one-tenth part.

Experiment IV. A circular section of the iliac artery, measuring two inches, when stretched and allowed to contract again, measured two inches and four-twelfths, and therefore gained one-sixth.

Experiment V. A circular section of the axillery artery, measuring one inch, when stretched and contracted again, measured an inch and one-eight, therefore gained one-eighth.

Experiment VI. A circular section of the carotid artery, measuring six-twelfths of an inch, when stretched, measured sixteen-twelfths and one-half; and when contracted again, ten-twelfths; therefore had gained two-thirds.

Experiment VII. A circular section of the crural artery, measuring ten-twelfths, when contracted after being stretched, measured one inch and two-twelfths, therefore gained one-third.

Experiment VIII. The humeral artery, near the joint of the elbow, in a contracted state, was thicker in its coats than the axillary; the circumference of the artery in that state being seven-twelfths and one-half; after being stretched and contracted again, it

	Stretched to	Recovered to	Had contracted by death
Aorta ascendens	$5\frac{6}{12}$ inch.	$10\frac{6}{12}$ inch.	6 inch. — $\frac{1}{11}$ part.
Aorta descendens at first intercostal,	$4\frac{1}{4}$	$7\frac{6}{12}$	$4\frac{6}{12}$ — $\frac{1}{17}$
Aorta descendens at the lowest part,			$\frac{1}{10}$
Illiac artery	2	$2\frac{4}{12}$	$\frac{1}{6}$
Axillery	1	$1\frac{1}{8}$	$\frac{3}{8}$
Carotid	$\frac{6}{12}$	$1\frac{4}{12}$ $\frac{1}{2}$	$\frac{10}{12}$ — $\frac{2}{3}$
Crural	$\frac{10}{12}$	$1\frac{2}{12}$	$\frac{1}{8}$
Humeral	$\frac{7}{12}$ $\frac{1}{2}$	$\frac{9}{12}$	$\frac{1}{7}$ $\frac{1}{2}$
Radial	$\frac{3}{12}$	$\frac{6}{12}$	equal to the whole.

measured nine-twelfths, therefore gained one-third and one-half.

Experiment IX. A circular section of the radial artery being taken, was found so contracted as hardly to be at all previous; and the coats, especially the inner, much thicker than even the humeral: when slit up it scarcely measured three-twelfths of an inch; when stretched, and allowed to contract again, six-twelfths; therefore gained three-twelfths of an inch, which was about the whole contraction of the artery.

To see how far this power of recovery in the same artery took place at different distances from the source of the circulation, I made the following experiments on the spermatic artery of a bull; and likewise, on the artery of the fore-leg and penis. The spermatic artery, near the aorta, when stretched longitudinally, recovered perfectly the former length; when stretched transversely, it likewise recovered perfectly. About the middle, when stretched transversly, it gained one-twelfth. Upon the testicle a portion separated; when stretched transversly gained one-fourth, which was its muscular power.

The humeral portion of the artery of the fore-leg, when stretched transversly, and also longitudinally, recovered entirely.

The artery of one hoof, or rather finger, when stretched transversly, gained one-twentieth, when stretched longitudinally it recovered perfectly; which one-twentieth was the muscular power.

The artery of the penis, when stretched longitudinally, or transversly, recovered itself perfectly. This artery is considerably more elastic longitudinally than the others, but not more transversly. This increased elasticity in the longitudinal direction may be intended to allow of the difference in the length of the penis at different times.

From these experiments we see that the power of recovery in a vessel is greater in proportion as it is nearer to the heart; but as it becomes more distant it lessens; which shews the decrease of the elastic, and the increase of the muscular power.

EXPERIMENTS on the power of arteries to contract longitudinally.

To prove that arteries do not produce the same power of muscular contraction in a longitudinal, which they do in a transverse direction, the following experiments were made:

Experiment I. A longitudinal section of the aorta ascendens, measuring two inches, when stretched and allowed again to contract, measured the same length.

Experiment II. A longitudinal section of the aorta descendens at the lower part of the thorax, of a given length, after having been stretched, contracted exactly the same length.

Experiment III. Two inches of the same carotid artery used in the sixth experiment,

when stretched longitudinally, recovered itself, so as not to be longer than before the experiment.

Experiment IV. A portion of that humeral artery used in the eighth of the former experiments was not altered in its original length, when it recovered itself after being stretched.

These experiments appear to be decisive, and prove that the muscular power acts chiefly in a transverse direction; yet it is to be observed that the elastic power of arteries is greater in a longitudinal than in a transverse direction. This appears to be intended to counteract the lengthening effect of the heart, as well as that arising from the action of the muscular coat; for the transverse contraction of that coat lengthens the artery, therefore stretches the elastic, which again contracts upon the diastole of the artery.

From the account we have given of those substances which compose an artery, we may perceive it has two powers, the one elastic and the other muscular. We see also that the larger arteries are principally endowed with the elastic power, and the smaller with the muscular, that the elastic is always gradually diminishing in the smaller, and the muscular increasing, till, at last, probably, the action of an artery is almost wholly muscular; yet I think it is not to be supposed but that some degree of elasticity is continued to the extremity of an artery; for the middle state cannot be procured without it; and I conceive the middle state to be essential to every part of an artery. Let us now apply those two powers of action; or, to speak more properly of re-action, with their different proportions in the different parts of the arterial system. From these we must suppose the elastic to be best fitted for sustaining a force applied to it, such as the motion of the blood given by the heart, and propelling it along the vessel: the muscular power, most probably, is required to assist in continuing that motion, the force of the heart being partly spent; but certainly was intended to dispose of the blood when arrived at its place of destination; for elasticity can neither assist in the one nor the other; it is still, however, of use through the whole to preserve the middle state. Elasticity is better adapted to sustain a force than muscular power; for an elastic body recovers itself again, whenever the stretching cause suspends its action; while muscles endeavour to adapt themselves to circumstances as they arise. This is verified by different sorts of engines whose pipes are made of different metals. A pipe made of lead will, for instance in time dilate and become useless*; whereas a pipe of iron will react on the fluid, if the force of the fluid be in proportion to the elastic power of the iron; but the lead having little or no elasticity whenever it is stretched, it will remain so, and every new force will stretch it more and more. We are therefore to suppose that the force of the heart is not capable of stretching the artery so much as to destroy its elasticity; or in other words, the force of the heart is not able to dilate the artery beyond the contracting power. As the motion of the blood is mechanical, elasticity is best adapted to take off the immediate force of the heart; and, as we go from the heart, this property becomes less necessary; because in this course, the influence of the heart is gradually lessened, by which means a more equal motion of the blood is immediately produced, and even in the first artery a continued stream is at all times obtained; although it is considerably increased by each contraction of the heart. Without this power the motion of the blood in the aorta would have been similar to what it is in its passage out of the heart, and would have been nearly the same in every part of the arterial system.

For though the motion of the blood out of the heart be by interrupted jerks, yet the whole arterial tube being more or less elastic, the motion of the blood becomes gradually

* This accounts for the size of aneurisins whose coats must have lost their elasticity before they could be dilated.

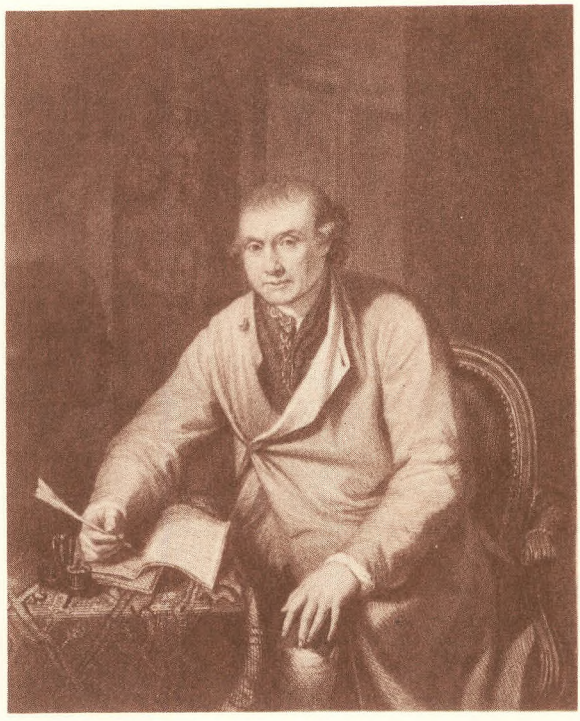
more uniform from this cause. Elasticity in arteries acts like a pair of double bellows; although their motion be alternate, the stream of air is continued; and if it were to pass through a long elastic pipe, resembling an artery, the current of air would be still more uniform. The advantage arising from elasticity in the arterial system, will be more complete in the young subject than in the old; for in the latter, the elasticity of the arteries being very considerably diminished, more especially in the larger trunks, where the force of the heart ought to be broken, the blood will be thrown into the second and third order of vessels with increased velocity. In the young, the current is slower, from the re-action of the elastic power during the relaxed state of the heart, whereas as the heart, the motion is equal to the contraction of the heart; and as the heart is probably twice the time relaxing that it is in contracting, from this cause alone we may suppose the whole is two thirds less in the smaller vessels. As elastic bodies, I have already observed, have a middle state, or state of rest, to which they return after having been dilated or contracted by any other power, and as they must always be acted upon before they can re-act, the use of elasticity in the arterial system will be very evident. It is by this means that the vessels are adapted to the different motions of the body, flexion and extention; so that one side of an artery contracts while the other is elongated; and the canal is always open for the reception of blood in the curved, stretched, or relaxed state.

The muscular power of an artery renders a smaller force of the heart sufficient for the purpose of circulation; for the heart need only act with such force as to carry the blood through the larger arteries, and then the muscular power of the arteries takes it up, and, as it were, removes the load of blood while the heart is dilating. In confirmation of this remark, it is observable in animals whose arteries are very muscular, that the heart is proportionably weaker, so that the muscular portion of the vessels becomes a second part to the heart, acting where the power of the heart begins to fail, and increasing in strength as that decreases in power. Besides, it disposes of such part of the blood as is necessary for the animal œconomy, principally in growth, repair, and secretions. At the extreme ends of the arteries, therefore, we must suppose that their actions are varied from that of simply conveying blood, except those arteries which are continued into veins.

JOHN HUNTER

John Hunter (1728-1793) was a Scotsman who spent his professional life in London and always has been associated with the London school of surgeons of the latter half of the 18th century.

Although Paré had ligated blood vessels in amputation stumps during the 16th century, and Servetus and Harvey recognized the nature of the arterial circulation in the 17th, knowledge of the elasticity of the blood vessels and its significance to surgery began with



John Hunter's *Treatise on the Blood, Inflammation and Gun Shot Wounds,* published first in 1794 by G. Nicol in London.

Its many editions reached the Continent and America shortly after its first issue and exerted a tremendous influence on the surgical management of blood vessels in wounds and in surgical interventions which involved them.

The following is the important chapter on which much subsequent experimental surgery on the vascular system was based. It is taken from the first American edition, published by Thomas Bradford of Philadelphia in 1796, only 2 years after its original printing.

Because of its length and the impossibility of editing Hunter's concise and meaty writing without spoiling his thought and development of the subject, it will appear complete in this and the following issue of *Clinical Orthopaedics,* both of which are concerned with vascular surgery.

CLASSIC 5

La Technique opératoire des anastomoses vasculaires et la transplantation des visceras

(The Operative Technique of Vascular Anastomoses and the Transplantation of Viscera)

ALEXIS CARREL, M.D.* (1873–1944)

During the last months of the year 1901, I began some research on an operative method for vascular anastomoses with the object of carrying out the transplantation of certain organs.

This transplantation consists of taking a gland, a thyroid or a kidney, for example, removing it with its artery and vein, and then grafting these vessels onto another point in the circulatory system. A simple operative curiosity today, the transplantation of a gland could perhaps someday have a certain practical interest.

We shall only study here the technique employed in obtaining a good connection between often very small vessels.

The method that I am going to describe is very simple. It is suitable to veins and arteries alike, also to vessels of large or small caliber. It respects the integrity of the tunica intima. The anastomoses are absolutely watertight and do not cause any diminution in the caliber of the vessel. It permits the realization of an end-to-side anastomosis as easily as an end-to-end one. Its execution is easy.

None of the methods currently employed presents all these advantages. This superiority is due to the use of extremely fine needles and to a maneuver which permits the dilatation of the vessels at the moment of suture and prevents narrowing.

We use Kirby No. 13 or 14 needles and linen thread used in the manufacture of Valenciennes lace or, more simply, Alsatian cotton, No. 500. The needles, which are straight, round, very sharp-pointed and much finer than those which surgeons have used until now, allow perforating sutures in the venous or arterial walls without fear of leakage. Moreover, their fineness easily permits interstitial sutures which respect the endothelium of arteries. Their only drawback is the smallness of the eye, which makes them difficult to thread. However, practice overcomes this difficulty.

The dilatation of the vessel, at the moment of suture, is obtained by a very simple contrivance. Three stay sutures are placed at equidistant points on the circumference of the vessel. Traction on each one of these sutures transforms the circumference into a triangle whose sides can be elongated as far as the elasticity of the tunicae will allow. A close, over-and-over running suture is placed rapidly on the 3 sides.

With the same goal of avoiding narrowing, we have tried anastomostic tubes or rods. Some were magnesium tubes, which

* Prosector at the Faculty.

are resorbable, according to Payr. The others were made of caramel, a substance soluble in blood.

The magnesium tube was inserted into the lumen of the vessel; the vessel ends were slightly overlapped, and a suture was placed. This procedure did not appear to me to offer any advantage; it is difficult to insert a large enough tube into the lumen of the vessel, and the circulatory compromise produced by this foreign body renders thrombosis likely.

The tubes or rods of caramel were designed to facilitate the running circular suture by stretching the vessel wall. I had no fear of compromising the circulation, because the caramel melts in several minutes as soon as the clamps producing the temporary hemostasis are released.

Also, I have abandoned their utilization because the insertion of large enough rods is difficult, and the dilatation by traction at 3 equidistant points on the circumference is more effective and enhances the ease of suturing.

A vascular anastomosis can be end-to-end or end-to-side, depending upon whether the vessels to be joined together are of equal or different caliber. For example, it is possible to anastomose end-to-end the common carotid and the renal arteries of a dog; on the other hand, an end-to-side anastomosis must be made to implant the thyroid artery into the carotid. Because of their thinness and great elasticity, veins of very different sizes can still be joined end-to-end.

We are going to describe the procedure for end-to-end anastomosis. We shall indicate thereafter the modifications for the end-to-side suture.

The operation consists of several steps:

1. *Temporary Hemostasis.* At 1 or 2 cm. from their free end the vessels are grasped with a rubber-shod clamp. The assistant takes a pair of forceps in each hand and brings the vessel ends together.

2. *Preparation of the Vessel Ends.* The surgeon frees the cut end with a snip of the scissors. If the tunica externa has slipped like a veil over the lumen of the vessel and has sealed it off, it has to be resected over a short distance. This step is difficult when dealing with very small arteries or veins.

3. *Placement of Stay Sutures.* Into one of the vessel ends 3 needles are inserted at equidistant points on the circumference from the tunica externa toward the endothelium. In arteries of sufficiently large caliber the needle point should remain interstitial and not engage the endothelium.

The 3 needles are withdrawn and leave 3 loops of suture in the vessel wall.

Into the other vessel end the 3 needles are inserted from the tunica intima toward the tunica externa at 3 equidistant points on the circumference. Then they are withdrawn.

The assistant brings together the vessel ends. The surgeon tightens and ties the 3 sutures.

The 2 vessel ends are joined at 3 equidistant points on their circumference.

4. *Transformation of the Circumference of Anastomosis onto a Triangle by Means of Traction on the Stay Sutures. Over-and-over Running Stitch.* The stay sutures are grasped with clamps. By means of these clamps, traction is exerted eccentrically on the arterial wall, transforming the circumference into an equilateral triangle by means of which the vessel ends are juxtaposed and are sutured.

This maneuver permits as much dilatation of the caliber of the vessel as is necessary before placing the running suture. If it has been well executed, any narrowing is avoided, and the suture is very much enhanced.

The assistant presents to the surgeon each one of the sides of the triangle in succession. Then it is very easy to stitch the stretched edges of the vessel ends by means

of a running over-and-over closely placed suture.

The operation is ended. The temporary hemostasis is released, and the circulation is re-established.

Where it has been possible to make interstitital sutures, the watertightness is absolute. In the anastomosis of small vessels where the sutures are through-and-through, a small leakage of blood takes place which stop spontaneously at the end of a very short time—1 or 2 minutes at most.

The end-to-side anastomosis has an almost identical operative manual. After temporary hemostasis and preparation of the end of the smaller vessel, a small incision is made in the wall of the larger vessel. The dimensions of this orifice must be slightly larger than the caliber of the smaller vessel.

Then the 3 stay sutures are placed, and the remainder of the operation is carried out according to the protocol already established.

I have utilized this procedure for the end-to-end suture of large arteries and large veins and for the transplantation of certain organs.

The suture of an artery or a vein cut transversely does not produce any narrowing. In a large artery, like the human femoral, the endothelium appears to be intact, the sutures are completely interstitial, and there is no narrowing. In the living dog, the circulation is re-established very easily.

Thanks to Professor Soulier, who placed his new laboratory of therapeutics at my disposition for these experiments, and to the precious collaboration of (Mms.) Morel and Marcel Soulier, I have been able to carry out in the dog, the transplantation of organs such as the kidney and the thyroid gland, whose vessels were grafted onto the common carotid artery and the external jugular vein.

Here is an example: On a dog, a kidney removed by nephrectomy was placed into the cervical region. The renal artery and vein were anastomosed to the carotid and the external jugular. The temporary hemostasis having been released, we saw the renal arteries pulsating with the flow of the arterial blood, the veins dilate and fill with dark blood, and the kidney lose its purplish-blue color and become red and warm. After a half-hour a small amount of reddish serous fluid flowed out of the end of the ureter opening onto the skin. For the present time we can only contemplate the operative result; the arterial suture was excellent, even though the renal artery was very small. The venous suture allowed a little bit of blood to leak for a minute and thereafter was leak-proof.

The experiments which we are pursuing on the transplantation of the thyroid gland, the kidney and the pancreas, etc., have not advanced far enough for any conclusion whatever to be drawn from them today.

We only know that the method which I have just described permits the carrying out in a simple enough fashion of the difficult anastomoses required by the transplantation of an organ.



ALEXIS CARREL

Alexis Carrel (1873-1944) was born at Sainte-Foy-les-Lyon, France. He was trained at the University of Lyon, receiving its M.D. in 1900. He became a member of its medical faculty and began, or perhaps continued, his studies on the surgery of blood vessels.

Among Carrel's many important contributions to medicine, the earliest and certainly one of the most effective was the first workable technic for arterial suture in the living body. Current clinical methods in this field stem chiefly from his original description in Volume 98 of the journal *Lyon Médicale* (1902), published while he was still a young prosecteur at the university. Later writings which developed the subject further appeared first in France and after 1905 in the United States, as a member of The Rockefeller Institute for Medical Research in New York City. Starting with end-to-end anastomosis, Carrel later developed the procedures used for arterial grafting. By 1910 he was preserving arterial grafts in refrigerators for later use. From this he went on to attempts at the transplantation of organs with reconstruction of their arterial supply, a matter already discussed in this original 1902 paper.

For his work in this and related subjects Carrel received the Nobel Prize in 1912. After attaining emeritus status at the Institute in 1939 he returned to France for further research.

CLASSIC 6 Some Few General Remarks on Fractures and Dislocations

PERCIVAL POTT (1714–1788)

I have already said, that in most cases of broken thigh or leg, the method just described will be attended with great success: but there is one particular case in which its utility is still more conspicuous; a case, which according to the general manner of treating it, gives infinite pain and trouble both to the patient and surgeon, and very frequently ends in the lameness and disappointment of the former, and the disgrace and concern of the latter: I mean the fracture of the fibula attended with a dislocation of the tibia.

Whoever will take a view of the leg of a skeleton will see that although the fibula be a very small and slender bone, and very inconsiderable in strength, when compared with the tibia, yet the support of the lower joint of that limb, (the ankle) depends so much on this slender bone, that without it the body would not be upheld, nor locomotion performed, without hazard of dislocation every moment. The lower extremity of this bone, which descends considerably below that end of the tibia, is by strong and inelastic ligaments firmly connected with the last-named bone, and with the astragalus, or that bone of the tarsus which is principally concerned in forming the joint of the ankle. This lower extremity of the fibula has, in its posterior part, a superficial sulcus for the lodgment and passage of the tendons of the peronei muscles, which are here tied down by strong ligamentous capsulae, and have their action so determined from this point or angle, that the smallest degree of variation from it, in consequence of external force, must necessarily have considerable effect on the motions they are designed to execute, and consequently distort the foot. Let it also be considered, that upon the due and natural state of the joint of the ankle, that is, upon the exact and proper disposition of the tibia and fibula, both with regard to each other and to the astragalus, depend the just disposition and proper action of several other muscles of the foot and toes; such as the gastrocnemii, the tibialis anticus, and posticus, the flexor pollicis longus, and the flexor digitorum pedis longus, as must appear demonstrably to any man who will first dissect and then attentively consider these parts.

If the tibia and fibula be both broken, they are both generally displaced in such manner, that the inferior extremity, or that connected with the foot is drawn under that part of the fractured bone, which is connected with the knee; making by this means a deformed, unequal tumefaction in the fractured part, and rendering the broken limb shorter than it ought to be, or than its fellow. And this is generally the case, let the fracture be in what part of the leg it may.

If the tibia only be broken, and no act of violence, indiscretion, or inadvertence be committed, either on the part of the patient or of those who conduct him, the limb most commonly preserves its figure and length; the

* F.R.S. and Surgeon to St. Bartholomew's Hospital.

same thing generally happens if the fibula only be broken, in all that part of it, which is superior to letter *A* in the annexed figure, or in any part of it between its upper extremity, and within two or three inches of its lower one.

I have already said, and it will obviously appear to every one who examines it, that the support of the body and the due and proper use and execution of the office of the joint of the ankle depend almost entirely on the perpendicular bearing of the tibia upon the astragalus, and on its firm connection with the fibula. If either of these be perverted or prevented, so that the former bone is forced from its just and perpendicular position on the astragalus, or if it be separated by violence from its connection with the latter, the joint of the ankle will suffer a partial dislocation internally; which partial dislocation cannot happen without not only a considerable extension, or perhaps laceration of the bursal ligament of the joint, which is lax and weak, but a laceration of those strong tendinous ligaments, which connect the lower end of the tibia with the astragalus and os calcis, and which constitute in great measure the ligamentous strength of the joint of the ankle.

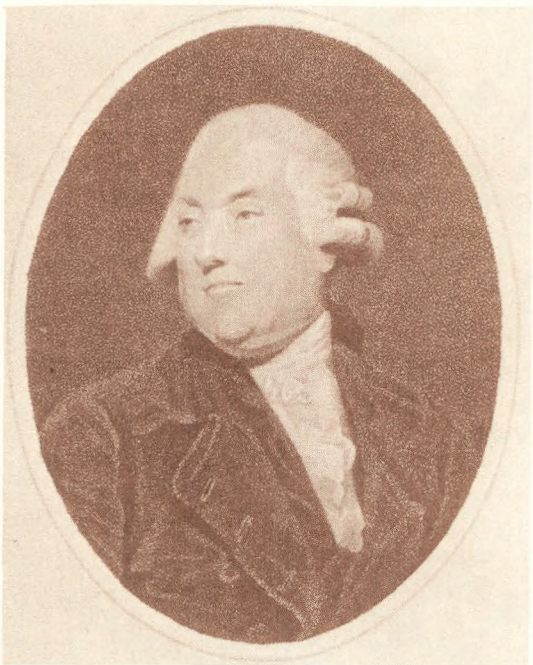
This is the case, when by leaping or jumping the fibula breaks in the weak part already mentioned, that is within two or three inches of its lower extremity. When this happens, the inferior fractured end of the fibula falls inward toward the tibia, that extremity of the bone which forms the outer ankle is turned somewhat outward and upward, and the tibia having lost its proper support, and not being of itself capable of steadily preserving its true perpendicular bearing, is forced off from the astragulus inwards, by which means the weak bursal, or common ligament of the joint is violently stretched, if not torn, and the strong ones, which fasten the tibia to the astragalus and os calcis, are always lacerated, thus producing at the same time a perfect fracture and a partial dislocation, to which is sometimes added a wound in the integuments, made by the bone at the inner ankle. By this means, and indeed as a necessary consequence, all the tendons which pass behind or under, or are attached to the extremities of the tibia and fibula, or os calcis, have their natural direction and disposition so altered, that instead of performing their appointed actions, they all contribute to the distortion of the foot, and that by turning it outward and upward.

When this accident is accompanied, as it sometimes is, with a wound of the integuments of the inner ankle, and that made by the protrusion of the bone, it not infrequently ends in a fatal gangrene, unless prevented by timely amputation, though I have several times seen it do very well without. But in its most simple state, unaccompanied with any wound, it is extremely troublesome to put to rights, still more so to keep it in order, and unless managed with address and skill, is very frequently productive both of lameness and deformity ever after.

After what has been said, a farther explanation why this is so is unnecessary. Whoever will take even a cursory view of the disposition of the parts, will see that it must be so. By the fracture of the fibula, the dilatation of the bursal ligament of the joint, and the rupture of those which should tie the end of the tibia firmly to the astragalus and os calcis, the perpendicular bearing of the tibia on the astragalus is lost, and the foot becomes distorted; by this distortion the direction and action of all the muscles already recited are so altered, that it becomes (in the usual way of treating this case) a difficult matter to reduce the joint, and, the support of the fibula being gone, a more difficult one to keep it in its place after reduction. If it be attempted with compress and strict bandage, the consequence often is a very troublesome as well as painful ulceration of the inner ankle, which very ulceration becomes itself a reason why such kind of pressure and bandage can be no longer continued; and if the bone be not kept in its place, the lameness and deformity are such as to be very

fatiguing to the patient, and to oblige him to wear a shoe with an iron, or a laced buskin, or something of that sort for a great while, or perhaps for life.

All this trouble, pain, difficulty, and inconvenience are occasioned by putting and keeping the limb in such position as necessarily puts the muscles into action, or into a state of resistance, which in this case is the same. This occasions the difficulty in reduction, and the difficulty in keeping it reduced; this distorts the foot, and by pulling it outward and upward makes that deformity, which always accompanies such accident; but if the position of the limb be changed, if by laying it on its outside with the knee moderately bent, the muscles forming the calf of the leg, and those which pass behind the fibula and under the os calcis, are all put into a state of relaxation and non-resistance, all this difficulty and trouble do in general vanish immediately; the foot may easily be placed right, the joint reduced, and by maintaining the same disposition of the limb, every thing will in general succeed very happily, as I have many times experienced.



PERCIVAL POTT

Percival Pott of London (1714-1788) served on the staff of St. Bartholomew's Hospital from 1744 until 1787 shortly before his death. He wrote a number of important monographs during this period, among which was "Some Few General Remarks on Fractures and Dislocation." In this book appeared the first definitive description of fracture about the ankle. It is memorable in that it describes a variety of fracture forms previously merely referred to as a single injury. Equally important, though still not always adequately appreciated, it discussed the importance of coincidental injuries to the soft tissues about the ankle and the tarsus, the proper care of which so greatly influences recovery. This group of fractures and soft tissue injuries still preserves the eponym of Pott's fracture, actually a generic term rather than the definition of a single fracture.

CLASSIC 7

The Reconstruction Operation for Arthritis Deformans of the Hip Joint

ROYAL WHITMAN, M.D.* (1857–1946)

The reconstruction operation may be defined as a mechanical adaptation of a hip joint disabled by injury or disease to the essential requirements of locomotion. Originally, it was devised for ununited fracture, particularly for a class of cases in which the neck of the femur had been in great part absorbed or worn away, so that direct union of the fragments by any means was doubtful, and in which, even at best, function must be impaired greatly by loss of the neck and consequent limitation of abduction. In this operation the head of the femur is removed, and the trochanter is cut from the shaft in an oblique direction with all its attached muscles so that the additional area thus obtained, together with the part of the neck that remains, may provide a secure weight-bearing surface. The reconstructed neck having been inserted into the acetabulum, the limb is abducted sufficiently to permit the trochanter to be drawn down and implanted upon the outer surface of the shaft. Thus by muscular tension, security of the new articulation is maintained, while the reconstructed neck and the transplanted trochanter restore the leverage for the hip muscles and permit a range of controlled motion that enables the patient to walk with security and to sit with comfort.

Recently, the scope of the operation has been enlarged to include a number of other conditions, such as pathologic dislocation or subluxations secondary to disease, in which the articulation has been in part destroyed. Cases of this class which require reformation of the acetabulum are not included in the present discussion, which is limited to the operative treatment of arthritis deformans.

In typical cases of this type, the disease, practically limited to the hip joint, is of the so-called hypertrophic or degenerative form, affecting primarily the cartilage and the underlying bone of the femoral head, as distinct from the generalized or infective group in which the soft parts are primarily involved.

In characteristic cases the disease is of long standing, beginning with indefinite symptoms of pain and discomfort in the joint and the limb (sciatic rheumatism).

The limitation of motion and the discomfort on changing from rest to activity become more noticeable, and eventually the limb assumes an attitude of flexion and adduction, the compensatory upward tilting of the pelvis being mistaken usually for actual shortening. At this stage a crutch or a cane is required for locomotion, and the patient, from an industrial standpoint, is practically disabled.

The etiology is obscure, but whatever may be the remote predisposing or exciting causes of the disease, constitutional or local, irregularities of the joint surfaces, either the result of congenital malformation or induced a great influence on its by injury or disease, have inception, and more especially on its progress when established, the articulation being gradually worn away and distorted by friction and pressure. (SIC)

* New York, N. Y.

Of the 7 cases that form the basis of this paper, 5 were in females. Three of the 7, including the males, were typical cases of morbus coxae senilis both as to age, symptoms and pathologic appearances. The 4th was in a woman of 48 years of age. The symptoms had become persistent 12 years before admission, but she had had, since childhood, occasional discomfort in the joint. The pathologic changes were similar to those of the preceding cases, but the cause may have been an incongruity induced by disease or deformity acquired in early life.

In the 5th case, a woman of middle age, the symptoms had followed a fall on the hip 4 years before admission which, if a fracture, had not caused immediate disability. At the operation only a part of the head and the neck remained, indicating apparently a so-called absorption following injury.

In the 6th case, in a woman of 45 years of age, the symptoms were first noticed after the birth of a child 5 years before, but if they were the result of infection, it was of a very subacute type.

The 7th case was in a woman 40 years of age. The symptoms had been noted 8 years before and had increased noticeably after the birth of a child 2 years later.

It would appear that the disease, at least in the typical form, usually begins in the head of the femur and that the cartilage first disappears on its inner and upper surface. The underlying bone loses its resistance and becomes flattened or otherwise distorted. The acetabulum is less directly involved, and the distortion is not marked until the flexion and the adduction of the limb concentrate the pressure on its outer and upper border, permitting a subluxation of the joint. It may be noted in this connection that the museum specimens pictured in the textbooks are usually of the most advanced type of the disease and quite unrepresentative of the class of cases under consideration.

If a diagnosis were made at the inception of the disease after the removal of all possible sources of infection, then internal medication, combined with measures designed to improve nutrition, to check the tendency to deformity and to regulate the strain and pressure on the joint, might check progressive disability. But in advanced cases, such as those under consideration, treatment by rest or traction or splinting can be but palliative; for from the character of the disease it is evident that only removal of friction, the direct cause of pain and of the progression of the destructive process can assure permanent relief.

The usual operative remedy has been arthrodesis to induce bony ankylosis. However, this is an uncertain outcome because abduction of the limb, the attitude of election, separates the upper surface of the head from the acetabular roof to which it should be apposed in order to secure union, and in a large proportion of cases, although sufficient restriction of motion may be assured after prolonged fixation to relieve pain, there is recurrence of a certain degree of flexion and adduction deformity after the support is removed. Fixation at the hip in patients of this class entails also the disadvantage that assistance is required in dressing.

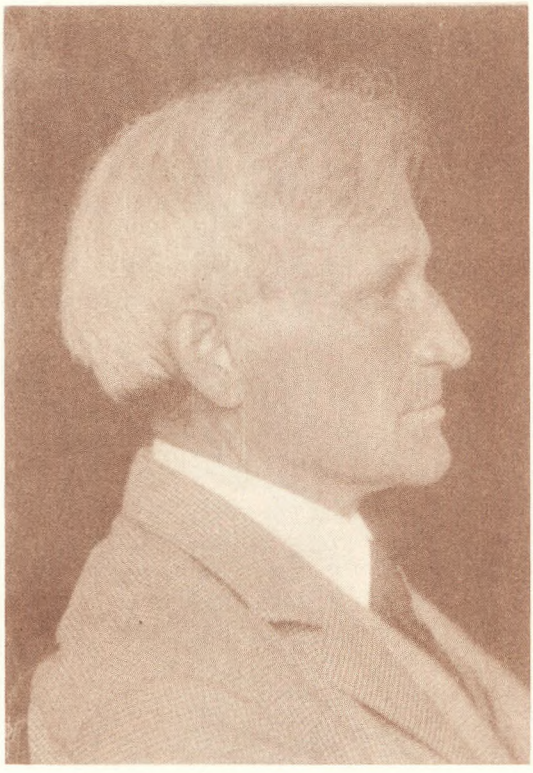
The only alternative to arthrodesis has been resection, an operation recently described by Groves (*Br. J. Surg.*, Oct., 1923). The head of the bone is removed through a posterior incision, and the extremity of the neck, covered with a fascial flap, is inserted into the acetabulum. This operation is effective in removing the disease, but it is defective from the functional standpoint because the trochanter is brought into contact with the rim of the acetabulum, thus mechanically limiting abduction. This is a very important defect because, in proportion to lessened muscular control, physical weakness or limited motion, the more essential for security is the crutchlike support of an abducted limb. This ability to spread the legs apart is dependent upon the length and the angle of the femoral neck and the lateral projection of the trochanter which assures muscular leverage.

In considering the operative relief of arthritis deformans at the hip joint from the functional standpoint, the objects to be attained are: (1) the removal of a destructive process and thus to check progressive disability; (2) security in weight-bearing, which implies a sufficient range of abduction; (3) the restoration of a fair degree of voluntary motion.

From this standpoint the reconstruction operation has manifest advantages over other treatment. It is conducted as follows:

The incision is in the shape of a half U, begins an inch below and behind the anterior-superior spine and crosses the femur at a point about 3 inches below the apex of the trochanter. The deep fascia is dissected backward, and the interval between the tensor vaginae femoris and the gluteus medius is opened, exposing the capsule. With a wide chisel the base of the trochanter is then separated from the shaft in the line of the neck and with its attached muscles is turned upward. The capsule is opened, and with a large curved chisel the greater part of the head is removed, the design being to include all the cartilage, the marginal exostoses and as much of the underlying bone as may be involved in the degenerative process, including in some instances a part and in others all of the femoral head. This articulating extremity is made round and smooth with a chisel and a file and is then inserted into the acetabulum, the cartilage of which, except on the outer and superior margin, is usually fairly normal. And, since in the abducted attitude there is little direct contact between the 2, there would seem to be no necessity for covering the neck with fascia, although this has been done in some instances in which the bone seemed to be particularly soft. A thin section of bone with the overlying muscle in the form of a flap is turned back from the upper and outer surface of the shaft, and the limb having been adducted sufficiently, the trochanter is brought down so that its base may be apposed to the bare surface on the outer part of the shaft, where it is fixed by deep sutures through the overlying tissues or by a bone screw. The wound is closed in layers, and a long plaster spica is applied in the extended and abducted attitude. This remains for several weeks in order to assure the fixation of the trochanter in its new position. The aftertreatment will vary according to the circumstances of the patient. If early locomotion is desired, as in the cases in which the hospital expense is a burden, a short spica extending only to the knee, holding the limb in about 20° of abduction, is applied, and the patient is discharged on crutches, weight-bearing being permitted if it causes but little discomfort. In cases which remain under supervision the limb is usually suspended from a frame by pulleys, and passive and later voluntary movements are begun, regulated by the degree of discomfort. The most important factor in the aftertreatment is persistent, methodic stretching of the limb outward to the proper degree of abduction and backward to complete extension, thus checking the tendency toward the former attitude of flexion and adduction and resulting compensatory shortening of the limb.

Since all the operations have been performed practically within a year, and several very recently, one cannot report on final results. The 1st operation was performed November, 1922. This was a typical case of morbus coxae senilis. The patient, a chauffeur, 60 years of age, was completely disabled because he could not get in or out of his car. When last seen he stated that he could walk 5 miles and that he could sit with comfort. The immediate effects in all the cases have been satisfactory. The deformity of the abducted limb and the tilted pelvis has been corrected, the range of motion increased, and the pain on movement and weight-bearing has been reduced to discomfort. Furthermore, it would appear that the patients may be assured of progressive improvement as contrasted with progressive disability and that the results already attained have substantiated the theory on which the treatment has been based.



ROYAL WHITMAN

Royal Whitman (1857-1946) was for many years Chief of Service at the Hospital for Ruptured and Crippled (now the Hospital for Special Surgery in New York City). The background of this important paper of 1924 is contained within its text. This was the first sustained attempt to relieve osteoarthrosis of the hip by surgical means other than fusion, and following it were developed the various modifications of Whitman's reconstruction operation since attempted. Before this, various arthroplasties had been tried occasionally for fused hips or ununited fractures but no series was published using the operation specifically for morbus coxae senilis. As a matter of interest it was believed up to Whitman's publication that such an attempt would be futile.

CLASSIC 8

Disability Evaluation

Principles of Treatment of Compensable Injuries

EARL D. MCBRIDE, B.S., M.D., F.A.C.S. (1891–)

METHOD OF EVALUATING EXTENT OF DISABILITY THROUGH ANALYSIS OF FUNCTION

The term "function" is one that is commonly used to denote the usefulness of a part of the body. In stating the extent of use, or function of a part, however, incorrect conceptions are often expressed. Loss of function has been confused with anatomic losses and physiologic changes to the extent that functional loss is often stated in terms of altered shape, size or motion, whereas the use of a part should be spoken of in such terms as ability of movement, power, and coördination in relation to the environment of the organism. Function, therefore, means what one can "do." Yet the question arises, when one performs an act, just what factors combine to make it possible? What constitutes activity with perfection? How shall the factors of function be measured so that when a disability occurs the extent of functional loss can be evaluated? When anatomic or physiologic changes have taken place, such as stiffness, atrophy and pain, the usefulness and efficiency of the organism are impaired. The extent of the clinical disturbances is revealed through physical examination. However, the extent of deficiency in functional ability does not correspond to the extent of physical limitation, i.e., a 50 per cent limitation of motion does not mean a 50 per cent loss of function. The clinical findings must be designated as factors contributing to the loss of function, not measuring it. The loss of function is measured, therefore, by determining what the affected individual cannot do because of these modifications of his organism. The answer will rate his physical capacity for work.

FUNCTIONAL FACTORS

An analysis of what is meant by the function of the organism reveals the following factors which make possible such acts as those of lifting, pulling, bending, turning, pushing, walking, jumping, running, grasping or throwing:

1. Quickness of action.
2. Coördination of movements.
3. Strength.
4. Security.
5. Endurance.

In respect to industrial injuries, two other factors should be added, i.e.,

6. Safety as a workman.
7. Prestige of normal physique in securing or pursuing employment.

A study of these terms reveal the following significance:

1. Quickness of Action

Alertness, nimbleness and speed of movement are essential to the usefulness of the motor elements of the body. As the result of an injury the part may be lacking in this capacity and the loss of function would be termed "delayed action." That is, the resulting physiologic or anatomic handicap such as a stiffness deformity will cause the individual to be slower than normal.

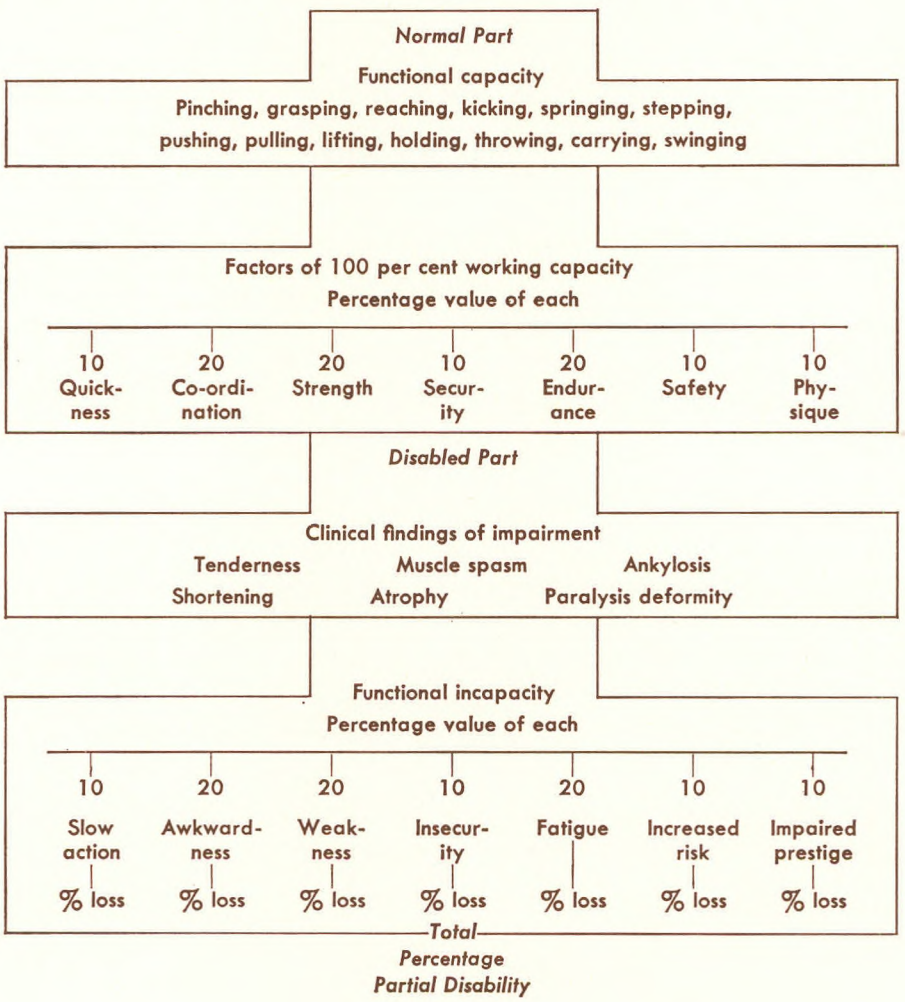
2. Coördination of Movements

This factor is necessary for smoothness and steadiness of action. It may be termed dexterity or synchronizing of movements resulting in proficiency, deftness, and good control. Organized habits of the motor parts, cultivated over a life time, are interrupted in their efficiency. The loss of this factor would be termed as "awkwardness," or "clumsiness," antagonistic interference or unevenness. For instance, because of a stiffness in the elbow, the individual might go to reach quickly for an object and miss it or drop it.

3. Strength

Physical energy and force of intensity is a very vital element of function. Loss of

TABLE 5. An Analysis of the Factors Which Compose Function and Their Approximate Relationship in Terms of Percentage, as Applied to Disability



strength in a part creates a necessity for unusual effort or strain to approach the normal standard. Motor power in the performance of pushing, pulling, lifting, grasping or other activities is distinctly an essential factor, the loss of which would be expressed in terms of "weakness" unsubstantial, dependent and incapable. This functional factor and that of endurance are often similar, but there is a distinction, in that the individual may have the power to accomplish certain acts but may be limited in ability to continue the activity throughout a normal period of time.

4. Security

Confidence and dependency in the use of the body is another very important factor. Once a member of the body has been injured, soreness results and interruption of the habits of activity is slowly overcome. An organ of the body has not regained trustworthiness and reliability until it can be used without a conscious effort. Accompanying this factor is the element of uneasiness, nervousness or even cautiousness. Where this factor has been affected, it may be determined, "insecurity or uncertainty of movement." For instance, in walking or running, an individual with a shortening of his leg would be constantly on guard to prevent making a misstep or falling.

5. Endurance

Endurance or vigor is a factor of work power that often depends on the willingness of effort and persistency of the individual. He may seem to be able to work but can withstand the strain of work for a short period only. He, therefore, cannot continue and maintain his work uninterruptedly. Inertia, exhaustion and fatigue produce restraint and may be expressed as "diminished endurance and vigor."

6. Safety

A workman is safe when he has normal ability to protect himself and others while at work. This is of great importance in hazardous occupations and may be greatly jeopardized by a disabled part of the body. It is the factor which is greatly responsible for prolonged treatment and the disability period in injuries. Inability to jump quickly, danger of letting go a heavy object that would strike others, or failure to exercise the part in a normal manner while working with others, are factors which would cause any superintendent to dismiss the individual. To be classed as an "increased risk" is a distinct loss in respect to earning capacity. "Endangering safety" then is a factor in the loss of function. It greatly comes about through the other factors mentioned, but should be given its share of evaluation because it may not be evaluated as a loss, even when awkwardness, slowness, or other factors are considered a loss.

7. Prestige of Normal Physique

Physical fitness as a factor to securing employment is of major importance in considering the extent of disability. The workman who has every appearance of perfect physique possesses a natural prestige. A deformity or a stiffness which decreases the competency and ability of a part of the body will be detected by a company examining physician who is passing only 100 per cent physically fit men. In times of distress, such a man will be the first to be laid off. Of course, many jobs are open which do not require physical examination, nevertheless, this factor plays a big role in the ability of the individual to obtain work. The reputation of having had an accident may influence working capacity even after full recovery. The averse influence of physical impairment involves the other functional losses but is not always a factor of loss even where other functions are disturbed.

Stated negatively, therefore, the functional factors of loss are:

(a) Delayed action; slowed up motions.

(b) Awkwardness and clumsiness in grasping, pushing and holding.

(c) Weakness of lifting power and muscular action.
(d) Insecurity and instability in holding or pushing or pulling power.
(e) Diminished endurance, vigor and vitality.
(f) Lowered safety and protective ability.
(g) Averse influence of physical impairment affecting the securing or maintaining of employment.

These functional factors may be applied to specific parts of the body in terms relative to the characteristic activities of the part.

In the hand, for instance, they may be stated as follows:

(a) Quickness and nimbleness of digital action.
(b) Coördination of fingers and thumb in apposing finger tips to thumb, and thumb to fingers and palm.
(c) Strength of grip and fist making ability, striking, slapping, holding, and pushing power.
(d) Security or reliability of delicate finger sense, and dependability on lifelong habitual and technical finger accomplishments.
(e) Endurance of pinching, holding or gripping action.

In respect to the leg, foot or toes, the factors may be considered as follows:

(a) Quickness, nimbleness, springiness of step and gait.
(b) Coördination of feet and toes in smoothness and steadiness of step and gait.
(c) Strength of weight bearing and power of action in standing, walking, running or jumping.
(d) Security or reliability of toe, heel or foot action in habitual and technical accomplishments of lifelong development.
(e) Endurance of gripping power of toes; toleration of continuous action.

Rating of Functional Factors

It is reasonable that if each of these functional factors enters into estimating the extent of disability of the individual, then each should bear its relation to the evaluated loss. No single factor, alone, is responsible for total disability. For instance, if the disabled member of the body is estimated to have lost 50 per cent in strength, it does not necessarily follow that the loss in the other factors of quickness of action, coördination of movements, security and endurance are affected to the same degree. It is necessary, therefore, that each of these factors should be given an evaluation according to its relative importance to the working capacity of the individual. The slowing up of activity is not important as a lack of coördination in respect to the earning capacity. Loss of strength or power of lifting, holding, pulling or pushing is of more consequence to disability evaluation than endurance and endangering safety. The relative value of any of these factors will vary in many ways, in various cases. If each factor is given a percentage value and the sum of all factors is 100, then even though their relative importance may vary, the percentage of loss of the part as a whole will be equitably estimated. There may be a difference of opinion on the individual functional values, but if each is a portion of 100 per cent, the resulting permanent loss of each will total a proportional percentage.

The relative value of each of these functional factors of loss in respect to 100 per cent incapacity may be generally rated as follows:

1. Delayed action	10 per cent
2. Awkwardness	20 per cent
3. Weakness	20 per cent
4. Insecurity	10 per cent
5. Diminished endurance.	20 per cent
6. Lowered safety factor..	10 per cent
7. Averse influence of conspicuous impairment ..	10 per cent

Some examiners might not agree on this evaluation of factors. They might feel, for instance, that weakness should be valued more than 20 per cent. If so, then some other function must be diminished in its rela-

tive value, because the total cannot be over 100 per cent. For instance, if weakness were considered 40 per cent in relation to the other functions, the value of each other factor would be rated in its proportional value of the 100 per cent. A percentage of disability based on this form of reasoning, therefore, establishes a definite basis for its existence. It permits the examining physician to base his evaluation upon established fundamentals just as in diagnosis of disease where the characteristic symptoms furnish the fundamental basis of reasoning. When therefore a physical examination reveals certain physiologic and anatomic limitations, the effect on each functional factor may be estimated as a percentage of loss in respect to that particular capacity. The total of these percentages of loss will represent the partial loss of the part as a whole.

Functional Measuring Rod. In formulating some comprehensible working guide for the studying of functional losses, a ruler composed of 100 units may be considered as the 100 per cent measuring rod. The value of each functional factor may be given its appropriation on the rule and an analysis made of the various meanings of the factor.

The method of evaluating extent of disability is graphically illustrated in Table 6.

In making an estimate of the extent of disability the percentage of loss of each functional factor is conceived from the standpoint of medical knowledge and the results expressed in terms of disability.

For instance if it is thought the activity factor will be affected 25 per cent, then 25 per cent of 10, the value of the factor means 2.5 per cent disability. Applying the test to each of the factors in the 100 per cent scale on the measuring rod of function and summing up the percentage of loss of each factor, the total amount of disability is determined. For example a back disability might be conceived as illustrated in Fig. 8.

In respect to an extremity the factors of function are interpreted according to the specific functions of the part. For instance in the arm the limitations would be measured as in Table 7; in the leg as in Table 8; and in the eye as in Table 9; and in the ear Table 10.

As a further illustration of covering the extent of disability, let us consider an injury to the elbow that has fully healed and on examination presents the following clinical picture:

The motion of flexion and extension is limited to an arc from full extension to 90° flexion, as in Fig. 11, other motions normal. The percentage of loss, at the end of the healing period, due to this physiologic and anatomic limitation, as it contributes to each functional factor, would be estimated approximately as follows:

DELAYED ACTION—25 per cent because the alert and rapid movements of the arm would be cut down one-fourth that of normal, in respect to work.

AWKWARDNESS—25 per cent because the coördination of movements and dexterity would be diminished at least this much.

WEAKNESS—15 per cent. This function would not necessarily be great because the arm can be strong, yet limited very greatly in motion.

INSECURITY—15 per cent because there would certainly be a lack of confidence and interruption of previously formed reliability upon use of the arm.

DIMINISHED ENDURANCE—15 per cent because persistency of effort in use of the arm would require increased physical and mental effort on the part of the person.

ENDANGERING SAFETY WHILE AT WORK —10 per cent because in a hazardous occupation he would be more likely to let go an object or fail to grasp an object in his protection.

AVERSE INFLUENCE IN SECURING EMPLOYMENT—15 per cent because an employer certainly would be prejudiced by the appearance of the crippled arm, or an examining physician or an employer would reject him because he would be more likely to get hurt, injure others, or fail to do his share of work.

Evaluation of the partial loss of the part

affected would be found by computing the percentage of loss to each functional factor value and adding the losses. The result in this case is 17.5 per cent loss and is determined as follows:

Conception of Working Ability		Estimate of Disability	
Delayed action	25 per cent	25 per cent of 10 (value of quick motion)	2.5
Awkwardness	25 per cent	25 per cent of 20 (value coordination)	5.
Weakness	15 per cent	15 per cent of 20 (value strength)	3.
Insecurity	15 per cent	15 per cent of 10 (value security)	1 5
Diminished endurance	15 per cent	15 per cent of 20 (value endurance)	3.
Increased risk	10 per cent	10 per cent of 10 (value safety)	1.
Averse influence to employment	15 per cent	15 per cent of 10 (value of physique)	1.5
		Percentage disability to arm	17.5



EARL DUWAINE McBRIDE

Earl Duwaine McBride was born in Severy, Kansas in 1891. He practiced and taught in Oklahoma City.

CLASSIC 9

Leçons orales de clinique chirurgicale faites a l'hôtel Dieu de Paris

(Original or Congenital Displacement of the Heads of Thigh Bones)

GUILLAUME DUPUYTREN (1777–1835)

There is a species of displacement of the upper extremity of the femur, of which I have not found any mention in authors, although I have carefully sought for it: and in directing attention to this subject, I have been prompted by a desire to guard practitioners against a serious error in diagnosis and treatment, rather than by the melancholy satisfaction of adding one more item to the already too extended catalogue of human infirmities.

This displacement consists in a transposition of the head of the femur, from the cotyloid cavity on to the external iliac fossa (dorsum) of the ilium, a transposition which exists at birth, and which appears due to a defect in the depth or completeness of the acetabulum, rather than to accident or disease. The class of dislocations to which it belongs is that in which the bone is thrown upward and outwards. There are already described two species or varieties of this disease, viz. accidental dislocation, and consecutive, spontaneous or symptomatic dislocation. That species of which I am about to speak constitutes a third variety, which I shall name *original or congenital dislocation,* to distinguish it from the two forms which I have mentioned above.

This dislocation possesses characters common to all those in which the head of the femur is carried upwards and outwards, viz.: shortening of the affected limb, the position of the head of the femur in the external iliac fossa, the prominence of the great trochanter; the retraction of nearly all the muscles of the upper part of the thigh towards the crest of the ilium, where they form, around the head of the bone, a sort of cone, of which the base is at the ilium, and the apex at the great trochanter; the almost denuded state of the tuber ischii, abandoned by its muscles; together with rotation of the limb inwards, by which the popliteal region and heel are directed outwards, and the knee and foot inwards: also an obliquity of the thigh in a direction from above downwards and inwards, which becomes more decided as the age of the subject approaches the adult period, and the pelvis becomes correspondingly developed: lastly, an acute reentrant angle at the junction of the inner part of the thigh with the pelvis, and wasting of the muscles of the whole limb, especially at its upper part, complete the list of signs by which this abnormal condition may be recognized.

In studying the individual movements of a limb thus affected, they are observed to be very limited, and especially so those of abduction and rotation, which accounts for the numberless difficulties experienced in the acts of locomotion and various exercises which the lower limbs are required to take part in. If, again, the form and development of those who are the subjects of this congenital deformity are examined, the beholder is at once struck with the want of proportion between the upper and lower parts of the body, with the imperfection of the lower

extremities, and with the attitude of the individuals. In fact, the trunk is very much developed, whilst the lower limbs are short and meagre, as if they belonged to a person of smaller stature. These peculiarities in the abdominal extremities are rendered still more striking by the breadth of the pelvis, which corresponds in external development to the trunk: moreover, the prominence of the great trochanters, with the obliquity of the thighs and inversion of the entire limbs, characterize the defect in question.

As to the attitude of the individuals who are the subjects of this deformity, the upper part of the trunk is carried very much backwards, whilst the lumbar region is hollowed behind and projects in front: the pelvis is placed almost horizontally on the thigh-bones, and the points of the feet alone touch the ground; which circumstances are evidently attributable to the transposition of the ilio-femoral articulation and the centre of motion (or of gravity) to points posterior to those which they would naturally occupy.

In walking, persons thus deformed step on the points of the feet, alternately inclining the trunk very much towards the limb on which the weight of the body is thrown; at the same time that the opposite extremity is raised from the ground, and in its turn receives the superincumbent weight, which is thus laboriously transferred from side to side. Indeed, each time that this effort is made, the head of the femur which receives the weight of the body is seen to rise distinctly on the external iliac fossa, whilst the pelvis descends and all the signs of dislocation become more marked on that side, and less apparent on the other, until the translation of the weight to the opposite limb converts the above conditions. The toilsome nature of these efforts in progression are clearly due to the instability of the heads of the thigh-bones, which, in consequence of their being thrown out of their natural and fixed cavities, are subject to continual displacement, alternately rising and falling as they are charged with, or relieved from. the superincumbent weight of the body.

The labour with which these individuals walk would naturally lead one to expect that the acts of running and leaping would be still more diffiicult to them: yet this is not so; for in executing these efforts the energy of the muscular contraction, and the rapidity with which the weight of the body is transmitted from one limb to the other, render the effects arising from the unstable condition of the heads of the thigh-bones almost inapparent. It is true that there is an unusual rocking or swaying motion of the upper parts of the body, and that the pelvis seems to describe, in its movements from side to side, a larger segment of a circle than naturally; in a word, the effort of transferring the weight of the body from one limb to the other is evidently laborious: but even these signs of defect generally become even less manifest in the act of leaping, which is executed in some measure as in certain animals unprovided with limbs,—the body being first curved and then suddenly straightened with a jerk, so as to dart the body to a height or distance. These acts are, however, at best of so toilsome a nature, as scarcely to permit the subjects of this congenital defect to pursue them for any protracted period: the displacement and rubbing of the heads of the thigh-bones, the inconvenient swaying of the body in walking, and the great muscular efforts in running and leaping, do not fail to produce fatigue which necessitates early repose; and this weariness is more speedily entailed when the weight of the upper part of the body is great.

When these individuals lie horizontally on their backs, one is surprised to observe that the signs of the deformity are much less apparent than in the erect posture: this must be attributable to the repose of the muscles, which cease to draw upwards the thigh-bones; and to the mode in which the pelvis is, as it were, wedged in between the heads of these bones.

There is one point which incontrovertibly proves the correctness of the explanation I have given of the nature of the infirmity in question; it is that, whilst the body is recumbent, the affected limb may be lengthened or shortened at pleasure. Very slight extension or pressure is sufficient to render apparent these variations in the length of the limbs; and if the crest of the ilium and summit of the trochanter are selected as points by which to judge of the amount of change, it is easily ascertained that it varies from two to three inches, according to the age, size and development of individuals, and chiefly according to the extent of displacement of the bones: and the signs of dislocation may be rendered more or less distinct in a few moments, by alternately lengthening and shortening the limb. In fine, all these changes of position may be produced with the greatest facility and without occasioning the slightest pain, so as to leave no doubt respecting the entire absence of disease, as well as the non-existence of any especial cavities appropriated to receive and retain the heads of the thigh-bones. Such is the condition of persons affected with this congenital dislocation.[1]

Whatever importance may be attached to this dislocation in the abstract, it is deserving of still more attention on account of its presenting all the signs of luxation consequent on disease of the hip-joint, with which it has always been confounded; and the same treatment has been adopted to remedy that which in reality is at most but an infirmity and has nothing in common with the displacement consecutive on disease. In consequence of this error in diagnosis, I have seen some individuals affected with this original deformity subjected to the restraint of being confined to their beds for years together; others I have seen forced to submit to the application of leeches, blisters, cautery and moxas, without number: and one case in particular I can call to mind, amongst the many victims of this blunder; it was that of a young girl on whom her attendants had, in their blind ignorance, inflicted the suffering of twenty-one moxas about the hips; and, as I might have been anticipated, without this barbarous and useless treatment having the slightest beneficial effect on the unfortunate patient. It has occurred to me to witness an instance, in which the patients unjustly accused their nurse of having carelessly or brutally caused dislocation in their infant; whereas, the truth was that the deformity was congenital. A still more remarkable case fell under my observation about fifteen years since: an individual of the name of Autun was barbarously assassinated, and his mutilated and disfigured corpse, which was found inclosed in a sack, remained for a long time unrecognized in spite of the most active investigation, until I remarked the peculiarity indicating the deformity I have been describing; this I made known in the proper quarters, and the information led to the body being identified. When careful inquiry was subsequently made into the history of this individual's life, it was ascertained that he had never suffered from disease of the hip-joints, but that he had come into the world with the defect which contributed to the recognition of his body; notwithstanding the horrible way in which it had been mutilated by the murderer, in the hope of thus preventing the identification of his victim.

The entire absence of pain, swelling, abscess, fistula, or cicatrix; the simultaneous existence of dislocation on both sides; the history of the individuals thus affected; to-

[1] [The cast of a young man, aged 18, the subject of this congenital deformity, was taken during the summer of 1844, at St. Thomas's Hospital, by Mr. Kearney, and is in the Museum of that institution. The leading features of the graphic description in the text are illustrated and confirmed by this case, with these exceptions, that the young man walks fairly on the soles of the feet, and that the limbs are not inverted. A report of this well-marked instance of congenital dislocation of the heads of thigh-bones will be found in the first volume of the Lancet, new series, p. 781.—Tr.]

gether with the progressive development of the signs which characterize this deformity, from the time that the feet first touch the ground, until the increasing weight of the body is wholly supported on the lower extremities at a later period,—are so many certain indications by which to distinguish these two affections, (congenital and consecutive dislocation); which, though so analogous in their signs, offer so many points of contrast as to their origin, nature and appropriate treatment.

The subjects of this original defect suffer no pain either in the hips or knees; indeed, the only local sensation of which they are conscious is that of fatigue and numbness when they have exercised the lower limbs too much. There is no morbid swelling about the ilio-femoral articulation in these cases; for the prominence of the great trochanter and fulness of the muscles about the neck of the femur are not of this character, but are only the natural effect of the abnormal position of the head of this bone; and there are neither abscesses nor indications of there ever having existed any in the neighbourhood of the joint. Lastly, the exactly similar alteration in form which is always observed in both hips, may be almost regarded as exclusively characteristic of the congenital affection, so extremely rare is this circumstance in cases where the dislocation is consequent on disease. The history which is always given with these cases entirely confirms the above observations; for it does not include any of those marked symptoms which characterize that painful and cruel disease of the hip-joint, which usually issues in spontaneous dislocation of the femur.

A careful investigation into the history of these cases does not lead to a negative result only, but it is likewise positively available, by putting us in possession of the first signs, the progress, the development and the effects of congenital dislocation of the thigh-bones. If a practitioner is called in at an early period, to see an infant thus affected, certain indications of this deformity may be detected immediately after birth; such, for instance, as immoderate breadth of the hips, prominence of the trochanters, obliquity of the ossa femoris, &c.: but, as it almost always happens that any vicious conformation, and the infirmities which spring therefrom do not attract the attention of parents until the children first attempt to walk, it is at this period that surgeons are, in most instances, called upon to establish the existence of the defect. Then the little patients experience considerable difficulty in walking or running, or even in sustaining the weight of the body in the upright posture; but sometimes it even happens that parents, from carelessness or inattention, imagine that their children are only backward in walking, and do not discover the deformity until three or four years have elapsed, that is, until the defects and imperfections in the form and motions of the parts have become so manifest, that they can no longer be reasonably attributed to retarded development.

It is especially when the pelvis begins to expand and when the child begins to join in protracted and fatiguing exercises, that the evil becomes more apparent still: then the swinging or see-saw motion of the upper part of the body, with its inclination forwards, the unusual bend in the back and corresponding prominence of the belly; the curved motion of the extremities, and mobility of the heads of the thigh-bones, &c., begin to exhibit themselves very decidedly; but the cause and nature of these signs are unintelligible even to many medical practitioners. Some attribute the defect to an accidental fall from the cradle or the nurse's arms, or to the habit of lifting the child by the legs or thighs; others ascribe it to a scrofulous affection, by which, either before or after birth, the margin of the acetabulum or head of the femur has been so far altered in form as to entail dislocation. It must be admitted that this latter notion receives some support from the fact that the subjects of this affection are frequently of a lymphatic

constitution and rickety appearance; and if I cannot myself subscribe to the opinion, it is because I have observed this vicious conformation in infants of a diametrically opposite constitution even at birth, and in whom there was not a single indication of disease: but I have been led to think otherwise, especially because I have had the opportunity of dissecting the affected parts, and have found their form and organization such as to exclude the idea of either existing or prior disease.

At a still more advanced period, that is to say, when each sex begins to assume a distinctive form, the development of the pelvis, which is both greater and more rapid in girls than in boys, renders the effects of the peculiarity in question more striking in the former: but when the growth is completed, and the body has attained its full weight, then the most careless attention is fixed, and doubts, if any still exist, are removed; for all the signs which have been already enumerated become so exaggerated that they cannot fail to strike the observer. All this is the natural and necessary consequence of the increased transverse diameter of the pelvis and augmented superincumbent weight. The upper parts of the body, pressing heavily on an articulation without a cavity, stretch the ligaments and fatigue the muscles, so as to force the heads of the thigh-bones towards the crests of the ilia; and such is the extent of this ascent, that I have in some instances seen the trochanters and heads of the thigh-bones attain an elevation, in the course of time, so as almost to touch the iliac crests. Moreover, the breadth of the pelvis, especially in women, by augmenting the interval between the heads of the ossa femoris, increases likewise the obliquity of these bones, and thus renders the defects arising from the absence of a fixed articulation still more palpable and mortifying. Thus I have known individuals who, as young girls, could walk, run and dance; but who, when full-grown, became almost entirely incapacitated for any violent exercise: and this difficulty becomes converted into an absolute impossibility in very stout persons, or in those who are dropsical or in the family way.

One point worthy of remark is that the state of things on the outside of the pelvis does not in the least influence the development of this part of the trunk; and that before puberty, throughout this period and after it is passed, the pelvis acquires dimensions which are most favorable to the perfect and healthy performance of the functions of the viscera which it contains; and that it is as fully competent to receive, retain and transmit the product of fecundation, as in persons of entirely natural conformation.

The opportunities of determining, by post-mortem examination, the nature of this singular species of dislocation are very rare; as it neither constitutes, nor gives rise to, disease, and is only an infirmity in no way involving the safety or threatening the life of the subject of it, I have been enabled to study it in only a few instances, where accident or disease unconnected with the deformity have placed individuals thus affected within my reach. The appearances I have found in such subjects are the following: All the muscles which have their attachment either above or below the acetabulum were drawn up towards the crest of the ilium. Amongst these muscles some were well developed, whilst others were attenuated and slightly atrophied; the former were those which had preserved their action, the latter those the action of which had been cramped and limited, or even entirely negatived by the altered relation of their attachments. Of the latter class some few were reduced to a sort of yellowish *fibrous* tissue, amid which the eye sought in vain for any trace of *muscular* fibre.

The upper part of the thigh preserves, in these cases, its natural form and dimensions, with the single exception of the upper and inner part of the head of this bone, which I have remarked has sometimes lost a little of

its roundness, a circumstance which appears due to the friction it has been subjected to, by contact with a surface unsuited for articulation. The cotyloid cavity is either altogether absent, or presents only a small osseous, irregular prominence, where neither trace of diarthrodial cartilage nor vestige of synovial or other capsule, nor fibrous margin is to be found; but which is surrounded by some tough cellular tissue, and covered by the muscles which are inserted into the smaller trochanter. Once, in two or three subjects which have been submitted for my examination, I met with the round ligament of the joint very much elongated, flattened above and, as it were, worn at certain points by the pressure and friction of the head of the femur.

The head of the bone itself is lodged in a hollow, samewhat analogous to that which is developed around it in accidental dislocations upwards and outwards which have remained unreduced. This new cavity, which is very superficial and almost without a rim, is situated in the external iliac fossa, that is to say, above and behind the acetabulum, at an elevation proportioned to the shortening of the limb, or to the ascent of the head of the femur, which amounts to the same thing. In fact, the only perceptible difference in this respect, that I have been able to detect between these congenital cases, and accidental dislocations of old date or those which were spontaneous, is that, in the former, the arrangement of the parts appears to have subsisted for a longer term, and gives the impression of its having been the primitive condition, or that which was assumed at the very earliest period of existence.

GUILLAUME DUPUYTREN

Guillaume Dupuytren (1777-1835), one of the masters of French surgery of the early 19th century, conducted his famous clinics at the Hotel Dieu in Paris. He was among the early teachers to emphasize the importance of the study of pathologic anatomy in the training and the practice of surgeons. Among his numerous contributions in the field of orthopaedic surgery, his recognition of the congenital nature of infantile dislocation of the hip was original. His description of failure of fetal development of the acetabulum was the first such notice in surgical writings. In appreciating this brilliant achievement, it must be recalled by the reader that roentgenograms had not been invented and that deformities due to tuberculous and pyarthrotic disease of the hip joints



were widespread in Europe at the time. The distinction between these and congenital dislocation demanded a most perspicacious clinician. Almost a half century passed before the syndrome began to receive the general attention that we now take for granted, but its progress dated from Dupuytren's published lectures which were read in several editions by at least 2 generations of surgeons. It should be noted that within 15 years the volume of lectures merited a published translation by London's Sydenham Society.

CLASSIC 10

Einige Fälle von künstlicher Ankylosen bildung an paralytischen Gliedmassen

(Some Cases of Artificial Ankylosis of Paralytic Extremities)

EDUARD ALBERT (1841–1900)

I have tried to use the idea of making paralytic legs in cases of diffused essential paralysis of the legs capable of standing unsupported with apparatus by artificial ankylosis and succeeded in doing so.

1. F. Josef, 22 years, admitted July 20, 1881. Left leg especially the lower part markedly atrophic. The muscles of the hip joint without any function. No support in the knee and foot joint. The last one in equinas position. Nominal shortening of the affected leg caused by an essential paralysis in childhood.

July 20, resection of the knee joint using Volkman incision with sawing of the patella. Extirpation of the capsule. From the femur was so much resected that the sawing plane was at the highest point of the fossa intercondyloidea. A small disk of the tibia was removed. Two bone sutures were placed between the femur and the tibia, one in between the parts of the patella. Suture, drainage, Lister dressing and placing on a resection board. On the day of operation postoperative bleeding. Healing of the wound, mainly per primum; on some places slow development of pus formation.

September 2, erysipelas in the wound.

September 11, pus formation underneath the tuberositas tibia was opened, erysipelas disappeared.

October 15, tight unification noticed.

November 2, silver sutures removed. Solid unification, immovable. The patient who walked on crutches received splinting apparatus to fix the loose joints of the base of the foot with lacing shoes and two lateral steel splints. The splints go above the knee to protect the stiff knee joint from the incidental injury temporarily. The leg is completely ankylotic on the day of discharge, December 12th.

2. H. Theresia, 13 years, admitted May 24, '81. Beginning of essential paralysis at the age of 8 originally affecting all four extremities but slowing improving after weeks. The right arm and left leg remain paralyzed. Later on improved condition, disappearance of arm paralysis. Active mobility in left hip, paralysis of muscles of the knee with slight flection contraction. Paralysis of foot muscles, only the toes can move actively in slight flection. Moderate pes equinus. Right side paralytic varoequinas but the muscles of the knee joint are not paralyzed. On June 6, the section of the left knee joint in the same manner as described in the previous case with splitting of the patella. Something had to be added. I refreshed the surface of the patella and of the fossa patellaris and put reunited patella into the refreshed fossa, fixing it on the femur with one suture. I wanted a bony fixation of the femur to the patella in order to

increase the stability of the joint. Tibia and femur were fixed bilaterally with a metal suture. Dressing of the wound, drainage, Lister dressing, position on an encaved board.

Dressings changed on June 8. Small tension gangrene in the skin, slight elevation of temperature in the evening.

June 15, drain removed, plaster bandage.

July 15, considerable stability present. Bone union, except for places of the bone suture.

On October 26, final removal of last suture. Complete union and stability.

3. ST. Derta, 10 years, child became paralyzed at the age of 3 months on both legs within one night. Achillo tenotomy was performed for paralytic pes equinus at the age of 5 prosthesis for both legs simultaneously given. The machines were not tolerated recently, and walking became exceptionally difficult.

The right leg was very atrophic and can be flexed in its hip joint only with great effort and be kept in that position. Slightest touch with the fingers throws the leg while the patient rests horizontally into the abduction or adduction position. Impossibility of active flexion or extension of the knee. The foot is in slight equinus contraction, active not moveable. Only the toes can be moved slightly.

The left leg also markedly atrophic can be lifted actively and can be kept extended. From the muscles which insert at the foot are only the peromei and toe flexes functioning. The foot falls while standing into valgus position.

June 4, '81, resection of the right knee joint with H incision. Removal of very small patella. Extirpation of capsule. The joint surface of the tibia and condyles of the femur are removed with the resection knife. The bones are sutured with three silver wires. The skin wound closed with catgut. Lister dressing. Position on Petiti shoe. It seems remarkable in the course that during the first days a symptom appeared which looked on first view almost frightening. The skin of the thigh up to the buttock on its lateral and posterior part was discolored to a brownish gray, partially even lead gray, the discoloration appeared partially also on the lateral front side. At the lower leg (burned) blisters covered the yellow-reddish skin. Underneath the groin where an Esmarch tourniquet had been applied, the skin looked green and violet, but all over the skin was warm and normal on touch and the general condition good. The discoloration at the skin disappeared slowly without trace. At the wound appeared areas of pus formation, and a counter incision had to be made on the seventh day on the outside of the thigh. Tension gangrene had developed on skin edges in different points. The later course was uneventful. The patient was discharged on July 21. The bones had grown together firmly except for a little trace of mobility. The patient could walk satisfactorily without prosthesis.

4. W. Therese, 11 years. Essential paralysis as child of 1-1½. The left atrophic leg is 3 cm. short. More atrophy on the lower leg than on the thigh! Hip and knee joint act normally. Active mobility normal. The foot is contracted in equino-varus contraction. Callous formation on dorsum, active mobility of toes in flexion, also the plantar flexion which is already present, can be increased actively. The dorsal group of muscles is paralyzed, the foot without support, walking difficult.

On December 29, 1881, achillotenotomy, then opening of the jumping joint (Sprunggelenk) with dorsal incision, which simultaneously cut the markedly thinned tendons of the extendors of the toes. The periosteum of the talus and of the joint surface of the fibula was removed. The cartilage could be easily scraped off as it is usually typical on paralyzed extremities. Suture of the wound.

Lister and plaster case. On the 16th day erysipelas over the entire lower leg which disappeared on the 23rd day.

In order to reduce the equinus position and to ankylose the middle position of the joint, the plaster cast had to be removed several times and had to be reapplied immediately in a step-by-step corrected position. With the last cast it appeared as if an overcorrection had been done, and it looked as if a slight degree of pes calcaneus was produced. Therefore, for the better control the foot was splinted, the longer splint attached to the lower leg, the short one was placed around the foot. Both splints were fixed to each other in a right angular position. After 6 weeks the patient was able to stand on her foot. She was discharged 9 weeks after the operation. The talus was finally united with the lower leg; the foot had a slight prone position. The lower leg was moved with stilts, but the foot had lost its lack of control, and the patient could walk on her sole. She used a prosthesis.



EDUARD ALBERT

Eduard Albert (1841-1900) of Vienna introduced the concept of joint arthrodesis into orthopaedic surgery. The report reprinted here appeared as the title paper in the issue of June 4, 1882, of the then widely read *Wiener Medizinische Press*. It has often been quoted but seldom read and to the best of my knowledge never translated. In it appears the first description of arthrodesis of an ankle for paralytic foot. Immediately thereafter in England, Germany and the United States appeared reports of a variety of arthrodeses of the foot and the ankle intended to improve on Albert's procedure. Such variations have continued to be developed up to the present time. The translation has been kept as literal as possible. The 4th case refers to foot arthrodesis. Albert's use of the word prosthesis is our brace.

CLASSIC 11

An Operation for Progressive Spinal Deformities

A Preliminary Report of Three Cases From the Service of the Orthopaedic Hospital

RUSSELL A. HIBBS, M.D. (1869–1932)

The treatment of Pott's disease or humpback by immobilization of the diseased joints has long been the accepted method, and is accomplished by various mechanical means, braces, plaster of Paris, etc. That much success has been obtained in the prevention of deformity and the cure of the disease by these means, there is no question. That there is still much to be desired is equally unquestionable, because these various means do not secure absolute immobilization, and for this reason it is necessary to continue treatment for long periods of time, and in almost every case the deformity increases more or less.

The treatment of lateral curvatures is still more unsatisfactory; the deformity is more complicated and its cause less definitely understood. In these, in spite of the best efforts by means of support to the column and the development of muscles, in a very large percentage of cases the increase of the deformity is progressive.

In the spine affected by tuberculosis, it is the body of the vertebra which is destroyed, and, in consequence of this destruction of bone, the deformity appears, and is, in the very large percentage of cases, a purely kyphotic curve. It is very rarely that the spinous or lateral processes are affected.

One of the reasons why the disease is so persistent in its destructive effect on the bodies of the vertebrae, is because of the motion which takes place between them, and while the various methods of treatment limit the motion, none absolutely prevents it. In the light of our present knowledge and experience, the greatest need in the treatment of this disease, both from the standpoint of shortening its duration and preventing deformity, is the perfection of a method which will absolutely immobilize the spine throughout the diseased area and make the development of deformity impossible.

The writer has done an operation for stiffening the knee joint (1), which consists of removing the patella from its periosteum and putting it in the joint after a space is freshened in the bones to receive it, the periosteum then being stitched to that of the tibia and femur. In these cases the patella was not absorbed, but formed a bridge between the tibia and femur, and the periosteum reproduced in every case new bone sufficient to make a large bony bridge and a perfectly safe bony ankylosis. This operation led to the conception, that if the periosteum of the spinous processes was carefully removed, and the processes were

divided at their base and placed longitudinally in the interspinous space touching with either end the base from which the processes were removed (see Fig. 1a)*, and then the periosteum brought back and sutured, a similar condition would be produced. That is, the process would become adherent to the base at either end, thus filling up the interspinous gap with solid bone, and the periosteum would reproduce more bone so that there would be secured a fusion of the posterior aspect of the vertebra by a bridge of bone which would increase in size and strength so that absolute ankylosis would be secured.

It was thought that if a bony bridge could be established, its size and strength would gradually increase to meet the force exerted upon it, as is the case with the fibula when it is utilized to take the place of the tibia. This it seemed would be sufficient to prevent the kyphotic curve, while in the lateral curvature cases, in which the deformity is more complicated, it was thought necessary to do an arthrodesis in the articulation between the lateral processes, thus giving a cantilever support.

Through the kindness of Professor George S. Huntington, of Columbia University, I was given the privilege of doing this operation three times on the cadaver, in the fall of 1910, and I am indebted to him as well for many helpful suggestions. I have since done it upon three patients, all with Potts' disease of the spine. A sufficient time has elapsed only in one case to give positive proof that the condition which we attempted has been produced. The x-ray pictures, Figs. 1b and 2, made by Dr. Caldwell, show the continuous bone formation between the vertebrae, three months after operation. One is a lateral view and the other an anteroposterior one.

Of course the report of these cases, as stated before, is preliminary, as there are many questions which arise that cannot now be answered, for instance, the earliest age at which the formation of this mass of bone may be expected, its effect on the future progress of the deformity, etc. The youngest patient was seven years old. The processes in this case were sufficiently ossified and long enough to fill the interspinous space. It is believed that in still younger children it will be successful.

The traumatism of the operation will hasten ossification and increase the activity of new bone formation from the periosteum. In the very young, however, I think it will be necessary to graft bone from the leg. This is a perfectly practical procedure. No case of lateral curvature has yet been done, but I propose to do exactly this same operation, and if it is not sufficient, to do an arthrodesis between the lateral processes, as already suggested.

This operation was done through a longitudinal incision directly over the processes; the ligament was split, and the periosteum of the processes removed very carefully and retracted with the muscles. The processes were divided at their base, as closely as possible, without opening the canal, then they were placed longitudinally so that there was fresh bone contact, one end, the proximal, touching the lower part of the fresh base from which the process was removed, and the distal end in contact with the upper part of the base from which the next process was removed, and so on throughout the diseased area, so as to ankylose the diseased one to healthy vertebrae above and below.

The periosteum was then brought back and sutured with chromic catgut, and the skin closed with silk, without drainage. Only in the first case were any bone sutures used, as it was thought unnecessary.

The ordinary sterile dressings were applied. The wound in each case was found completely closed at the first dressing, on

* Because this article was first published a considerable number of years ago, the illustrations are not available.

the eleventh day. The first patient got up at the end of five and a half weeks, and all support was removed after three months.

Case I. E. Q., American, male, aged nine years. Entered ward of New York Orthopaedic Hospital, December 27, 1910. Lumbar Pott's disease. Patient had moderate kyphos involving last dorsal and upper four lumbar vertebrae. Disease was quite active as shown by intense spasm of muscles, occasional pain, protective gait. Indeed he was admitted for rest because of acute symptoms, as there was no thought at that time of operating on him. Patient was kept on back in bed, wearing a spinal assistant; under this treatment he became free from pain and had no night cries at the end of two weeks. General condition good. Temperature normal. X ray showed disease to have almost completely destroyed the bodies of the second and third lumbar vertebrae.

January 9, 1911. Under gas and ether, an incision was made in the median line of the back from the eleventh dorsal to last lumbar vertebra, down to the periosteum. The periosteum was then divided over tips of spinous processes, and stripped down to base of spinous processes, the interspinous ligaments being split in median line, thus leaving a continuous layer of periosteum and ligament on either side of spinous processes. The last dorsal and three upper lumbar spinous processes were thus denuded. The four repective spinous processes were then fractured by means of a small bone chisel, close to their bases.

The third lumbar spine was then placed longitudinally so that its apex rested on the upper part of the base of the spinous process of fourth lumbar spine; in this position a No. 2 chromic gut suture was passed through the end of the third and body of the fourth lumbar spines, thus fastening the two processes together. In like manner the second lumbar was fastened to the third, the first to the second, and the last dorsal to the first lumbar.

The reflected periosteum was then brought together over the spinous processes and sutured with a running chromic suture, No. 1, and reinforced in three places with silk sutures. The skin wound was closed with silk. The wound was dressed and a plaster spica applied from knees to axilla, the spine being kept in slight overextension while plaster was applied. Patient was put to bed on back. On the first night after operation patient suffered severe pain which was difficult to control, even with opiates.

January 11, 1911, pain still severe and plaster was amputated at groin; this gave him very little relief. January 13, entire plaster jacket was removed. Wound found to be in excellent condition, with primary union. The wound was dressed and a modified spinal assistant applied. At no time after this did the patient have the slightest pain. It is evident that the pain and discomfort were due to the overextension of the spine, and the pressure of the plaster.

The temperature rose to 100° F. on the day following the operation. On the third day after operation, the temperature dropped to normal and has remained so.

Patient was kept in bed, until February 20th. At that time he was in excellent condition and seemed to have bony union in spine. He was allowed up on that date, wearing a brace, with no adverse effect. After getting up he continued to improve and on March 10, 1911, was transferred to the country branch.

April 5, 1911, all support was removed. There was solid bony fusion of the posterior aspect of the vertebra. This is absolutely demonstrated by x ray pictures made by Dr. Caldwell. (See Figs. 1b and 2. Fig. 3 is a photograph after the operation.)

Case II. W. M., Italian, male, aged seven years. Entered ward of New York Orthopaedic Hospital December 31, 1910, with dorsolumbar Pott's disease of two years' duration. Patient had moderate kyphos extending from tenth dorsal to fourth lumbar vertebra. Back was very painful, spasm of back muscles very acute. He also had double psoas spasm which caused flexion deformity of both thighs of about 90°. Slight thickening in left inguinal region. Patella reflexes exaggerated.

Patient was put at rest on back and extension applied to both legs. General condition remained good and at the end of one week he had no pain and flexion of thighs was entirely reduced. Psoas spasm still present and patella reflexes +. Patient continued gradually to improve and by the middle of April, 1911, psoas spasm was very slight. Patella reflexes were normal.

April 26th. Under gas and ether a spinal operation was performed. Incision was made over the kyphos from tenth dorsal to fourth lumbar inclusive. Periosteum and ligaments were stripped back as in Case I. Spinous processes were found to be quite large and almost completely ossified.

The bases of the spinous processes (tenth dorsal to fourth lumbar inclusive) were then fractured with a small bone chisel, and placed so that the base of the fourth lumbar remained in contact with the lower part from which it was removed and the tip was placed in contact with the spinous process of the fifth lumbar, the third against the fourth, second against the third, etc., until the bridge was formed of continuous bone. The processes were not sutured in place as in the preceding operation, as it was thought that the close adjustment and suture of periosteum and muscle would hold them in place. The periosteum was then brought back over the bone and held with deep continuous chromic gut sutures. The skin wound was closed with silk without drainage.

Having in mind the extreme discomfort that the preceding patient had experienced from the plaster jacket, a modified spinal assistant was applied with perineal straps. The patient was placed in bed on the back. Patient had some discomfort for the first twelve hours after operation, but not severe enough to require any attention. On the following day he was free from pain and at no time since has he had the slightest discomfort. General health good.

Preceding the operation, temperature had never gone above 99.5° F., minimum being 97.5° F. Since operation the temperature has never gone above 98.6° F., minimum being 98° F. The wound was dressed on the tenth day and the sutures were removed, union being found perfect. (Fig. 4 is a photograph before, and Fig. 5 after operation.)

A sufficient time has not elapsed to make a final report. This will be done later.

Case III. Mrs. B., American, aged twenty-five years, mother of two children. Entered ward of New York Orthopaedic Hospital, March 13, 1911, with dorsolumbar Pott's disease, of five years' duration. Marked kyphos involving ninth dorsal to second lumbar vertebra inclusive. Patient had considerable pain when in erect posture and intense muscle spasm of back; psoas spasm on left side; large fluctuating abscess in left inguinal region, which had burrowed under Poupart's ligament, and extended down the anterointernal aspect of thigh about six inches. General condition good, temperature normal. Patient was kept at rest in bed until April 27, 1911, when it was decided to operate on her spine. The abscess during this time had remained about the same.

April 27, 1911, under gas and ether an incision was made over the kyphos, down to spinous processes, the same technique being observed as in Case II. The last four dorsal and three upper lumbar spines were then fractured as in the preceding operations. The periosteum was then closed over the spines with continuous chromic gut sutures, reinforced at intervals with deep silk sutures. Skin was closed with silk, dressing applied, and the spine immobilized with modified spinal assistant with perineal straps. The patient being very heavy, she was put on a Bradford frame to facilitate moving her. She had very little pain after operation and slept during the first night without opiates.

Since the first twenty-four hours after operation, the patient had no discomfort; temperature normal; the abscess had given her no discomfort and was slightly diminished in size.

The wound was dressed on the tenth day, and sutures were removed; union by first intention.

The most striking feature of the operation is the marked reduction in the kyphos. This patient is still in the recumbent posture. (Fig. 6 is a photograph before, and Fig. 7 after the operation.)

It is too early in this work to reach any final conclusion as to its value. It seems, however, that this method may possibly do much in the prevention of kyphotic curves and shorten the duration of the disease, saving the patient at the same time the necessity of wearing an apparatus for years.

In the lateral curvatures, it would seem to offer a means of preventing a progress of that distressing deformity.

REFERENCE

1. Hibbs, Russell A. An operation for Stiffening the Knee Joint. *Annals of Surgery*, March, 1911.



RUSSELL A. HIBBS

Russell A. Hibbs (1869-1932) of the New York Orthopaedic Hospital and Fred H. Albee of New York Post-Graduate Hospital both worked independently to develop a technic of spine fusion at about the same time. Both published reports in 1911. The judgment of time has discarded the Albee technic of a cortical tibial strut graft and developed the operation of posterior spine fusion on the basis of Hibbs' procedure. This reprint of Hibbs' first report in the New York Medical Journal of May 27, 1911 remains the classic in the field.

CLASSIC 12 Synovéctomie du genou

(Synovectomy of the Knee)

M. A. MIGNON

M. A. Mignon: The patient whom I present has undergone the excision of the synovia of the right knee in June, 1900.

He had a chronic arthritis following a trauma received in December, 1899. The principal reason for the intervention was the difficulty, almost the impossibility, of walking. The patient barely could put his foot on the ground without experiencing a very lively pain in the area of the superior pouch of the synovial cavity, and the pain would increase rapidly to the point of preventing all movement. Articular function was far more restricted than is seen ordinarily in similar cases. There was a veritable impotence of the inferior extremity. Passive motion was not possible beyond a right angle, and there was some lateral mobility of the tibia.

Anatomically, the knee was globular in appearance. The capsule of the joint was normal. The bones did not appear to be altered. The synovia seemed to be the sole cause. One felt its surface thickened and roughened; the superior pouch especially was very indurated. It formed a very obvious projection above the patella, 3 fingerbreadths in height and bordered by a very bulky rim. The abundant joint fluid was serous, because of the ease of ballottement of the knee cap.

Even though the condition of the patient was not very good, I thought of a chronic synovitis, nontuberculous, and I attributed the severity of the pain to the compression of the superior pouch of the synovial cavity during extension of the knee.

That is why I decided to perform a synovectomy.

The operation was done on June 30: Through 2 laterolongitudinal incisions, I excised without difficulty all of the superior pouch and the lateral parts of the synovia to the lateral ligaments.

As I had foreseen, the serous fluid was thick, reddish and viscous. The bundle of fat also was very red and resembled an inflamed uvula. There was no lesion of the cartilage or the bone.

The postoperative reaction was most mild.

The patient began some small movements of the knee by himself on the 5th day. He arose from his bed on the 15th day and sat up from noon to 5 o'clock on the 17th day, experiencing no more than an insignificant pain.

Histologic examination showed that it was a chronic synovitis without sign of tuberculosis. Guinea pig inoculation remained sterile.

The patient stood up on the 20th day. He still suffered pain on moving the limb, but the pain was not the same as before the operation. He felt the strains of scar tissue and not the lancinating pains of the inflammation. All pains subsided at night.

The 25th day flexion of the restricted leg on the thigh approached a right angle without quite reaching it. The patient remained up all day.

I began at that time some small forced motions and 20 days later attained complete flexion.

This was August 4. But the last visit had produced more pain and crepitus than usual. Perhaps I was going a bit fast. Following the last movements of the improving knee, there occurred considerable swelling reaching to the inferior third of the thigh and a light ecchymosis of the skin on the lateral surface of the joint. The pains, very acute, lasted 48 hours.

The crises subsided gradually, and the patient began to walk.

One month passed after the patient had resumed his walks in the garden, when a sharp pain at the level of the lateral femoral condyle again immobilized him in bed. On September 15, we found in front of and at the base of the lateral condyle a tumefaction of bony consistency, oval in shape and about 3 centimeters wide by 5 centimeters long. Adhering to the bone, it was tapering on top and rounded at the bottom. Flexion of the knee was limited to a right angle.

Experience and radiography made us accept an osteoma, the consequence of manipulation in mobilizing the knee.

I proceeded with excision of the tumor on September 27. The operation was performed without difficulty through an incision in the lateral longitudinal scar. The excised mass was the size of a thumb and consisted of newly formed bone tissue. The synovial cavity was exposed during the operation; the synovia was very dense and very clear.

During the chloroform sleep, flexion did not go beyond a right angle. I did not wish to force the movement in fear of inflaming the synovia.

The healing of this little intervention was rapid: the patient began to get out of bed on October 7.

Since this episode, I have allowed him the liberty to gain mobility of his knee by grading the amplitude of his movements according to his pain.

He has come little by little to the state where you see him today.

Walking, gymnastic pacing and even the track are easy. Walking is possible for half an hour without fatigue. Kneeling is not painful.

Some small twinges in the joint from time to time are the only subjective symptoms. Flexion is possible to 70°.

The shape of the knee is almost normal. There is a very slight effusion. One feels above the lateral condyle of the femur some roughness which represents the residue of the old osteoma.

The muscles of the thigh are a bit atrophic (2 centimeters less in the circumference of the right thigh).

Among his many contributions to clinical surgery, Richard vonVolkmann of Leipzig (1830-1889) had attempted to eradicate tuberculous infections of the joints by removing grossly involved areas of the synovial membrane. The process was described in his collected works published during the 1870's. The attempt was obviously futile, and in no sense was it a synovectomy as that procedure was understood at a later date. Not until 1900 was the operation of synovectomy for nontuberculous arthritis of the knee proposed, and then by M. A. Mignon before the Surgical Society of Paris. His report of a case and description of the operation appeared in the prominent and widely read French journal, *Le Bulletin et Mémoires de la Société de Chirurgie de Paris* (26:1113, 1900). This was the introduction of the operation into modern orthopaedic surgery. His report is reprinted here as its first translation into English.

The original report was presented at the Meeting of the Surgical Society of Paris, December 12, 1900.

CLASSIC 13 Amputation at the Ankle Joint

JAMES SYME (1799–1870)

John Wood, aged 16, recommended by Mr. Aitchison of Dunbar, was admitted on the 8th of September 1842, suffering from disease of the foot, which had suppurated and ulcerated, in consequence of a twist he had given it in walking about twelve months before. On the instep, which was very much swollen, there were two openings that permitted a probe to enter freely into the substance of the tarsal bones, and more particularly the astragalus and os calcis. In these circumstances, it was plain that the patient, already much emaciated and reduced in strength, had no chance of recovery except from amputation.

As the disease extended beyond the limits of Chopart's operation, it would have been necessary, in accordance with ordinary practice, to remove the leg below the knee, but as the ankle-joint seemed to be sound, I resolved to perform disarticulation there. With this view, I cut across the integuments of the instep in a curved direction, with the convexity towards the toes, and then across the sole of the foot, so that the incisions were nearly opposite to each other. The flaps thus formed were next separated from their subjacent connexions, which was easily effected, except at the heel, where the firmness of texture occasioned a little difficulty. The disarticulation being then readily completed, the malleolar projections were removed by means of cutting pliers.

The patient suffered no constitutional disturbance or any alarming symptom after the operation, but recovered slowly, as was to be expected, from his general weakness and the unhealthy state of the soft parts composing the stump. A small slough separated from the edge of the lower flap, in which, as well as the upper one, I found it necessary, during the healing process, to make a counter opening for the free discharge of matter. He was dismissed on the 2d of December, and I learn from Mr. Aitchison, that he continues quite well. The wounds are soundly healed; and any degree of pressure can be borne by the stump, which has a round form well suited for the adaptation of a boot or artificial foot, and is strongly protected from external injury by its thick integuments.

The result of this case is very encouraging to the performance of amputation at the ankle-joint,—an operation of greater importance than at first sight may appear, since, if found to be practicable with safety and success, it should in a great measure supersede amputation of the leg below the knee. The circumstances requiring this operation seldom affect the leg itself, because the limb, if so seriously injured or diseased as to require

amputation, must almost always be removed above the knee. But while compound fractures and malignant tumours of the leg are thus in general subjects for amputation of the thigh, diseases and injuries of the foot have too frequently claimed amputation of the leg. Modern surgery, no doubt, has circumscribed this field for the operation, by introducing partial amputations of the foot, but there still remain cases of no rare occurrence which are held to demand its performance.

When caries attacks the metatarsal articulations of the toes, it is usually confined to a single joint, that of the great toe being the one by far most frequently affected; and Mr. Liston's happy employment of straight cutting pliers, instead of the variously formed saws previously in use, for dividing the bones, has rendered removal of the disease from this situation so easy, that the old practice of amputating the leg on such occasions seems hardly credible. If the caries again be seated at the other or proximal extremity of the metatarsus, it is sure to engage also the adjoining tarsal bone or bones, and therefore the operation suggested by Mr. Hey of Leeds, which was to disarticulate the metatarsus from the tarsus, is not applicable. In many cases, however, as only one of the tarsal bones is engaged, it may be taken away with the corresponding part of the metatarsus, so as to render the foot merely narrower without diminishing its length. Thus the first metatarsal is removed along with the internal cuneiform bone, and the os cuboides with the two metatarsal bones articulated to it. But the operation of Chopart, which leaves only the astragalus and os calcis, is the most valuable of all partial amputations, as it commands the largest portion of the foot requiring removal for disease or injury, and at the same time preserves a support for the patient not less useful than that which is afforded by the whole of the tarsus. Its introduction was long opposed on the ground that the extensor muscles of the ankle acting through the tendo achillis, when no longer antagonised, would draw up the heel and point the cicatrix to the ground. I performed this operation in 1829,[1] so far as I know for the first time in Edinburgh, and have frequently done so since, with the most satisfactory result, no inconvenience having ever been experienced from the source just mentioned, as the cut extremities of the tendons on the fore part of the joint speedily acquired new attachments, enabling them to counteract the extensive power.

But when caries affects the astragalus, or os calcis, or, as very frequently happens, is seated in the articular surface between these bones, no form of partial amputation can be of any avail, and attempts to cut out the diseased bone generally prove unsuccessful. In cases where the tuberosity of the os calcis is alone affected, excision may be executed completely and certainly; and it is sometimes, though rarely possible to extirpate the disease, even when it extends to the articulation, either directly by gouging out the carious part, or by making a perforation through it across the foot, and passing a seton, which may be made the vehicle of suitable applications, such as the red oxide of mercury, the mineral acids, or a saturated solution of the nitrate of mercury. When these means fail, or are abstained from, in despair of their efficiency, amputation of the leg is the ordinary resource, and the same measure is of course considered necessary for similar disease of the ankle-joint. In the case of compound dislocation of the astragalus, with or without fracture of the malleoli, it is deemed proper, in the first instance, to give the patient a chance of retaining his limb:—unless his habit of body, or the circumstances in which he is placed, should be unfavourable for his recovery, when prudence is thought to require amputation of the leg.

[1] Quarterly Report of the Edinburgh Surgical Hospital. Edin. Med. and Surg. Journal, 1842.

It thus appears that compound dislocation of the astragalus, and caries of this bone, with its adjoining articulating surfaces, are the principal cases for amputation of the leg, and that consequently this operation may usually be superseded by amputation at the ankle-joint. It may be objected that, when the joint itself is diseased, entire removal of the articulation must be requisite. But in what is commonly called disease of the ankle, the joint between the astragalus and os calcis is affected much more frequently than that between the astragalus and bones of the leg; and even when the latter condition really exists, it would be easy to remove all of the bone that is essential for recovery, by sawing off a slice from the articulating extremities of the tibia and fibula, as the caries penetrates to no great depth of the cancellated texture.

The advantages promised by amputation at the ankle-joint, instead of the operation near the knee, are—1*st*, That the risk of life will be smaller; 2*d*, That a more comfortable stump will be afforded; and, 3*d*, That the limb will be more seemly and useful for support and progressive motion.

The risk of life must be less, because the parts divided and removed are not nearly so extensive as when the leg is amputated, hardly exceeding, indeed, those concerned in Chopart's operation; because there is less room for hæmorrhage, either immediate or secondary, owing to the smaller size of the vessels cut, which are merely the branches of the posterior tibial, and the anterior tibial artery, very near its termination; and because the cavities of cylindrical bones not being opened, the danger of exfoliation from the dense osseous texture, and of inflammation in the medullary veins, is avoided. The stump will be more comfortable, because it is formed of parts peculiarly well calculated to protect the bone from injury, and not disposed to contract like the muscular tissue; because the cut extremities of the nerves being smaller, will be less apt to enlarge and become the seat of uneasy sensations; and because the absence of exfoliation insures complete union of the integuments over the bone. And the limb will be more useful, as well as seemly, from full play being afforded to the movements of the knee joint, without the embarrassment of an imperfect stump.

On these grounds, I think amputation of the ankle-joint may be advantageously introduced into the practice of surgery. I regret having cut off many limbs that might have been saved by it, and shall be glad if what has been here said in its favour encourages others to its performance.



JAMES SYME

During the early part of the 19th century, a large number of new amputation technics were introduced by Liston, Pirogoff, Larrey, Chopart and others. Of all of these, the one amputation that has withstood time is that described first by James Syme of Edinburgh (1799-1870). It was still in favor during World War I and World War II, especially in the British and the Canadian Armies, but only later in the United States Army. By 1944, Harris, of Toronto, then the Director General of Medical Services of the Canadian Army, wrote, "This is the most useful of all amputations of the lower extremity because of the perfection of its weight-bearing properties." Since World War II, there has been a large literature on the subject of the Syme amputation. However, from the reading of much of it, it was obvious that the authors did not read Symes' paper directly but used indirect sources. This is one of the classics in the field of amputation and is reprinted herewith.

CLASSIC 14 Nieve wijze van aanwending van het gypsverband bej beenbrencken. Eeme bijdraze tot de militaire chirurgie

(A New Method for the Application of Plaster-of-Paris Bandage)

ANTONIUS MATHIJSEN (1803–1878)

Fractures have always played an important role among curable conditions. Mere separation is not the only consequence of a fracture; the smashing, contusion, injury, rupture, etc., of the soft parts may just as well be some of the causes endangering the patient's life. When caused by firearms, a fracture is even more dangerous, for instance on a battlefield, the patient has to be moved immediately.

Ever since ancient times, we have been searching for an appropriate treatment to prevent the occurrence of risks.

One has only to glance at the wound-dressing manuals to see that many bandages and dressings and instruments were recommended to treat these injuries.

All these methods, instruments and dressings have not kept the broken parts immovably in their place; therefore, they only had an external effect, and the patient was forced to stay in bed.

Therefore, man has always tried to find a treatment, a so-called stationary dressing, that could be applied to keep the bones together in such a manner that the patient could leave his bed and could be transported without harmful consequences.

In ancient times already, for instance, in the Egyptians, Greeks, Persians, Arabs, traces were found of immovable dressings for fractures.

The well-known French military physician, Baron Larrey, adopted a quite effective method from Don Eugenio de la Penna. He bandaged the fracture with linen, which had been first moistened with a mixture of spirits of Camphor, egg whites and lead-acetate.[1]

Once the bandage had dried it would keep together the broken parts immovably. This bandage, which became quite popular, is hardly used any longer because of the cost when used on a large scale.

At the same time, attempts were made to cover the limb with a thin solution of plaster of Paris. Therefore the limb would first be put in a container or tray and then covered with plaster of Paris, whereby the limb received a solid casing.

Even though the plaster-of-Paris casing was known in early times and was later on used by Prof. Hendriksz from Groningen,[2] by surgeon Schröder from Amsterdam, by Kluge, Keijl, and Dieffenbach in Berlin,[3] it was not used very widely and now it is completely out of use. The necessity of a mold, the thickness of the layer of plaster of Paris, the difficulties in providing access to the broken parts, the constriction in case of swelling, the inadequate attachment in case of a subsiding limb, created many objections against this kind of bandage.

A few years ago, the Belgian inspector of Military Health Services, Baron Seutin, succeeded in introducing a treatment for fractures, which was favorably accepted by the physicians. This treatment was called Starched Bandage (Bandage Amidonné).[4] This dressing consists of strips of linen or bandages and carton splints, soaked in starch, wrapped around the limb; after drying, this dressing became a solid tube encircling the limb.

This Seutin dressing has many advantages and has been used throughout Europe and even in the most remote parts of Russia, but, just like the plaster-of-Paris casing, this dressing has the following disadvantages:

a. The casing cannot adjust itself to the changing conditions of the limb.

b. It takes a few days before the casing becomes solid enough.

c. The injury or the broken parts cannot be reached.

d. No fomentation can be used.

e. In case of suppuration, or, with small children urinating, the dressing might soften and loosen.

f. The carton splints, which are soaked in water, in drying, may shrink and become shorter; which, of course, will have bad effects on the fractures.

Seutin realized all these objections and tried to prevent them, in the first place by changing his immovable dressing to a "bandage amovo-inamovible" which he obtained by cutting the bandage in the middle. In order to see the injuries and broken parts, Seutin made openings in his bandage, and in order to accelerate the drying process, he suggested that heated objects be placed near the dressing.[5] These changes, in addition to the two-valved method of starched dressing introduced by van Meerbeeck, could not eliminate the above mentioned disadvantages.

In particular, with regard to the time needed for the dressing to become solid, much was left to be desired. Speed is one of the essential factors—e.g., mentioning the fractures with little children and those occurring on a battlefield, proves this point.

In the year 1839, Lafargue made an immovable dressing for fractures, that had the great advantage of hardening immediately. He used a mixture of fresh warm starch-paste, with a consistency like that of cream, mixed with powder of plaster of Paris.[6]

The limb would be wrapped with various layers of linen strips, overlapped strips; between these layers he applied the mixture of starch and plaster of Paris, first placing small metal pins, between these strips pointing toward the axis of the limb. The difficult and cumbersome application was the reason why this method was never accepted.

From the above-mentioned examples we can deduce that the immovable dressing and the "bandage amovo-inamovible" still lacked the desired requirements, which were considered most important by civil, and especially by military physicians, such as:

a. It should be easily applicable.

b. It should acquire its solidity within minutes.

c. One should have access to the injury or broken parts.

d. The bandage should mold itself to the shape of the limb.

e. The suppuration or the moisture of the damaged limb should not have any effect on the dressing.

f. It should not be too heavy or too expensive.

I already wrote in No. 5 of the 1852 edition of the Repertorium, a small article on a plaster-of-Paris dressing which I used and which combines the above-mentioned advantages.[7] The important properties of these methods of dressing are based on the fact that dry powdered plaster of Paris is applied between two or more layers of wool or other rough material and, after moisten-

ing with water, the powder absorbs water immediately and acquires a solid form.

It is interesting to compare this dressing with a covered poultice. It molds itself entirely to the unevenness of the part on which it is applied; one can mold it in different shapes, while it is still moist, and it keeps the form imparted, once it has hardened.

From the above mentioned properties we can realize at once that this dressing is not only used in fractures of the trunk and limbs, but also in the joints and in various other conditions with the name of orthopedic dressing in general, even in all those conditions in which Seutin has used his starched-dressing.

With military surgery in mind and, for example, field armies marching, in combat, where fractures are often accompanied with shattered bones, we believe that these methods of dressing can be of great use. The bandage is effective within minutes, and the patient can be moved immediately, the moving could even be done on horse-back, in the event that there should not be more suitable means of conveyance available.

I do not maintain, however, that this kind of dressing can be used only by military physicians, it can be of great use also in civil surgery and it is more useful, in my opinion, because of its simplicity and easy application, than the presently used and manufactured bandage-instruments for fractures, which I also used earlier. The various modifications the plaster-of-Paris dressing can be subjected to, are as follows:

a. The simple, original plaster-of-Paris poultice

b. The two-valved plaster-of-Paris dressing

c. The two-valved plaster-of-Paris dressing with extra parts put in

d. The immovable dressing

e. Bandages for diseases of the joints

A. Simple, original plaster-of-Paris poultice[8]

To be used: two compresses of the same size to be cut according to the length and size of the limb. Between these two compresses, a thin layer of dry plaster-of-Paris powder is evenly applied.[9] The plaster of Paris should not reach the edge of the compress, but it should be at a distance of about one inch from the edge. The limb is put on the bandage, and the bandage is then moistened with water and applied around the limb, thereafter the edges are put over each other, and fastened with pins—(note, cold and hot water can be used).[10]

B. Two-valved plaster-of-Paris dressing

According to the length and size of the limb, one cuts a pattern from a double-folded piece of white unbleached cotton or linen. The closing sides should overlap each other about one inch on the frontal part of the limb. At the rear, this double folded compress has to be stitched length-wise with woolen thread. In case of emergency, a couple of pins, at preset distances, may have the same effect.

The necessary amount of plaster of Paris is evenly applied between the compresses and one inch from the edges should be left open. The limb is now placed on the prepared dressing which is then moistened with a wet sponge. Thereafter, the bandage is wrapped around the limb, the edges overlapping, and it is tightly put together and attached with pins.

In case one should want to provide a hole or opening in the dressing, because of a wound or for other reasons, a piece of cotton of the size of the hole is put between the compresses, before the plaster of Paris is applied after the bandage has become solid. The compresses are cut and the cotton is removed.

C. Two-valved plaster-of-Paris dressing with an inlay.

The pattern is from an old woolen blanket, linen, or thick unbleached cotton, according to the length and size of the limb.

This piece, which is divided into two equal halves, becomes the inner part of the dressing. The stitched-through, double-folded outer part or compress-described is also a part of this dressing. And it is used to take up the separate pieces of the inlaid part. The outer part of the dressing has to reach over the inner piece all around for about one inch. Whereas the complete overlapping on the front-part of the limb has to be effected and has to be fastened with pins.[11] When the dressing has reached this point, the separate pieces, covered with powder of plaster of Paris are put on the outer part, then the limb is put on the dressing and the bandage is wrapped around the limb; the edges of the outer part overlap the inner part, and each other, and are pulled tight and fastened with pins. The dressing is then moistened with a wet sponge. In the case that the dressing should be immovable in the back, then the outer part need not be stitched, neither need the inlaid piece be cut into halves; the treatment remains otherwise the same.

In case one should need a hole to be able to reach a wound, one cuts beforehand a small piece from the inner part of the dressing-fig. In the same way, this dressing is applied to the thigh and to the whole leg, from the coccyx to the foot joint in the latter case it is necessary to make the inlaid parts of the dressing from a thick woolen material.

D. Immovable plaster-of-Paris dressing

For this bandage are needed two layers of linen, that cover the limb, one and a half times, and an inlaid piece with plaster-of-Paris, like the dressing mentioned without separating the inlaid piece.

Place on a pillow, covered with a folded blanket or sheet, one layer of linen bandages, overlapping each other ⅓; the inlaid piece of the dressing-covered with powder of plaster-of-Paris is placed on this layer of strips; another layer of linen strips is put on top of the inlaid piece again overlapping each other ⅓. Then the limb is put on the dressing and the upper layer of strips is moistened with water. This dressing is wrapped around the limb. Then the inner piece with plaster-of-Paris, is moistened and wrapped around the limb, and then the outer layer of bandage is put around the limb. The edges are tightly pulled together. Excessive parts of the inlaid piece (or inner part) can simply be cut away with scissors.

In case one wishes to have access to the wound or broken parts, one has to make holes, as described under C. When one wants to look at the limb, or take off the dressing, the two layers on the front part of the limb are moistned, between the inlaid piece (where the two ends of the inner piece meet) and cut.

Another way to apply the immovable plaster-of-Paris dressing is to take a piece of cotton cloth, about 1½ yards long and about ½ yard wide, one rubs both sides of the cloth with plaster-of-Paris-powder, then this piece of cotton cloth is cut into narrow bandages about 5 inches wide and rolled up.

After wrapping the limb evenly with linen bandages, one takes one of the plaster-of-Paris powdered bandages of cotton, soaking wet, and wraps it around the limb, winding it like the shape of an 8; then one takes the second plaster-of-Paris bandage, which also is soaking wet, and one winds that around the limb in the same manner, one continues with this, until the bandage is high enough around the limb. The windings have to overlap each other about ⅘ and they have to be applied smoothly.

In order to provide access to the broken parts, one cuts a piece of cotton cloth which is covered with plain ointment of hog's lard on both sides, in small square pieces. In the event that one should desire holes in the dressing between a little square has to be placed between the windings of the bandage. Since the plaster of Paris will touch

the greasy substance, it will not harden, and therefore it will be fairly simple to cut a hole in the dressing. In the same way small strips of cotton prepared in the same manner are to be placed between the windings of the dressing on the front part of the limb, in order that one may be able to cut the bandage easily.

E. Dressings for diseases of the joints

One cuts the two halves of the dressing from a woolen blanket of even thickness according to the form and size of the joint.

The two halves of the dressing for the foot joint and elbow joint, are in the rear (in the front for the knee joint) sewn together with a large needle. By sewing the two halves together one gets a shape that is tight around the joint; the edges have to overlap again for about one inch.

The outer part of the dressing is then covered with plaster-of-Paris powder, moistened with water, and covered with layers of cotton. Then the dressing encircling the joint is put together (the joint is first wrapped with a regular bandage), the loose edges are applied so as to overlap, and the bandage is kept together by another dry upper bandage. In case one has to put the joint in a particular position, or in case it has to be bent, one has to apply a plaster-of-Paris splint.

In order to do this, a woolen blanket is covered on both sides with powder of plaster of Paris; from this piece one cuts two to four strips, as long and as wide as needed for the splint. Then the limb is put in the desired position, the strips of blanket are moistened and placed against the limb, the splint is then fastened tightly to the limb with bandages; the limb should be held in the desired position, until the plaster-of-Paris splint has hardened. To prevent the plaster of Paris from touching the skin one layer of linen is placed around the broken part or joint. According to these various types of application, experts will realize that these methods are used not only in the above mentioned cases, even when an immovable bandage is needed.

All physicians who will accept and apply my bandaging methods are kindly requested to publish their findings in one of the professional magazines.

FOOTNOTES

1. See Clinique Chirurgicale des Hopitaux Militaires (Clinical Surgery for Military Hospitals) Paris 1830, Vol. III.
2. In an earlier report on immovable bandages by Inspector of Health of the Army and Navy Snabilié; the following statement is made: "In 1814 I saw my esteemed teacher, Professor Hendriksz, successfully use a plaster-of-Paris bandage, in the Nosocomium Chirurgicum in Groningen." Netherlands Lancet first volume 1838-39, page 357.
3. See M. Muttray: the criribus fractis gypsoliquefacto curandis, Berlin 1831.
4. See Bulletin Medical Belge, year 1835, page 83-90.
5. The most detailed descriptions of his complete treatment is to be found in "Traité de la méthode amovo-inamovible, 1848." Copied from the "Mémoires de l'Académie Royale de Médecine" (Memories of the Royal Medical Academy).
6. See "Appareil inamovible instantanément solidifiable" (immovable bandage, solidifying instantly), treatment introduced April 29, 1839, by G. V. Lafargue of Saint Emilion, Montpellier 1839 in 4e.
7. The factory price of plaster of Paris is only six guilders per hundred Netherland pounds (metric pounds).
8. This and the bandages mentioned under B, C, and D, are supposed to be applied to the leg (crus).
9. The amount of plaster of Paris depends on the size of the bandage and the required strength, e.g., for the leg, three Netherland ounces (metric system) are sufficient. The quality of the plaster of Paris should be excellent and particles of chalk and plaster should not occur. The plaster of Paris has to be kept in tightly closed containers, because of its hygroscopic characteristic.
10. When applying plaster-of-Paris bandage, either cold or warm water can be used.
11. If material that cannot absorb powder of plaster of Paris easily, e.g., cotton and linen, the redundant plaster of Paris should be equally spread over the inlaid piece.



ANTONIUS MATHIJSEN

In 1852, a most effective innovation was dramatically introduced into the age-old regimen of fracture therapy, a method which was destined to influence the practice of orthopaedics in many directions. In that year, Antonius Mathijsen (1803-1878), a Belgian Army Surgeon of Brabant, introduced the effective use of plaster-of-Paris bandages. The importance of this contribution cannot be overestimated. Mathijsen not only described it in several subsequent papers and monographs but also spent a tremendous effort in overcoming the resistance of "established authorities" to the introduction of so novel a procedure. He himself in this first major report gives its immediate historical background. To the best of my knowledge this is the first time that Mathijsen's paper has been translated into English.

CLASSIC 15 Récerches sur la paralysie musculaire pseudohypértrophique, ou paralysie myoscléosique

G. B. A. DUCHENNE DE BOULOGNE (1806–1875)

A. DEFINITION AND DESCRIPTION OF THE DISEASE

The disease which I will describe is characterized principally: (1) by a weakness of movements, generally settling at first in the muscles of the lower extremities and the lumbar spine, progressively spreading finally to the upper extremities, worsening at the same time to the abolition of mobility, (2) by the increase of volume either (ordinarily) of several of the paralyzed muscles or (exceptionally) of all the paralyzed muscles, (3) by the hyperplasia of the interstitial connective tissue of the paralyzed muscles, with an abundant production of fibrous tissue or fatty vesicles in the more advanced periods.

I propose to call this disease *paralysie musculaire pseudo-hypertrophique* (pseudohypertrophic muscular paralysis), after its principal objective clinical signs, or *paralysie myo-sclérosique,* after its peripheral anatomic characteristics. These terms will be justified finally by study of the symptomatology and the pathologic anatomy in the living during the course of the disease. I prefer the first of these terms.

B. HISTORY OF MY INVESTIGATIONS

The discovery of pseudohypertrophic muscular paralysis goes back to the beginning of the year 1858; I owe it to the observation of a child who was overtaken by a paralysis of an unknown type and was sent to my clinic by my friend M. Bouvier.

Having received, in 3 years, several cases absolutely similar and of which I did not know anything analogous in science, I believed myself well justified in considering this muscular affection as a type of syndrome not yet described and peculiar to childhood. When, in 1861, I recognized the principal clinical characters,[1] I had wished only to attract the attention of observers to a disease which seemed to be rare. Faithful to the rule of conduct which had been given me in my previous pathologic studies, I promised to offer a more complete description as soon as it was possible to base it upon a larger number of cases matured by time.

I am happy today to have followed that step, because the new cases which I have received and those which have been observed in France and in Germany have modified a bit my ideas on its nature. Meanwhile these new cases have confirmed the correctness of the principal characters which I had outlined and gave me greater authority to enter it into nosology as new disease.

1. Eléctrisation localisée, 2nd edition, 1861. paraplégie hypertrophique congénitale. p. 364.

C. DESCRIPTION OF THE DISEASE

I will trace the description of pseudotrophic paralysis in relation to the observation which I chose in 1861 as an example and type case of this disease. This will be stated in a manner more complete and more precise, following the observations and the new information given by the mother of the child who is its subject. (The information which I shall first give of the patient had been furnished by the father who had observed its earlier years more accurately than its mother.) She offered further a greater interest, because since the preceding relation (of 1861) I could follow the progression (in extension and exacerbation) of this pseudohypertrophic paralysis for some years until its general involvement and its termination by death.

First Case: *Pseudohypertrophic paralysis; first noticed in infancy by weakness of the lower extremities; considerable enlargement of the muscles of the lower extremities and the extensors of the lumbar vertebral column to the age of 7 years; progressive generalization of the paralysis and complete abolition of all movements at 13½ years; intelligence dull; death pulmonary at 15 years.*

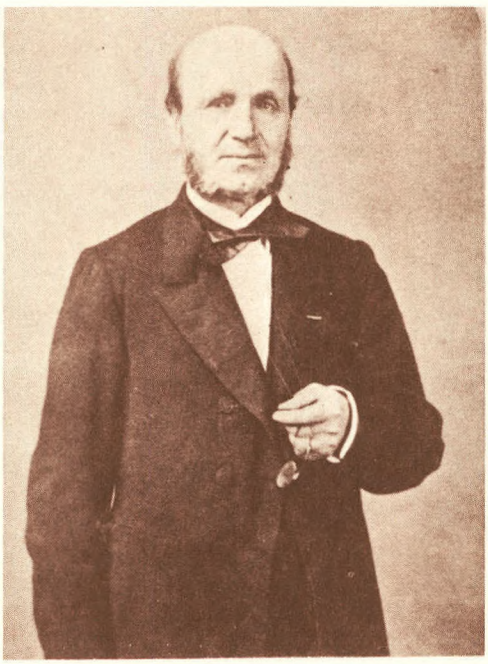
Joseph Sarrazin, residing at Paris, was born well built, of a good constitution, without any apparent difficulty in the mobility of his extremities, of which the lower were a bit more developed than the upper. His mother said he was a beautiful baby. No one in the family had been affected with a disease similar to that which he developed; his brother and sister, today aged 14 and 21, were well formed. It was only when toward the age of 8 to 10 months that a weakness in his lower extremities was noted. If one tried to stand him up, he collapsed. He could not sit a little while in a chair without fatigue and cried until he was taken up in one's arms. He commenced to walk much later than his brother and sister, at about the age of 2½ years, and still always needed a support. He could never walk except with legs spread apart for lateral balance (swinging gait) and somewhat arched. Toward the age of about 3 years, his mother noted that his lower extremities grew in volume; at first her attention was attracted to this by the growth of the calves which were difficult to place in his stockings which were large enough a short time before. This excessive development of the lower extremities had progressed during 2 years. . . . Since then, the condition of the boy remained stationary until the moment when he was presented for the first time in 1858 at the age of 7 years.

Here is what I then ascertained: the muscles of the lower extremities and the lumbar spine were so developed and contrasted so with those of the upper extremities, which were slender that I immediately made a photograph. They were firm and even hard, like hypertrophies, especially the gastrocnemius and the lumbar spinal (erectors) seemed ready to break through the thin and distended skin. Also I was not a little surprised to learn that these muscles of an athlete, at least in appearance, had been deprived of power since birth and hardly had been exercised, the child having a dislike for moving his lower extremities, and consequently almost always resting, seated or lying down. All the movements of the lower extremities were performed, but the force of each measured individually was very feeble except for extension of the foot on the leg, which had preserved great power. If when he was seated he was bent forward, he could not straighten up, even though the lumbar muscles were enormously swollen. In standing, he had to hold to a support to prevent falling. Supported, he could walk, but laboriously, spreading his legs and inclining his trunk with each step to the side of the lower extremity which rested on the ground. These efforts (standing and walking) tired him enormously and could not be kept up

but for short duration. All the muscles responded perfectly to electric stimulation. On each side there was an equinovarus of first degree: as soon as the child attempted to flex the foot on the leg, the muscles effecting this movement went into action, but their antagonists, the triceps surae already retracted, opposed them, and the foot seemed extended instead of flexed. The superior extremities, although thin, compared with the inferior extremities, exercised all their mobility, serving the child normally. The intellect was dull, and words were difficult. The temporal regions were extremely projecting as one observes in certain hydrocephalics. Nothing that I prescribed was able to ameliorate this disease state: neither faradization (30 treatments) nor hydrotherapy nor massage, etc.

The pseudohypertrophic paralysis was still localized in the lower extremities in 1863. . . . But toward the end of 1863, the weakness increased rapidly to the point that the child was obliged to remain constantly in bed or seated. In the first months of 1864, the paralysis progressed to involve the superior extremities, where the muscles had not yet increased in volume. Six months later, the paralysis was generalized, and his movements were almost completely abolished.

His general health had been rather good, and the excessive volume of the inferior extremities was maintained until June, 1863. From that date the digestive functions became deranged; he suffered alternations of constipation and diarrhea, and the lower extremities had lost their volume bit by bit. Finally, in January, 1866, he succumbed to a respiratory infection (phthysie), in a state of extreme emaciation, at the Frères Saint-Jean-de-Dieu, rue de Sèvres, where he had been given asylum since 1863. He was 15 years of age. There was no autopsy.



G. B. A. DUCHENNE

Guillaume Benjamin Amand Duchenne (1806-1875) of Boulogne first used a simple faradic electric stimulator to study muscle function in its normal and in its pathologic states. This extended and original approach culminated in his classic volume *Electrisation localisée* published in 1855 (recently translated by Emanuel Kaplan into English). It was followed by later editions. In the second edition (1861), he first noted a previously unrecognized disease of the muscular apparatus which he referred to as pseudohypertrophic paralysis. In 1868, he published his definitive description of this disease, noting with an occasional exception that electric response of the muscles remained normal. This syndrome retained the name of pseudohypertrophic (a descriptive adjective), but later nosology changed the word paralysis to dystrophy. This was the first recognition of the group of muscular syndromes now known as the dystrophies. Shortly thereafter came further publications by Aran, Landouzy, Déjerine, Erb and Duchenne himself.

Here published in the introduction and Case I of Duchenne's classic is the presentation of the first of the muscular dystrophies. The reference to the entire divided report is given above for those who would go further.

I wish here to express my thanks to the staff of the Library of the New York Academy of Medicine for securing a photostatic copy of the article published in the difficult-to-find 1868 volume of the *Archive générale de médecine.*

CLASSIC 16 An Account of the Bones of Animals being changed to a Red Colour by Aliment Only

JOHN BELCHIER, SURGEON, F.R.S. (1706–1785)

That the Circulation of the Blood is carried on through the Bones, is evident from many Phoenomena observable in Surgery; but that the Circulation is universally and intimately distributed through the most solid and compact Substance of the Bones (tho' hitherto by some made a Matter of Doubt) will appear undeniably from the Instances here produced; which are the Bones of several Hogs, of a different Breed, changed to a deep red Colour merely by Aliment. And what makes this still more surprising is, that neither the fleshy nor cartilaginous Parts suffer the least Alteration in Colour or in Taste.

The Diet with which these Hogs are fed is Bran, after it has been boiled in a Copper with printed Callicoes, in order to clean them from a dirty red Colour occasioned by an Infusion of Madder Root, which is made use of to fix the Colours printed on the Cloth; some of which Colours are made with Alum and Sugar of Lead. The Parts printed with the Preparation of Iron produce Black and Purple; those printed with the Mixture of Alum, Red of different Degrees, according to the Strength of the Mixture. The Bran having absorbed the red Colour discharged from the Cloth, is mixed with the common Food of the Hogs, and produces this Effect on their Bones.

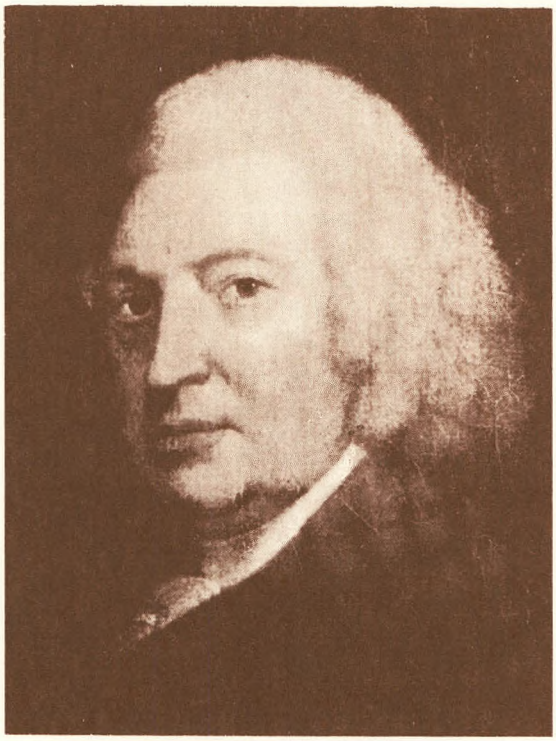
Upon examining these Bones, I observe in general the solid Parts to be most tinctur'd, and the Teeth particularly, except the enamell'd Part, which is of a different Substance; and upon sawing them through, I find the internal Parts equally tinged except at the Ends of the Bones, where the Substance is more spongy. And in order to discharge the Colour, I have macerated them in Water for many Weeks together; have boil'd them often, and steeped them in Spirits, but all hath prov'd ineffectual; nor is the least Tincture given to any of the Liquids, in which I have made Experiments.

Whether this Colour is produced from the Madder only, or from all the Colours blended together, I purpose to make further experiments.

A Further Account of the Bones of Animals Being Made Red by Aliment Only

In the former Account, which I gave concerning the Red Bones of the Hogs, (see No. 442. p. 286) I mention'd, That the Colour was occasion'd by Bran, (being mix'd with their common Food) after it had been made Use of to clean printed Callicoes; the Colours of which were made, some from Preparations of Iron, which were the Blacks and Purples; other from Preparations of Alum, and Sacc. Saturni, which produces the Red Colours; and that Madder Root was made use of to fix these Colours on the Cloth.—To which of these Preparations. the Colour was owing, I could not determine. Some were of Opinion, that it was intirely occasion'd by the Preparations of Iron; others, that it was the whole blended together: And, in order to clear up this Point, I determin'd to make some Experiments. The first I made was upon a Cock, by mixing some of the Madder Root with Fig Dust, on which they feed.—The Cock dying within fifteen Days after his first feeding of the Madder, I dissected him, and examin'd the Bones, not in the least Expectation of finding them ting'd in so small a Time; but, to my Surprise, found them universally of a Red Colour: So that, from this Experiment, it appears that the Madder alone causes this Alteration: But why the Bones only are affected, I shall consider of in the Course of more Experiments.

The original essay appeared in *Anatomical and Pathological Observations,* Edinburgh, Myles Macpail; London, Simpkin, Marshall & Co., 1845.



JOHN B. BELCHIER

John B. Belchier (1706-1785) of Guy's Hospital, London, observed that when a hog was fed on red madder and later its bones were examined, they were found to be partly stained red by this material. Other tissues were not. The reports in 2 parts were accepted by the *Philosophical Transactions of London* for the volumes dated 1735-36 and appeared in print in 1738. At about the same time, experiments from the laboratories of Henri Louis Duhamel-Dumonçeau (1700-1782) confirmed these observations.

These experiments and reports of Belchier represent the earliest attempts at vital staining and became fundamental to all subsequent research in bone physiology. Much later, in similar investigations the dye, alizarin, derived originally from red madder, was used in its place.

CLASSIC 17 The Structure and Economy of Bone

JOHN GOODSIR (1814–1867)

A texture may be considered either by itself, or in connection with the parts which usually accompany it. These subsidiary parts may be entirely removed without interfering with the anatomical constitution of the texture. It is essentially non-vascular, neither vessels nor nerves entering into its intimate structure. It possesses in itself those powers by which it is nourished, produces its kind, and performs the actions for which it is destined, the subsidiary or superadded parts supplying it with materials which it appropriates by its own inherent powers, or connecting it in sympathetic harmonious action with other parts of the organism to which it belongs.

In none of the textures are these characters more distinctly seen that in the osseous. A well macerated bone is one of the most easily made, and, at the same time, one of the curious anatomical preparations. It is a perfect example of a texture completely isolated, the vessels, nerves, membranes and fat, are all separated, and nothing is left but the non-vascular osseous substance.

The osseous texture of a fresh bone, considered in this way, consists of two parts, a hard and a soft. The hard part, composed of earthy salts, deposited in a cartilaginous matrix, has already been carefully examined by anatomists. The soft has not yet attracted attention, in consequence of the manner in which it is isolated, divided into small portions, and concealed in the cavities of the osseous corpuscules.

The hard part of the osseous texture, considered in a long bone, presents four surfaces, all communicating with one another, a periosteal or external, a medullary or internal, a haversian or intermediary, and a corpuscular or canaliculard. The periosteal surface communicates with the haversian in three ways; by those haversian canals which open in it; by the canal for the medullary artery gradually subdividing and diminishing till it breaks up into arterial haversian canals; and by the more numerous canals for the veins, principally met with at the extremities of the bone. The medullary surface is to be considered as a portion of the haversian, having been formed by the enlargement, and subsequent blending of neighbouring haversian canals into medullary cavities and cancelli. The canalicular or corpuscular surface forms the walls of the innumerable corpuscules and canaliculi, and communicates by the latter with the haversian, medullary, and less freely with the periosteal surface.

The compact osseous substance, in which the corpuscles and their canaliculi are situated, is not homogeneous in texture. It consists, of cells filled with bony substance, ossified or calcified primordial cells.

The soft part of the true osseous texture is not continuous like the hard, but is divided, as has been stated, into as many por-

tions as there are corpuscules in the bone. Each of these portions consists of a little mass of nucleated cells of great transparency. They do not appear to extend along the canaliculi, but to be confined to the cavity of the corpuscule.

These two parts, the hard and the soft combined, constitute the true osseous texture. They differ from one another only in in this, that the cells of the one are ossified, those of the other retain their original delicacy and softness. The masses of soft cells in the corpuscules, I am inclined to consider as the nutritive centres, germinal centres, or germinal spots of texture. These centres are the source of all the hardened cells, each of them being the centre of all those comprehended within the range of its own canaliculi. Each of these soft germinal masses is the centre of attraction for the proper nutriment of bone, and is the active agent in withdrawing this from the vessels, and appropriating it, partly for the nourishment of the hard cells, each of which has a centre of attraction, within itself, but more probably for the formation of new calcigerous cells, as the old cells dissolve and their debris falls back into the returning circulation. The canaliculi are undoubtedly the principal channels for the passage of nutriment from the capillaries to the calcigerous cells and germinal centres. They are necessary in a hard texture, and like similar canals and fissures in certain hard cells in vegetables, only appear at a late stage in the developement of bone. Each osseous corpuscle has its own system of canaliculi, these extending, for the purpose of communicating with others, to the confines of its own territory; that is, to the boundaries of the space which was at one time contained within the sphere of the primary cell of which it was the nucleus.

The accessory parts of the osseous texture, are the vessels, nerves, membranes, and oil. For my present purpose it is only necessary for me to allude to the membranes, as one of them, the periosteum, has been held to play a most important part in the formation and economy of bone.

The periosteum is not so important an element in the constitution of a bone as has usually been supposed. In the adult bone, it is nothing more than the fibrous sheath of the organ, similar to the bounding or limiting membrane of other organs, and in which the vessels ramify sufficiently to anastomose with those of the comparatively few haversian canals which open on the external surface. In the foetus it is much more vascular, the external surface of the bone being at that period actively engaged in growth.

There exists in every true bone, a membrane or layer of much greater importance, and infinitely more extended than the periosteum. Between the blood vessels and the walls of the haversian canals, there is a layer of cellular substance. This cellular substance is the product, its cells being the descendants of the corpuscules of the cartilage or matrix in which the bone was originally formed. It forms a blastema, originally produced round each cartilage corpuscule by developement into a linear series perpendicular to the ossifying surface: each of the secondary corpuscules remaining as centres, or the sources of new centres of nutrition, of the future bone, their progeny forming the cellular mass which becomes enclosed in the capsules of compact primary bone. When these capsules have opened into one another to form the haversian canals, a process similar to the mode of developement of gland ducts, and capillaries, the cellular mass surrounds the vessels in their course, and separates them from the walls of the canals.

That this cellular layer plays an important part in the economy of bone, appears probable from the prominent position it holds in its developement, and from the intimate connection of the haversian canals with all the morbid changes of bone. Its existence, great extent, and probable powers, cannot be over-

looked in any question regarding the economy of bone in health or disease.

The cellular mass, just described, fills the cancelli, or enlarged haversian chambers, of foetal bones, and, in this situation, has not been overlooked by former observers. In adult bones, it is in the medullary cavity, cancelli, and, to a certain extent, in the larger haversian canals, replaced by fat cells.

On the surface of young and vigorous bones I have observed numerous cells, flattened, elongated, and more or less turgid, belonging doubtless to the system of haversian cells.



JOHN GOODSIR

John Goodsir (1814-1867) of Edinburgh described the bone-forming properties of certain corpuscles (cells) found within the osseous texture (tissue). The description appeared among the essays in his book, *Anatomical and Pathological Observations,* published with his brother Harry in 1845. This essay represents the first significant recognition of cellular development of human tissue. Turner, in his 1868 biographic edition of Goodsir's book, suggests its importance to Virchow's later generalization in his monumental Die Cellularpathologie of 1858. Virchow's textbook was dedicated to John Goodsir in recognition of his contributions to the understanding of cell function. Gegenbauer named these cells osteoblasts in 1867. Goodsir's classic paper of 1845 was the foundation of osteogenesis as distinct from descriptive osteology.

CLASSIC 18 Traumatic Separation of the Epiphyses in General

JOHN POLAND (1855–1937)

Historical

An often quoted fable attributes to the Amazons the custom of separating the epiphyses of their male children, with the design of assuring to the female the supremacy of strength and beauty.

Among ancient writers Hippocrates has often been referred to as the first to make any allusion to separation of the epiphyses. An equivocal quotation from a passage where he treats of dislocations of the wrist has led to some discussion on the subject: ἔστι δ' ὅτε καὶ ἡ ἐπίφυσις ἐκινήθη· 'Quandoque autem et epiphysis emota est' (*Hipp. de articulis,* 27, Littré's ed. vol. iv. p. 138). It would be useless to attempt any precise explanation of the phrase, for Hippocrates appears to have used the term *epiphysis* in a very indefinite manner. With the same uncertainty he alludes to abruption of the epiphysis or trochlea of the humerus as being a much milder form of accident than other injuries at the elbow joint.

Many centuries appear to have elapsed without any mention of this kind of injury.

Realdus Colombus (*De re anatomica,* Venetiis 1559, lb. i. p. 6), in the sixteenth century, clearly pointed out the possibility of the occurrence of epiphysial separation, alluding to it in the following passage: 'Quam luxationem nunquam, aut summa quidem certe cum difficultate, curari posse crediderim propter sinuum tuberculorum multitudinem, quibus utraque pars tam appendicis quam ossis cui adnascitur abundat & eorundem mutuum ingressum postulat.' He was the first to point out the existence of separation of the epiphyses in newly born infants.

Morgagni quotes (*De sedibus et causis morborum,* Ep. lvi. a) another passage from Colombus in the following words: 'Si les os tendres des enfants sont maniés trop fortement par les mains d'un médecin inhabile, les ligaments s'étendent jusqu'à entraîner les appendices (epiphyses) avec eux.'

Rognetta (*loc. cit. infra*) and others have on insufficient grounds considered a case to be one of separation of the great trochanter which Ingrassias describes in his commentaries on the works of Galen (ch. xx.), but it does not appear that Ingrassias was cognisant of epiphysial injuries (J. P. Ingrassias, *In Galeni librum de ossibus doctissima et expectatissima commentaria, Panormi* 1603). It was the case of a young man who, whilst fencing with a halberd, had torn off the trochanteric process by a violent movement.

Coming to 1614 we find Ambrose Paré noticing, in two places at least in his works, the probable occurrence of epiphysial sepa-

ration. In one of them he expresses himself thus: 'Nous avons vu une autre sorte de luxation qui se fait, principalement en os des jeunes, par une séparation des épiphyses, comme la tête de l'os adjutoire (humérus) et fémoris, et autres iointures, et cela se cognoist en ce qu'on voit séparation des os avec crépitation et impotẽce de la partie.' Again, with reference to dislocations, the following quotation is from Thomas Johnson's translation of the *Chirurgical works* of Ambrose Parey. (London, 1634, p. 596): 'Also that dislocation is uncurable, whenas the ligaments, steeped and swollen up with an excrementitious humiditie, are so much shortened and contracted in their length, as they have acquired in their breadth; and thus they draw away and plucke off the *appendices* of the bones from whence they arise, and by reason the bone and the appendix doe enter and receive each other by manie cavities and prominences, therefore they cannot, by how skillful hand soever they may be handled, be again fitly placed and put together.' Paré quotes Hipprocrates as calling the upper appendix (epiphysis) of the tibia the diaphysis. He has only recorded one case of detachment of an epiphysis, that of the pelvic end of the femur, which at first had been mistaken for a dislocation of this bone.

Poupart and others about this time observed cases following small-pox and scurvy, and denied that separation could take place without some pathological condition.

Ruysch is said to have made some experiments on new-born children.

In 1632 a Neapolitan surgeon, Marcus Aurelius Severinus, drew attention (*De abscessuum recondita natura lib., de gibbis, valg. et var.,* Lugd. Bat. 1724, cap. vii. p. 428) to separation of the upper and lower epiphyses of the tibia as well as to the deformities of the knee and foot which result from such separation.

Towards the middle of the same century, Eysson specially studied diseases of the bones in children, and particularly treated of separation of the epiphyses (H. Eyssonius, *De ossibus infantis,* 1625; also V. Coiter, 1659). Rognetta states that the work of Eyssonius (*Tractatus anatomicus et medicus de ossibus infantis cognoscendis, conservandis et curandis,* Groningæ, 1659, vol. i.) was in 1834 exceedingly scarce in Paris.

Fabrice de Hilden about the middle of the seventeenth century (Fabricius Hildanus, Francofurti, 1646), and Jean B. Verduc towards the end of the same century, 1696 (*Bandages et fractures,* 1696), also vaguely alluded to the separation of the upper epiphysis of the femur.

It was not, however, until the beginning of the eighteenth century that any real work on this subject appeared.

Both J. L. Petit (*Maladies des os,* Paris, 1705; also *Description exacte des os,* Leyden, 1709) and G. J. Duverney (*Maladies des os,* Paris, tom. i. 1751; also trans. by Sam. Ingham, Lond. 1762) allude to this injury in connection with fractures of the neck of the femur. While the former associated it with fractures themselves, the latter did not believe in its existence without some morbid condition of the bone (scurvy, &c.).

J. M. Schwartz mentioned the subject in his thesis (*Disputatio de ossium epiphysibus,* Lipsiæ, 1736).

Although, as we have seen, separations of the epiphyses were admitted as possible by so many writers from the earliest times, but little practical interest or importance can be attached to the published records before Reichel's special treatise in 1759, one hundred and thirty-seven years ago (M. Geo. Christian, Reichel, *Dissertatio de epiphysium ab ossium diaphysi diductione,* Thesis, Lipsiæ, April 27, 1759; Edwardus Sandifort, *Thesaurus Dissertationum.* vol. i. Roterdami, 1768–78). He was the first author who had made a special study of these lesions and insisted upon their reality. The pathological specimens, however, brought forward by him appear to have been fractures which oc-

curred in persons of very advanced years, for the three figures given by him as united epiphysial lesions are probably united fractures—two specimens of separation or fracture of the neck of the humerus, and one a spontaneous separation of the lower epiphysis of the femur. He was, nevertheless, the first to correctly distinguish traumatic separations from those due to disease (or spontaneous). From an examination of Reichel's plates, Delpech (*Chirurgie clinique,* 1823, tom. i. p. 246) doubted the real occurrence of epiphysial separation in these instances.

Reichel also described a case of separation of the upper epiphysis of the femur.

We then come down to Ambrosio Bertrandi of Turin, who, in an article in 1787, 'Della Separazione delle Epifisi delle ossa' (*Opere anatomiche et cerusiche: Malattie delle ossa,* Turin, 1787, tom. v. cap. xv. p. 156), noted one or two cases which he had established by dissection in infants; but the data he gives are not very accurate and cannot be relied upon as at all certain. He endeavoured to draw up a general description of these lesions, and was the first to direct attention to disjunction of the humeral epiphysis during delivery. He mentions instances at the upper extremities of the humerus and tibia, and at the lower extremity of the femur and ulna.

Rognetta and others also allude to another Italian surgeon, Monteggia of Milan (Monteggia, *Instit. de chirurgie,* tom. iv., Milano, 1814), as having given some attention to this subject. Monteggia refers to cases at the upper extremity of the tibia and the lower extremity of the humerus.

J. B. Palletta, also an Italian surgeon (*Exercitationes anatomicæ,* Mediolani, 1820), likewise added a few new cases in support of the occurrence of this lesion.

Portal (in his *Anatomie médicale,* Paris, 1803, tom. i. p. 31) says the epiphyses are sometimes detached from the body of the bones, especially in children. He believed that the upper extremity of the radius and the neck of the femur were the most frequent subjects of these disunions; and that, as they were often mistaken for dislocations of these bones, errors in their treatment took place.

De la Motte also mentions some cases of the same injury.

Petit-Radel (*Chir. encyclopéd* art. Épiphyses,' tom i. p. 433), like Bertrandi, added but little to the knowledge of the subject; while his article in 'L'Encyclopédie Méthodique' is merely a translation of Bertrandi's work.

In 1816 M. J. Delpech, with much reason, seeing the uncertainty felt in the minds of surgeons by these first attempts at descriptions of these injuries, doubted the existence of the occurrence of detachment of the epiphyses. But some years later, in 1823 (*Chirurgie clinique de Montpellier,* tom. i. 1823), he was convinced of their occurrence after seeing the pathological specimens of separation of the lower epiphyses of the femur and of the radius described and recorded by M. Roux. In this volume Delpech describes the specimen of separation of the lower epiphysis of the femur published by M. Coural, and at that time in his possession (the first of Roux's specimens).

Boyer, about the year 1815, and likewise Dupuytren, dismissed the subject in a few words. The former only mentions (*Chir.* tom. iii. 4me édit. p. 211) the possibility of these lesions at the upper end of the femur and humerus, and asserts that they usually take the place of fractures.

In 1817 Champion (*Bull. de la Fac. et de la Soc. de Méd.,* Paris 1817) made careful observation of several cases, which he proved anatomically by examination after death (see also Champion, 'Decollement des épiphyses des os longs,' *Journal complém. du dict. d. sc. méd.,* Paris, 1818).

Laurent, in his article 'Observations pour servir à l'histoire du Décollement des épiphyses des os longs' (*Journal complém. du*

dict. d. sc. méd. Paris, 1818, tom. i. pp. 317–26), was unable to throw any fresh light upon the subject.

In England James Wilson (*Lectures on Diseases of the Bones and Joints,* London, 1820) added a few facts with regard to the mechanical production of these injuries; but he gives no description, and indeed makes no mention, of epiphysial separation as met with in the living subject. We shall allude to this again later on.

Epiphysial separations were described nearly at the same time by MM. Roux and Guéretin.

M. Roux de Brignolle wrote his thesis at Montpellier entitled *Dissertation sur la disjonction des épiphyses,* February 8, 1822. It contained a description of two specimens obtained by amputation: (1) Coural's case of separation of the lower epiphysis of the femur, which had occurred in 1816; and (2) a very remarkable case of disjunction of the lower epiphysis of the radius, the styloid epiphysis of the ulna, and the upper epiphysis of the first phalanges of the thumb, index, and middle fingers. This occurred in 1821. Both these cases are fully described in their proper chapters.

Roux says that his thesis was written to prove to some sceptical minds the possibility of such a lesion of the osseous system after the first few years of life. He insisted upon, 'first, the danger of ignoring epiphysial separation when its reduction ought to be possible; secondly, the progress of the phenomena which result from such an error of judgment; thirdly, the possibility of separation of the epiphyses occurring up to the eighteenth year; fourthly, the possibility of such separation taking place on the largest cylindrical bones, as well as on the medium-sized and smallest.'

Writing in 1825 (*loc. cit. infra*), Jarjavay says: 'Aussi en clinique, il est bien difficile, sinon impossible dans certains cas, de déterminer si la lésion est un décollement plutôt qu'une fracture. Il ne faut pas perdre de vue, si l'on cherche à arriver à ce diagnostic, ce fait anatomique, à savoir, que les épiphyses ne comprennent généralement que les deux tiers seulement des extrémités des los longs, et que la diaphyse fournit l'autre tiers.'

Goyrand in 1836 published his first observations on separation of the lower epiphysis of the radius.

Guéretin's valuable work, 'Recherches sur le Décollement spontané et traumatique des Épiphyses' (*La Presse Médicale,* 10 Mai, 13 Mai, 17 Mai, 1837, i. No. 7, &c. pp. 290, 297, 305), was published in 1837, and added some important facts. This author collected a number of cases (forty-five) published up to this date. Many of these were fractures in adults, some were separations through disease. He also endeavoured by numerous experiments on the dead body, as well as by careful examination of clinical cases, to clear up the many obscure points with which the subject was then surrounded. But from want of sufficient material his descriptions were very incomplete, and many points of interest were not even mentioned.

Nearly a century after Reichel's thesis, M. Rognetta ('Mémoire sur la Divulsion traumatique des Épiphyses,' *Gazette Médicale,* Paris, 1834, p. 433) published an elaborate memoir upon traumatic separation of the epiphyses. To this interesting memoir we are indebted for much valuable information, and in it we find brought together everything bearing upon the subject that had been previously published. M. Rognetta has collected some instances of epiphysial separations met with in the trunk as well as in the long bones. His work is unfortunately too full of theories to the neglect of direct anatomical research, and he appears to believe in a simple separation of the epiphysial cartilage from the bone in most cases without any portion of the latter ever being dragged away.

M. Roux, fifteen years after the publication of his first work, states ('Sur le Décol-

lement épiphysaire,' *La Presse Médicale,* Paris, 1837, tom. i. No. 55, July 12, 436–438) that on August 30, 1836, he communicated a memoir to l'Académie Royale de Médecine containing several (4) new cases of epiphysial separation occurring in his practice, but only one of these was verified by direct examination.

Sir Astley Cooper in England, in his *Fractures and Dislocations* (new edition by Bransby B. Cooper, 1842), was one of the first to clearly point out that epiphysial separations are mostly mistaken for dislocations rather than for fractures. He especially so alludes to this lesion at the lower end of the humerus. He has added one or two interesting cases.

In 1840 M. Piscart, in his inaugural thesis (Thèse de Paris, 1840, No. 219), indicated the occurrence of traumatic separation during delivery and after birth. Champmas' thesis in the same year (Thèse de Paris, 1840, No. 139) furnished no further facts for the elucidation of these injuries beyond those of his predecessors (especially Rognetta).

The distinguished Nélaton, in his *Éléments de pathologie chirurgicale* (tom. i. p. 678, sec. 3: 'Divulsion traumatique des Épiphyses'), treats the subject in the following manner:

'Bien que les decollements des épiphyses se trouvent indiqués dans les livres hippocratiques, et que depuis Armbroise Paré un grand nombre d'auteurs aient parlé de cette lésion, on peut cependant affirmer que nous manquons de documents nécessaires pour faire un exposé dogmatique de cette affection. En effet, presque tout ce que nous possédons sur ce sujet se réduit à des assertions sans preuves et à quelques observations sans valeur, à cause de l'absence complète des détails.' However, he quoted some valuable examples which were known at this time.

Voillemier, in 1842, made a special study of the mechanism of separation of the lower epiphysis of the radius.

M. Salmon's doctoral thesis on traumatic solutions of continuity of the bones during youth (P. A. Salmon, *Des solutions de continuité traumatiques des os dans le jeune âge,* Thèse de Paris, 1845) contains out of 129 cases a description of sixty-eight experiments on the upper extremity, in which he detached the epiphyses by extension of the fore-arm on the arm. They are mostly (64) of the lower end of the humerus, one of the internal epicondyle, two of the upper end of the ulna, and one of the upper end of the radius. This series of experiments contributed some details as to the anatomical character of separations. Salmon was the first to prove that when the periosteum is lacerated, the separation is accompanied by displacement. He also noted the frequency of separation, and the easy mode of its production at the upper end of the femur in newly born infants (ten out of eleven being in infants less than a month old), but he was unable to detach the upper epiphysis of the humerus. Those of the upper end of the femur were, as he describes, a detachment of the whole cartilaginous end of the bone, to which he alludes in an earlier part of his thesis. Salmon's thesis is, however, entirely without clinical cases.

Detachment of the cartilaginous ends of the bones during delivery was especially investigated by M. Pajot in his thesis *Des lésions traumatiques que le fœtus peut éprouver pendant l'accouchement,* Paris 1853.

Prof. R. W. Smith, of Dublin, showed (*Treatise on Fractures in the Vicinity of Joints,* Dublin, 1847) a very clear conception of one or two of these lesions, and paid considerable attention to the subject. His accounts of certain forms of separation of the upper and lower epiphyses of the humerus and of that of the lower end of the radius are still regarded as most trustworthy descriptions (see also, *Dublin Quarterly*

Journal of Med. Science, vol. ix. New Series, 1850, p. 63).

Cruveilhier, writing in 1849 (*Traité d'anatomie pathologique,* Paris, tom. i. p. 101), says of the thirty-eight cases of traumatic epiphysial separation then known to science, that there was but little reliance to be placed on them.

E. E. Klein devoted a thesis to this subject (*De epiphys. dissolutione,* Diss. inaug., Gryphiæ, 1854; see also C. R. Zuehlke, *De diatasi epiphysium et ossium diaphysi.* Halis Sax. 1859).

Dr. J. Ludw. Thudichum appears ('Die Absprengung der Epiphysen,' *Münchener illustrirte medicin, Zeitung,* 1855, Bd. iii. s. 188) to have given some attention to fracture of the epiphyses, and furnishes a brief account of epiphysial separation of most of the long bones. Thudichum also wrote 'Ueber die am oberen Ende des Humerus vorkommenden Knochenbrüche,' Giessen, 1851.

Malgaigne admitted (*Traité des fractures,* 1855) the occurrence of epiphysial separations as proved by dissection at both ends of the humerus, femur, and tibia, and at the lower end of the radius, and ranked them among fractures because they have 'the same causes, present the same symptoms, call for the same treatment, and, lastly, cannot always be exactly distinguished from fractures properly so called.' He therefore did not attach much importance to distinguishing between them. He considered, and rightly so, that in the majority of cases there is a more or less considerable detachment of the osseous end of the shaft. Malgaigne attributed the first distinct and satisfactory notice of separation of the epiphysis to Bertrandi towards the close of the last century. He quoted several cases, and also added that he knew of no instance occurring in a female.

These lesions were also especially alluded to by Gurlt (*Handbuch der Lehre von den Knochenbrüchen,* Berlin, 1862). This author carefully collected the literature of the subject up to this date, and after the examination of anatomical specimens, experiments, and clinical cases, came to the conclusion that epiphysial separations were very rare injuries. He thought that this was to be accounted for by the fact that the epiphyses, being in relation to the diaphyses larger in infants than at a later period, were less frequently the subject of injury, and that infants were less exposed to external injury than children at puberty, when epiphysial separation very unfrequently occurred. Gurlt collected eighteen cases verified by dissection.

Bardeleben, in his 'Handbook of Surgery,' agreed with Gurlt's decision.

Another French surgeon, M. Foucher, in 1860 ('Recherches sur la disjonction traumatique des épiphyses,' *Monit. des Sciences méd. et pharm.* No. 90, 1860; *Annales du Congrès médical de Rouen,* 1863), added some valuable experimental knowledge of the subject, gave a clear description of the pathology of the lesion, indicated several varieties of separation, and drew up a classification which is even now more or less adhered to. His experimental work is still the best on the subject, and he summed up in a very complete manner all that was known up to that time as to the mechanism of these lesions. Nevertheless this author states that separation is effected with great difficulty even in infants. In 1863 Foucher collected a number of cases ('De la Divulsion des Épiphyses,' *Cong. méd. de France,* Paris, 1863, tom. i. pp. 63–72).

Prof. R. W. Smith, writing in 1865 and 1867 (*British Medical Journal,* August 17, 1867), believed them to be very frequent and common. This view was also held by Broca and Uffelman. Smith has described many interesting specimens and cases which still maintain their value to the practical surgeon.

Dr. A. Coulon, in 1861 (*Traité des fractures chez les enfants,* Paris, 1861), totally

denied the existence of these injuries, notwithstanding the writings of M. Guéretin and Rognetta. He came to this conclusion after many years' experience at children's hospitals, and quotes (Richet, *Anatomie chirurgicale,* p. 64) M. Richet's decision in the following words: 'A l'état normal, l'union est si intime entre le cartilage de conjugaison et le tissu osseux en voie de formation, qu'on peut les regarder comme un seul organe, les vaisseaux sanguins se portant sans interruption de la diaphyse dans l'épiphyse. Howship, qui avait étudié avec le plus grand soin ce point d'anatomie, a dit, avec raison, que le cartilage épiphysaire était continu et non pas contigu à l'os. C'est donc une erreur de dire que le cartilage de conjugaison et l'os se touchent par deux surfaces, l'une osseuse et l'autre cartilagineuse, onduleuses et anfractueuses, se recevant réciproquement; ce n'est qu' après macération qu'on trouve cette disposition, car, à l'état sain et frais, le cartilage et l'os ne font qu'un, il y a fusion intime, continuité en un mot.

'Cette remarque conduit à rejeter le décollement des épiphyses admis par quelques chirurgiens, puisque la diaphyse et l'épiphyse ne sont pas accolées, mais bien réunies par l'intermédiaire de leur cartilage de conjugaison; et quand, par suite de violences extérieures, il y a séparation en ce point, c'est une véritable fracture comme celles qui s'opèrent dans la continuité des os. M. Guéretin (*loc. cit.*), MM. Cruveilhier et Bonamy (*Traité d'anatomie pathologique,* tom. i.), qui, dans le but d'éclaircir cette question, se sont livrés à une série d'expériences et de recherches, ont vu à peu près constamment que l'épiphyse, en se séparant, entraînait toujours avec elle une lamelle plus ou moins considérable du tissu osseux; et les faits de disjonction des épiphyses observés sur le vivant ont présenté le même phénomène. A la rigueur, cependant, on conçoit que le cartilage de conjugaison puisse se rompre précisément au niveau de sa fusion avec le tissu osseux, et les faits observés par Bertrandi sur la tête du fémur et celle de l'humérus, par MM. J. Cloquet et Rognetta sur l'extrémité inférieure du radius, tendent à prouver que la brisure peut quelquefois avoir lieu dans ce point même et sans solution de continuité du tissu osseux; mais, dans ce cas encore, c'est à une fracture et non à un décollement simple que l'on a affaire, puisque l'inspection anatomique a prouvé qu'il y avait fusion des deux tissus.

'Ce n'est là d'ailleurs, il faut bien en convenir, qu'une discussion sans importance pratique, puisque le pronostic et le traitement de ces prétendus décollements épiphysaires sont identiques avec ceux des fractures des extrémités articulaires complétement ossifiées.'

M. Coulon, after quoting Malgaigne's words, sums up the matter by saying that traumatic separation of the epiphyses is extremely rare, that it is recognised by the same signs as fracture in the neighbourhood of the joints, that its gravity is the same, and that it demands the same treatment.

In Russia these injuries have been studied by Michniowsky, especially by means of experiments ('Untersuchungen über den Heilungsvorgang bei gewaltsamer Epiphysenlösung,' *Militärärztl. Journal* (Russisch), 1864; *Petersb. Med. Zeitschr.* 1866, Bd. x. s. 300).

Richet, denying the existence of true separation, considered, from the anatomical evidence which could then be produced, that the cases brought forward by Bertrandi, Cloquet, and Rognetta of solution at the site of the epiphysial junction were really fractures.

Guersant (*Chirurgie des enfants*), during twenty years' service at the Children's Hospital, met with very few instances.

The injuries were the subject of a special discussion at the Société de Chirurgie

de Paris in 1865, by many able surgeons, on M. Dolbeau presenting before the society two specimens of separation of the lower epiphysis of the radius (*Gazette des Hôpitaux,* 1865, No. 145, 147; Extract in New Sydenham Society's *Retrospect,* 1865–6, p. 248). M. Marjolin believed separations of the epiphyses to be so extremely rare that their existence might almost be denied, and produced in proof of this opinion some details of fractures at the Hôpital Ste. Eugénie which showed, at any rate, that they had been very rarely diagnosed at the hospital from which his statistics were drawn. Out of 600 fractures in children, he found no cases of separation of the epiphyses. He added Malgaigne's opinion that this lesion was rarely perfect, being almost always accompanied by a fracture of the diaphysis which adhered to the epiphysis. M. Guersant also said that he had never been able to diagnose the injury with certainty, nor had he ever had occasion to verify it anatomically, but spoke in favour of its occurrence. M. Chassaignac expressed his opinion that true separation of the epiphyses hardly ever occurred; that a small portion of the shaft almost always adhered to the epiphysial cartilage, and that it was impossible to make a special diagnosis. M. Trélat maintained that an epiphysial separation, from a surgical point of view, in symptoms and cure, in contradistinction to a fracture, was not to be accepted. M. Broca, however, reminded the Society that the injury could easily be produced in the dead subject, and therefore was very probably more frequent in the living than was supposed. In experiments on the dead subject, the cartilage was usually found attached to the epiphysis. M. Richet and M. Blot spoke in the same sense.

M. A. T. Cosseret's doctoral thesis, *De la divulsion des épiphyses* (Thèse de doctorat, Paris, 1866, No. 141), was suggested by Foucher's work in 1860 (*loc. cit. supra*), but contains little of importance in addition to what had been previously written. He adhered to the opinion of Malgaigne, Marjolin, Coulon, and others by placing these lesions amongst fractures.

Bouchut describes (*Traité des maladies des enfants,* 1867) separation of the epiphyses in young children in his article on fractures, but gives no examples. He states that in this solution of continuity of the bone there is no rupture of the osseous tissue, and that the injuries are generally produced by a considerable strain on the articulation, and are not as a rule the result of a direct blow. He also says that besides the pain and swelling, there is preternatural mobility, and often a dull *grating* crepitus, very different from the crepitus of bone.

The labours of Professor Ollier did much to put epiphysial separations on a well merited footing. By his researches on the regeneration of bones (*Traité de la régénération des os,* tom. i. 1867), on the unequal growth of the two extremities of the long bones, and on the physiology, anatomy, and pathology of the diaphyso-epiphysial region, a complete study has been permitted of these interesting lesions. He calls these lesions *diaphysial separations* because the separation almost always takes place between the diaphysis and the cartilage, and not between the latter and the epiphysis.

Professor Poncet, of Lyons ('Des Déformations produites par l'arrêt d'accroissement d'un des Os de l'avant-bras,' *Lyon Médical,* 1872), has also given some valuable remarks upon the arrest of development following lesions of the epiphysial cartilages, and upon the deformities which result from them, in the parallel bones of the forearm and leg.

Epiphysial separation was the subject of M. Jules Colignon's thesis (*De la disjonction traumatique des épiphyses,* Thèse de Paris, 1868, No. 226), especially as regards the lower epiphysis of the radius. Some interesting experiments on the dead body were included, and the number of published

cases was brought up to seventy-nine; many, however, of these were very incomplete. This thesis was based upon those of Guéretin and Foucher, the former of which was one of the best memoirs then published.

Even up to that date the possibility of these injuries on the living subject was still doubted by certain authors. M. Colignon brought some exact clinical observations to bear upon the question, the study of which by means of post-mortem experiments had now been fairly well carried out.

From this time the pathological and clinical observations of many authors began to place the study of the lesions upon a firmer basis.

Mr. Timothy Holmes, in his *Diseases of Children,* 1868, attached some importance to these injuries, and drew some conclusions from a study of the museum specimens then existing in the London hospitals. His inquiries, he says, were due to his desire of testing the relative accuracy of M. Chassaignac's and Professor Smith's opinions on this subject. He thought the precise line of solution of continuity was the chief point of importance in the probability of suspension of growth after such injuries. 'Thus it is seen that out of the preparations from the lower end of the femur, three are uncomplicated with visible fracture—one in early infancy, the other two in late puberty; and that these are the only genuine specimens of epiphysiary disjunction which our museums contain; the two of the fibula at St. George's being somewhat doubtful, and that of the upper end of the ulna in infancy rather a fracture of the cartilaginous extremity of the bone than a separation of its epiphysis, which at that early age can hardly be said to exist, at any rate has not begun to ossify.'

Émile Barbarin, in his thesis (*Contribution à l'étude des fractures chez les enfants,* 1873), while admitting the occurrence of epiphysial disjunctions, thought, nevertheless, that they were rare in practice.

M. Alfred Leblois (*Contribution à l'étude des fractures chez les enfants et de leur traitement,* Paris, 1894) alludes to them in a cursory manner.

Manquat, in his essay 'Sur les Décollements épiphysaires traumatiques' (Thèse de Paris, 1877), collected 130 cases of epiphysial separation—all of which had been previously published. Even at this period he believed they were rare accidents. He classed 'toute solution de continuité brusque survenant par le fait d'un traumatisme entre la diaphyse et l'épiphyse d'un os au niveau du cartilage épiphysaire' as traumatic epiphysial separation.

In the same year Professor Novaro (*Gazzetta delle cliniche,* 1877), whilst referring to a clinical case of separation of the upper epiphysis of the humerus, briefly expounded traumatic separation of the epiphyses in general.

Writing in 1878 M. E. Pingaud (*Dict. encycl. des Sciences médicales,* I^me^ sec. tom. xxi. p. 627) thought that all cases should be considered as true fractures. He says: 'Et d'ailleurs, comment une semblable séparation pourrait-elle avoir lieu, quand on considère combien est intime, à l'état physiologique, l'union qui existe entre le cartilage de conjugaison et le tissu osseux en voie de formation? Car il n'y a pas simplement juxtaposition entre ces deux parties de l'os, mais fusion complète, continuité absolue de tissu; à l'état frais, l'os et le cartilage ne font qu'un, et les vaisseaux sanguins se portent sans interruption de l'un à l'autre. Le périosté enfin, très dense et très adhérent au niveau de la ligne de conjugaison, ajoute encore à la solidité de l'union de l'épiphyse avec la diaphyse. Quand donc une violence extérieure paraît diviser un os au niveau de la ligne de conjugaison dia-épiphysaire, il y a toujours une véritable fracture, le cartilage, en raison de son élasticité et de sa ténacité, arrachant toujours, plutôt que de céder, une lamelle plus ou moins considérable de tissu osseux. Il suffit d'ailleurs de

considérer la forme du segment détaché pour voir du suite qu'il n'est pas uniquement constitué par l'épiphyse, et que la calotte diaphysaire qui le pénètre a été arrachée en même temps que lui.'

Professor Syme, in 1842, wrote on diastasis or separation of the epiphyses thus: 'The symptoms resemble those which would result from fracture in the same situation, and the treatment does not in any respect require to be different' (*Principles of Surgery,* p. 179, 1842).

Sir William Fergusson also wrote (*System of Practical Surgery,* 1846, p. 123): 'No particular allusions will be made to separation of the epiphyses—diastasis, as the accident is called—a kind of injury which is occasionally met with in the young subject; and the reason for this is, that I know of no difference of treatment which such cases may require, whilst every anatomist must be aware that a solution of continuity is as likely to occur in such a situation as elsewhere. If they deserve especial comment, it is that crepitus will probably be less distinct; and also with reference to the proximity of the injury to the joint; but on the latter point, the principles of treatment for ordinary fractures are equally applicable, whilst if the symptoms are so obscure as to make crepitus essential to the diagnosis, it is evident that if there be a fracture at all, it must certainly be one of a most simple character.'

Joseph Amesbury, in his work on 'Fractures of the Trunk and Extremities,' does not even allude to the possibility of epiphysial injury.

In 1862 Gurlt was able to collect only eighteen cases of separation of the epiphyses during life, in which the diagnosis was verified by dissection; of these, five were of the humerus (four being of the upper and one of the lower end), four of the lower end of the radius, five of the lower end of the femur, and three of the tibia. Gurlt was of opinion that separation was a rare form of accident.

Writing in 1863, Stimson says that his experience of these injuries was limited to two cases, both compound, one of the proximal phalanx of the great toe and the other of the upper end of the fibula.

In a later edition of his work, Syme, in 1866 (*Principles of Surgery,* 4th edit. 1866, p. 170), dismissed the subject in the following words: 'Before the epiphyses are united to their respective shafts, they are apt to suffer separation from them by such violence as, in the adult, would occasion fracture of the bones concerned, or dislocation of their articulating extremities.'

Holmes says, in 1869: 'The conclusion to which my experience of this injury would lead me is, that fracture occurs not very rarely at or in the immediate neighbourhood of the epiphysial line; that the line of fracture coincides in these cases partially with that of the epiphysial cartilage, but seldom completely; that the general symptoms are therefore the same as those of fracture, while the special symptoms must be sought for from the anatomy of each joint.'

It is thus only during the last twenty years that traumatic separations of the epiphyses began to be generally admitted, and described with any accuracy. But there can now be no doubt of their frequent occurrence; and in this country their importance has been often alluded to for many years by Mr. Jonathan Hutchinson, Professor Sir George Humphry, and others.

Their chief exponent is Mr. Jonathan Hutchinson who has from time to time since the forties published a number of cases and specimens bearing out the reality of these lesions, and also the not infrequent result of loss of growth in length of the bone affected.

Mr. Hilton and his surgical colleagues at Guy's Hospital were also amongst the first

to point out many important details respecting these injuries.

Mr. T. Bryant, in his *Practice of Surgery* and elsewhere, has published numerous cases of separation of the various epiphyses, many of them of great value and many showing arrest of growth.

The London hospital is indebted to Mr. Nathaniel Ward for many specimens in its museum, and others have been added by Mr. Hutchinson.

As to our current works on surgery, we find these injuries are still scarcely mentioned in many of them, while only a few give any information with reference to them. Though not so common as fractures, the number of separations now recorded leads to a more careful investigation of their clinical signs.

We find, even at late as 1884, Hamilton, in his *Fractures and Dislocations,* 7th edit. p. 37, stating: '*Epiphysial separations* we shall not hesitate to class with fractures, and to submit them to the same rules of nomenclature. These accidents rarely occur after the twentieth year of life; since after this period, and in the case of some bones at a much earlier period, the epiphyses are usually united to the diaphyses by bone.' However, he gave a distinct heading to many of these injuries, and in a few cases considered their diagnosis from fractures. He published a number of new cases from his own observation.

Even at the present day we see that there are very contradictory opinions with regard to these injuries; one surgeon detects them very frequently while another never does so, or only admits that they are rarely met with. This difference of opinion has been due in part to the absence hitherto of direct examination in a large proportion of cases, and in part to the ease with which epiphysial separation may be confused with dislocation or fracture of the end of the diaphysis.

Numerous cases followed by an autopsy or by amputation, others in which the presence of a wound has permitted a direct examination of the separated fragments, and many instances in which an open operation has been undertaken in simple cases for replacement of fragments, have now clearly and definitely established the frequent occurrence of epiphysial separation.

Germany has furnished us with two important monographs on the subject by P. Vogt and Paul Bruns, both of which appeared in Langenbeck's Archiv (*Archiv für klin. Chirurg.* 1878 and 1882), and proved that these injuries are by no means so rare as had been previously held by some. Vogt believed that separation without displacement was common in early life. Paul Bruns has published a large series of cases (verified by an autopsy) for statistical purposes, and in order to throw some light upon their history and after consequences. He collected eighty-one such cases and added three from his clinic at Tübingen. He believed the injury to be not at all an uncommon one, and that if he had included simple cases the number collected would have been much greater.

Some other French writers have contributed special articles on one or other of the epiphyses (Delens, *Archives générales de Méd.* 1884, p. 272; Farabeuf, *Bull. et Mém. de la Société de Chir.,* Paris, tom. xii., 1886, p. 692; Bergès, Thèse de Paris, 1890).

In 1882 Dr. Erasmo De Paoli published (*Del distacco traumatico delle epifisi,* Torino, 1882) a concise account of these injuries, adding some new cases and experiments of his own.

G. Mazziotti has also furnished some articles ('Del distacco delle epifisi, e sue differenze dalla frattura,' *Giorn. internaz. d. sc. med.,* Napoli, 1880, ii. p. 957; *ibid.* 1882, new series, iv. p. 371; also *Ann. clin. d. osp. incur.,* Napoli, 1882, viii. p. 162).

'The diagnosis of traumatic separation of the epiphyses' formed the subject of a paper read by the author before the West Kent

Medico-Chirurgical Society in April 1886.* In this paper attention was drawn to the frequent occurrence of separation *without displacement,* especially at the lower end of the femur, and to the common escape from injury of the neighbouring joint in many of the more simple separations, e.g., at the lower end of the radius. Allusion was also made for the first time to the gradual displacement of the diaphysis or epiphysis subsequent to the accident in instances in which the lesion had been overlooked or not diagnosed. This want of recognition the author believed to be due to the absence of displacement at the time of the accident. Permanent deformity and pressure upon important structures, leading to disastrous consequences, resulted in several cases. After examination of the specimens in the hospital museums of London and other cities, and after collecting statistics, the fact was noted that the epiphyses of certain bones, from their anatomical peculiarities, were more liable to be broken off at particular ages than at others.

The thesis of Dittmayer deals with arrest of growth in length following traumatic separation of the epiphyses, and that of Wilhelm Stehr with arrest of growth of the radius following epiphysial separation (Dittmayer, Thèse de Wurtzbourg, 1887; Wilhelm Stehr, Thèse de Tübingen, 1889).

M. Joseph Curtillet has given (*Du décollement traumatique des épiphyses,* Lyon, 1891, pp. 107) the proportion of cases of epiphysial separation to those of ordinary fracture met with in children as twenty to a hundred. His figures were taken from cases under the care of M. Vincent of Lyons.

In 1891 Mr. Jonathan Hutchinson, jun., was awarded the Jacksonian Prize at the Royal College of Surgeons for his essay upon 'Injuries to the Epiphyses of Long Bones,' and he has supplemented much of his father's work in this direction.

He embodied this work in his lectures in 1893 on 'Injuries to the Epiphyses and their Results,' delivered at the Royal College of Surgeons.

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* (Printed in *Pediatrics,* New York and London. Vol. iv. No. 2 July 15, 1897, p. 49).

JOHN POLAND

In 1898, John Poland (1855-1937) published a monograph of some 900 pages on *Traumatic Separation of the Epiphyses.* The book was a definitive study in its time and included a vast amount of material which, perhaps because the subject may not have been in fashion, was neglected for several decades. Although it was commendably referred to in the *Source Book of Orthopaedic Surgery,* of 1948, it rarely appears in reference lists of papers related to the subject. Much of what has been since presented as new was already available in Poland's monograph and the works that he cites. Little of the observations that he quoted or reported himself has been changed although of course considerable has been added from the studies of newer technologic disciplines. John Poland held several hospital appointments during his long life but is chiefly associated with Guy's Hospital in London. The reprint here presented is the first chapter of the book which reviews the preceding history of the subject. In itself, it is a valuable essay.

CLASSIC 19 On Dislocation of the Ancle-Joint

A Treatise on Dislocations and on Fractures of the Joints

SIR ASTLEY PASTON COOPER (1768–1841)

The bones which enter into the composition of the ancle-joint, are the tibia, fibula, and astragalus. The tibia forms an articulating surface at its lower part, which rests upon the astragalus; and there is a projection on the inner side of the lower portion of this bone, which forms the malleolus internus, and this part is articulated with the side of the astragalus. The fibula projects beyond the tibia at the outer ancle, and forms there the malleolus externus, which has also an articulating surface for the astragalus. The astragalus, which is the superior tarsal bone, rises between the malleoli, and the lower part of the tibia, and moves upon it principally in flexion and extension of the foot.

Thus nature has strongly protected this part of the body, by the deep socket formed by the two bones of the leg, and by the ball of the astragalus which is received between them.

A capsular ligament, secreting synovia on its internal surface, joins the tibia and fibula to the astragalus. A strong ligament unites the tibia to the fibula, but without any intervening articular cavity, as the ligament proceeds directly from one surface of bone and is received into the other.

The peculiar ligaments joining the tibia and fibula to the tarsus, consist of a deltoid ligament, which proceeds from the tibia to the astragalus, os calcis and os naviculare. The fibula is united at its lower end by three excessively strong ligaments, one anteriorly from the malleolus externus to the astragalus, one inferiorly to the os calcis, and the third to the astragalus posteriorly; and it is the strong union of this bone which leads to its being more frequently fractured than dislocated; and even when the tibia is luxated, the fibula is fractured in two of the species of dislocation of the ancle, and generally in all; but when the tibia is thrown outwards I have known the fibula escape a fracture.

I have seen the tibia dislocated at the ancle in three different directions; inwards, forwards, and outwards; and a fourth species of dislocation is said sometimes to occur, viz. backwards: and the foot has been known to be thrown upwards between the tibia and fibula, by the ligament which unites these bones giving way: but this accident is only an aggravated state of the internal dislocation.

OF THE SIMPLE DISLOCATION OF THE TIBIA INWARDS

This is the most frequent of the dislocations of the ancle; the tibia in this accident, has its internal malleolus thrown inwards, which so forcibly projects against the integuments as to threaten their bursting. The foot is thrown outwards, and its inner edge rests upon the ground. It rotates easily on its axis.

There is considerable depression above the outer ancle, much pain, some crepitus often at three inches from the lower joints of the fibula upwards, facility of lateral motion of the foot, and considerable tumefaction.

Upon dissection, the internal appearances are as follow: the end of the tibia rests upon the inner side of the astragalus, instead of on its upper articulatory surface; and if the accident has occurred from a person jumping from a considerable height, the lower end of the tibia, where it is connected to the fibula by ligament, is split off, and remains connected with the fibula, which is also broken from two to three inches above the joint, and the broken end of the fibula is carried down upon the astragalus occupying the natural situation of the tibia; the malleolus externus of the fibula remains in its natural situation, with two inches of the fibula and the split portion of the tibia; the capsular ligament attached to the fibula at the malleolus externus, and the three strong fibular tarsal ligaments, remain uninjured.

This accident generally happens by the person jumping from a considerable height, or in running violently with the toe turned outwards, when the foot being suddenly checked in its motion, while the body is carried forwards upon the foot, the ligaments on the inner side of the ancle give way; or from the foot being fixed and the person falling to that side.

To distinguish a fracture of the fibula, the hand must grasp the leg just above the ancle, and then the foot must be freely rotated; and the motion of the foot is communicated to the fibula, and pain as well as a crepitus are perceived.

For the reduction of this dislocation, which cannot be too soon accomplished, the patient is to be placed upon a mattress properly prepared, and is to rest on the side on which the injury has been sustained; the surgeon is then to bend the leg at right angles with the thigh, so as to relax the gastrocnemii muscles as much as possible, and an assistant grasping the foot, gradually draws it in a line with the leg. The surgeon fixes the thigh, and presses the tibia downwards, thus forcing it upon the articulating surface of the astragalus. Great force is required if the limb be placed in the extended position, from the resistance of the gastrocnemii; and it is pleasing to observe, after most violent attempts by others, a well-informed surgeon gently bend the limb, and, under a comparatively slight extension, return the parts to their natural situation.

When the limb has been reduced, it is still to remain upon its outer side in the bent position, with the foot well supported; a many-tailed bandage is placed over the part to prevent it slipping from its place, and this is to be kept wet with an evaporating lotion. Two splints are then to be applied; and each is to have a foot-piece, to give support to the foot, prevent its eversion, and preserve it at right angles with the leg. If much inflammation succeeds, leeches are to be applied to the parts, and the constitution will require relief by taking blood from the arm, and by attention to the bowels; but I shall say no more on this subject until I describe compound dislocation of this joint. A person who has had this accident, may be removed from his bed in five or six weeks, long straps of plaster being passed around the joint to keep the parts together, and he may be suffered to walk on crutches; but from ten to twelve weeks will elapse before he has the perfect motion of the foot; and much friction and passive motion are required after the eighth week, to restore the natural motion of the joint.

Of the Simple Dislocation of the Tibia Forwards

In this accident the foot appears much shortened and fixed, the heel proportionably lengthened and firmly fixed, and the toes are pointed downwards. The lower extremity of the tibia forms a hard projection upon the upper part of the middle of the tarsus, under

the projected tendons, and a depression is situated before the tendon achilles. Upon dissection, the tibia is found to rest upon the upper surface of the os naviculare and os cuneiforme internum, quitting all the articulatory surface of the astragalus, excepting a small portion on its fore part, against which the tibia is applied. The fibula is broken, and its fractured end advances with the tibia, and is placed by its side; its malleolus externus remains in its natural situation, but the fibula is broken about three inches above it; the capsular ligament is torn through on its fore part; the deltoid ligament is only partially lacerated, and the three ligaments of the fibula remain unbroken. This accident arises from the body falling backwards whilst the foot is confined, or from a person jumping from a carriage in rapid motion, with the toe pointed forwards.

The treatment consists in attending to the following rules: the patient should be placed in bed on his back; one assistant grasps the thigh at its lower part, and draws it towards the body, and another pulls the foot in a line a little before the axis of the leg, and the surgeon pushes the tibia back to bring it into its place. The same principles are held in view in this mode of reduction as in the former, with respect to the relaxation of the muscles. A many-tailed bandage must be lightly applied, dipped in an evaporating lotion; and the local and constitutional treatment is the same as in the dislocation inwards.

As to position, it is best to keep the patient with the heel resting on a pillow, and to have a splint, properly guarded, on each side of the leg, having foot-pieces to keep the foot well supported at right angles with the leg, so as to prevent the muscles again drawing it from its place. As in five weeks the fibula will be united, there will then be no danger in taking the patient from his bed; and gentle passive motion may be begun.

The application of a long splint on each side, with a foot piece to each splint, and this, padded in such a manner as to give the foot a direction inwards, outwards, or at right angles, according to the direction of the dislocation, answers better than any other mode of securing it. (*see Plate.*) When this is applied, the foot cannot escape from the situation in which the surgeon has placed it.

M. Dupuytreer, of the Hotel Dieu, who is a very scientific as well as an excellent practical surgeon, has recommended a single splint, well cushioned along the outer or inner part of the leg, according to the direction of the dislocation, and fastened to the leg and foot by bandages. (*see a Plate in Johnston's Medico Chirurgical Review.*)

Of the Partial Dislocation of the Tibia Forwards

This bone is sometimes partially luxated forwards, so as to rest half on the os naviculare, and half on the astragalus. The fibula, in this accident, is broken; the foot appears but little shortened, nor is there any considerable projection of the heel. The signs of this accident are as follow: the foot is pointed downwards, and a difficulty is experienced in the attempt to put it flat on the ground: the heel is drawn up, and the foot is in a great degree immoveable.

The first case of this kind which I saw, was in a very stout lady who resided at Stoke Newington, and had by a fall, as she said, sprained her ancle. When I examined the limb, I found the foot immoveably fixed and pointed downwards, attended with great pain just above the ancle. I attempted to draw the foot forwards and bend it, but could not succeed. Some years after I saw this lady at Bishop Stortford, walking upon crutches; her toe was pointed, and she was unable to bring any other part of the foot to the ground; the degree of distortion was less than that which occurs in the complete luxation of the bone forwards; but now all tension having been subdued, the nature of the injury was more evident, though I should not have known it decidedly, but by an examination of a foot

shewn me by my friend and late apprentice Mr. Tyrell, who was so kind as to give me the parts which were taken from a subject dissected at Guy's Hospital. The articular surface of the lower part of the tibia was divided into two; the anterior part was seated upon the os naviculare; the posterior upon the astragalus; these two articulatory surfaces formed at the lower extremity of the bone, had been rendered smooth by friction. The fibula was found fractured. (*See Plate.*) The result of this dislocation clearly proves the necessity which exists in these accidents, however slight they may at first sight appear, of not resting satisfied until the foot be returned into its natural position, and restored to its motion; for if neglected in the commencement, severe inflammation and tension will prevent even a forcible extension being afterwards useful; and if still longer neglected, the changes in the state of the muscles, and the union of the fractured fibula, will preclude the possibility of a reduction, even under the most violent attempts. The mode of reduction and after-treatment, will in no respect differ from that required in the perfect dislocation of the bone forwards, either as respects the relaxation of the muscles, the bandages, or the local and constitutional treatment.

Of the Simple Dislocation of the Tibia Outwards

This luxation is the most dangerous of the three, for it is produced by greater violence, is attended with more contusion of the integuments, more laceration of ligament, and greater injury to the bone; the foot is thrown inwards, and its outer edge rests upon the ground. The malleolus externus projects the integuments of the ancle very much outwards, and forms so decided a prominence that the nature of the injury cannot be mistaken; the foot and the toes are pointed downwards.

In the dissection of this accident, it is found that the malleolus internus of the tibia, is obliquely fractured and separated from the shaft of the bone; the fractured portion sometimes consists only of the malleolus, at others, the fracture passes obliquely through the articular surface of the tibia, which is thrown forwards and outwards upon the astragalus, before the malleolus externus. The astragalus is sometimes fractured, and the lower extremity of the fibula is broken into several splinters. The deltoid ligament remains unbroken, but the capsular ligament is torn on its outer part; the three fibular tarsal ligaments remain whole, in most cases; but when the fibula is not broken, they are ruptured: none of the tendons are lacerated, and internal haemorrhages scarcely ever occur to any extent, as the large arteries generally escape injury. This accident happens either by the wheel of a carriage passing over the leg, or by the foot being twisted inwards in jumping or falling.

The mode of reduction consists, in placing the patient upon his back, in bending the thigh at right angles with the body, and the leg at right angles with the thigh; the thigh is then grasped under the ham by one assistant, and the foot by another; and thus an extension is made in the axis of the leg, whilst the surgeon presses the tibia inwards towards the astragalus. The limb, in the simple dislocation, is to be laid upon its outer side, resting upon splints, with foot-pieces; and a pad is to be placed upon the fibula, just above the outer ancle, and extending a few inches upwards, so as in some measure to raise that portion of the leg and support it; and to prevent the tibia and fibula slipping from the astragalus, as well as to lessen the pressure of the maleolus externus upon the integuments, where they have sustained injury.

The local and general treatment will be the same as in the former cases, although more depletion is required, as greater inflammation succeeds; the greatest care is necessary to prevent the foot from being twisted inwards, or pointed downwards, as either of

these states prevents the limb from being afterwards, useful; and this is effected by having two splints, with a foot-piece to each and padded, applied to the ancle on the outer side of the leg. Passive motion should be given to the joint in six weeks after the accident, when the patient may rise from his bed, and be allowed to walk upon crutches, unless great swelling of the ancle prevent it. In general, in these cases, from ten to twelve weeks elapse before the cure is complete.

Of the Compound Dislocation of the Ancle-Joint

These accidents take place in the same direction as the simple dislocations, and the bones and ligaments suffer in the same manner as in those dislocations. The difference therefore in these cases is, that the joint is laid open by a wound in the integuments and ligaments, opposite to the laceration of the skin, by which the synovia escapes, and through which the ends of the bone protrude; this opening in the integuments is generally occasioned by the bone, but sometimes by the pressure of some uneven surface on which the limb may have been thrown.

The bones being replaced by the same means as are employed in the simple dislocation, the effects of this accident upon the parts composing the joint, are as follow. The synovia, as I have stated, escapes by a large wound through the lacerated ligament, and in a few hours inflammation begins; and when an additional quantity of blood is first determined to the part, an abundant secretion issues from this membrane, and is discharged through the wound; the ligaments participate in the inflammation as well as the extremities of the bones, which enter into the composition of the joint. The inflammation of the internal secreting surface of the ligament, in about five days proceeds to suppuration; at first but little matter is discharged, but it continues increasing until it becomes very abundant, and the lacerated parts of the ligaments and periosteum also secrete matter. Under this process of suppuration the cartilages become partially or wholly absorbed, but in general only partially; for the ulceration of the cartilage is a very slow process, and attended with severe constitutional irritation, and often lays the foundation of exfoliation of the extremities of the bones. When the cartilages are absorbed, granulations arise from the surface of the bones and from the inner side of the ligament, and these inosculate and fill the cavity between the extremities of the bones. Sometimes we find after accidents to joints, that the adhesive process occurs at one part, and that the cartilage is not absorbed; whilst granulations are formed at others, where the cartilage was removed by ulceration; and I have seen, after inflammation in joints, the cartilages remain, and their surfaces adhere.

Neither does this inosculation of granulations nor the process of adhesion lead to permanent anchylosis, for if passive motion be begun as soon as the parts from cessation of pain and inflammation will permit, motion will be restored, not always entirely, but with very little diminution; and the other joints of the tarsus will acquire such an extent of motion as to render the deficiency in the mobility of the ancle-joint but little apparent: the aperture in the ligament is filled by granulations; and with respect to the extremities of the bone, when they are joined by ossific union, it is by the deposit of cartilage and by a secretion of phosphate of lime, in the usual manner in which bones are formed and repaired.

Thus then the compound dislocation of the ancle leads to inflammation over a very extensive secreting surface; it produces an extended suppuration over the lining of the joint, which occasions much constitutional derangement; and further, it becomes the source of an ulcerative process, more or less extensive according to the treatment pursued, by which the cartilage is partly or wholly removed, and by which an irritative fever is supported for a great length of time; and the

ulceration sometimes extends over the extremities of the dislocated bones, and leads to great additional constitutional irritation and protracted disease from exfoliation.

These local effects are accompanied by the common symptoms of constitutional irritation. In two or three days from the accident, or sometimes as early as twenty-four hours, the patient complains of pain in his back and in his head, shewing the influence of the accident on the brain and spinal marrow. The tongue is furred; white, if the irritation be slight; yellow, if greater; and brown, almost to blackness, if it be considerable; the stomach is disordered; there is loss of appetite, nausea, and sometimes vomiting; the intestines cease to secrete, and the glands connected with them, as the liver, &c.; costiveness is therefore an attendant symptom. The skin has its secretion stopped; it becomes hot and dry; the kidneys also have their secretion diminished; the urine is high-coloured and small in quantity. The heart beats more quickly, and the pulse becomes *hard;* which is the pulse of constitutional irritation from local inflammation, and in great degrees of it, becomes irregular and intermittent; the respiration is quicker, in sympathy with the quicker circulation; the nervous system becomes additionally affected in high degrees of local irritation; restlessness, watchfulness, delirium, subsultus, tendinum, and sometimes tetanus occur. These are the usual effects of local irritation upon the constitution, occurring in different degrees, according to the violence of the injury, the irritability of the system, and the powers of restoration.

The cause of the violence of these symptoms is the wound which is made into the joint, and the great efforts required for its repair: for when there is no wound, and the process of adhesion can unite the part, little local inflammation or constitutional irritation occur; and if this be the cause of the violence of the symptoms, the principle in the treatment of this accident is easily comprehended, and it consists in closing the wound as completely as is possible, to assist nature in the adhesive process by which the wound is to be closed, and to render suppuration and granulation less necessary for the union of the opened joint.

The first question which arises upon this subject is the following: *Is amputation generally necessary in compound dislocations of the ancle?* My answer is, certainly not. Thirty years ago it was the usual practice to amputate limbs for this accident, and it was then thought absolutely necessary for the preservation of life, by some of our best surgeons; but so many limbs have been of late years saved, indeed, I may say, so great a majority of cases, that such advice would now be considered not only injudicious, but cruel. It is far from being my intension to state that amputation is never required; but only to observe, that in by far the greater number of these accidents this operation is unnecessary.

But before I give the proofs of what I have advanced, I shall state the mode of treatment which is to be pursued in these cases.

When the surgeon examines the limb, he finds a wound of greater or less extent, according to the degree of the injury. The extremity of the tibia projects, if the dislocation of the tibia be inwards; and the tibia and fibula are protruded, if the dislocation of the former be at the outer ancle. The ends of the bones are often covered with dirt, from their having reached the ground. The foot is loosely hanging on the inner or outer side of the leg, according to the direction of the dislocation. Sometimes, though very rarely, a large artery will be divided; and it is surprising that the posterior tibial artery so generally escapes laceration; the anterior tibial being the only vessel I have known to be torn. The arrest of haemorrhage is the first object; and for this purpose, if the anterior tibial artery be wounded, it much be secured by ligature. The extremity of the bone is to be washed with warm water, as the least

extraneous matter admitted into the joint will produce and support a suppurative process, and the utmost care should be taken to remove every portion of it adhering to the end of the bone.

If the bone be shattered, the finger is to be passed into the joint, and the detached pieces are to be removed; but this is to be done in the most gentle manner possible, so as not to occasion unnecessary irritation: and if the wound be so small as to admit the finger with difficulty, and small loose pieces of bone can be felt, the integuments should be divided with a scalpel, to allow of such portions being removed without violence; the incision should be so made as to leave the joint with as much covering of integument as possible. The integuments are sometimes nipped into the joint by the projecting bone; and then it cannot be reduced, without making an incision, to allow of the skin being brought from under the bone; and when the edges of the incised wound are afterwards brought together, no additional evil arises from the extension of the wound.

The mode of reducing the bone is (in other respects) similar to that which I have already described, when speaking of simple dislocation, by bending the leg upon the thigh, so as to relax the muscles before the extension is made. When the bone has been reduced, a piece of lint is to be dipped in the patient's blood, and applied wet over the wound, upon which the blood coagulates, and forms the most natural, and as far as I have seen, the best covering for the wound. A many-tailed bandage is then applied, the portions of which should not be sewn together, but passed under the leg, so that any one piece may be removed when it becomes stiff; and by fixing another to its end, it can always be applied afresh, without any disturbance to the limb: this bandage is to be kept constantly wet with spirits of wine and water. A hollow splint, with a footpiece at right angles, is to be applied on the outer side of the leg, in the dislocation inwards, and the leg is to rest upon its outer side: but in the dislocation outwards, it is best to keep the limb upon the heel, with a splint and foot-piece both upon the outer and on the inner side; with an aperture in the splint opposite to the wound.

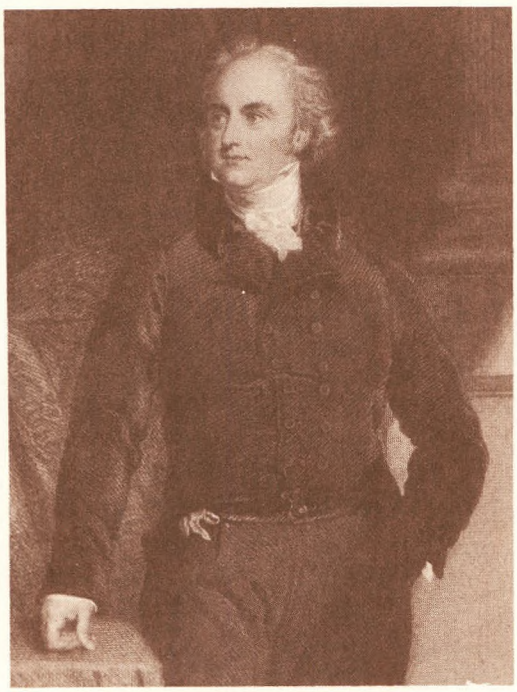
The patient's knee is to be slightly bent in each dislocation, to relax the gastrocnemius muscle. The foot must be carefully prevented from being pointed; great care being taken to preserve it at right angles with the leg, otherwise the limb will be useless when the wound is healed. The patient is to be placed on a mattress, and a pillow is to reach from half way above the knee beyond the foot, and another is to be rolled under the hip, to support the upper part of the thigh-bone.

Blood-letting must be had recourse to, or not, according to the powers of the constitution, as it is necessary to bear in mind that the patient has a great trial of his powers to undergo, and will require throughout the process of restoration, all the support which his strength can receive. Purgatives must also be used with the utmost caution, for there cannot be a worse practice, when a limb has been placed in a good position, and adhesion is proceeding, than to disturb the processes of nature by the frequent changes of position which purges produce; and I am quite sure, that in cases of compound fracture, I have seen patients destroyed by their frequent administration. That which is to be done by bleeding, and emptying the bowels, should be effected as soon as is possible after the accident, before the adhesive inflammation arises; after which the liquor ammoniae acetatis and tinctura opii, form the patient's best medicine, with a slight aperient at intervals.

If the patient complain of considerable pain in the part in four or five days, the bandage may be raised, to examine the

wound; and if there be much inflammation, a corner of the lint should be lifted from the wound, to give vent to any matter which may have formed; but this ought to be done with great circumspection, as there is a danger of disturbing the adhesive process, if that be proceeding, without suppuration. By this local treatment it will every now and then happen that the wound will be closed by adhesion, but if in a few days it be not, and suppuration take place, the matter should have an opportunity of escaping; and the lint being removed, simple dressings should be applied. After a week or ten days, if there be suppuration with much surrounding inflammation, poultices should be applied upon the wound, leeches in its neighbourhood, and upon the limb at a distance, and the evaporating lotion should be still employed; but as soon as the inflammation is lessened, the poultices should be discontinued, as they encourage too much secretion, and relax the blood-vessels of the part, so as to prevent the restorative process.

If the cure proceeds favourably, in a few weeks the wound is healed with little suppuration. If less favourably, a copious suppuration takes place, the wound is longer healing, and exfoliation of portions of the extremity of the bone still further retards the cure. The motion of the joint is not always lost, but is sometimes in a great degree restored; but this depends upon the greater or less extent of suppuration, or ulceration. Under the most favourable circumstances, three months elapse before the patient can walk with crutches; in many cases however, a greater length of time is required; he bears upon the foot at different periods of time, according to the degree of injury sustained, as in compound fracture, when adhesion is not at first produced; only that in compound dislocations the patient is longer in recovering.



SIR ASTLEY PASTON COOPER

In 1822, Sir Astley Paston Cooper of London (1768-1841), a pupil of John Hunter, published the first edition of his *Treatise on Dislocations and Fractures of the Joints.* Subsequent editions continued to be issued for 30 years. During this period and for many years thereafter, it was the principal reference work on the subject, not only in Great Britain but to continental and American surgeons as well. Many later clinical modifications were developed from Cooper's original methods. When it is realized that these fracture studies were accomplished long before the invention of roentgenograms it appears to be quite prodigious. The chapters on "Dislocation of the Ancle-Joint" and on "Fractures of the Tibia and Fibula, Near the Ancle-Joint" are herewith reprinted.

Pott's classic description of fractures about the ankle which bear his pseudonym has been published already in the series, vol. 30.

CLASSIC 20

Eine neue Extensionsmethode in der Fracturen Behandlung

(A New Traction Method in the Treatment of Fractures)

DR. FR. STEINMANN OF BERN (1872–1932)

The employers' liability act and roentgen-ray photography have shown us how bad the results of fracture treatment still are in general. When we think that according to Hoffa, two thirds of disability compensation is accounted for by fractures, we can judge what improvement in the national economy even the least improvements in this treatment represents. The most frequent causes of trouble after fractures are severe contractions and stiffness of the involved joints, then muscle atrophy, hypertrophic callus, decubitus, gangrene and so forth. Various methods have been attempted in fracture therapy, from the purely anatomic (open suture) to the purely functional (Lucas-Championnière). The essence of successful fracture therapy lies in the correct combination of both. The fragments must be well reduced and reduction maintained; but the function of the uninjured neighboring muscles and joints on the contrary must be immediately exercised (early motion, massage). Extension best meets this requirement. One of the bloodless methods may be used to reduce a serious dislocation and permanent elastic traction to control it. But most traction methods constrain the fractured limb to absolute rest or overburden several of its parts (decubitus) or afford no advantageous line of extension.

Bardenheuer gained considerable competence with traction and obtained the best results of modern times. Next to the development of transverse and rotational traction, one of his chief innovations is the introduction of the use of sufficient weight to overcome the displacement, that is, much greater weight than was formerly employed (e.g., 30 Kg. for femoral shaft fractures). The high weight must be applied from the first day. Along with this, gymnastic measures should be instituted early. The Bardenheuer adhesive plaster bandages served these demands better than all others. But these too have their drawbacks. The technic is not easy; for it, one needs continual control, which in reality can hardly be conducted properly in a hospital, and in rural circumstances it is impossible. To use traction of 15 to 30 Kg. by means of adhesive plaster bandages without pressure or damage is an art. We see eczema, decubitus and even gan-

grene appear with adhesive plaster traction. I myself have seen a case of the last in a hospital which led to amputation. Bardenheuer would certainly object that such a case could be traced back to a defect in technic or control. It merely proves to me that adhesive plaster traction is not simple enough to make such an occurrence impossible. A further unacceptable consequence of adhesive bandage traction is the occasional appearance of lax joints due to the incorporation of the entire surface of the limb segment. Although, therefore, Bardenheuer would not leave the adhesive bandage stuck over the joints, the mobility of the limb for gymnastic practice still would be hindered greatly.

I believe that the procedure that I now present as nail traction is a method which does not possess all these disadvantages. Let us take, for example, a femoral shaft fracture. My management of this is as follows. I take 2 very pointed, slender, nickel-plated, steel nails from 6 to 8 cm. long with a broad head, sterilize them by boiling and strike them with a hammer through opposite sides at the lower end of the femur through the disinfected skin and the soft tissues into the condyles. As place of entry I sometimes choose the upper edge of the condyle and direct the point obliquely downward toward the opposite epicondyle. At entering, the nail is held with a sterilized pair of pliers. From the head of the nail projecting about 1 cm. out of the skin a suitable weight can be attached by cord, or better by wire, on the usual traction apparatus. The traction is set up in a few minutes.

Either of 2 designs of nail may be chosen in the special material for my method in place of the adhesive plaster.*

A double hook with cap grasps the nail-head and takes the traction wire through a slide along a groove, thereby preventing pressure on the skin. Furthermore, one requires sterilized pliers to fasten the nail during its insertion and later for bending the wires.

The needle holder from the pocket instrument case may be used, if necessary, in place of the pliers. A piece of wire may be found in every house. If by necessity our need is replaced by an ordinary thin nail, it may well suffice.

The insertion of the nail is in itself bearable without local anesthesia, as I have proved in the fixation of a chronic clavicular luxation. In fractures, because of anticipated shock, usually I have given a short anesthesia, less often in fractures of the leg, or at times omitted it here unless the patient had complained of unbearable pain. Perhaps, a satisfactory fixation of the outer fragments or the construction of an apparatus to drive the nail more slowly would make the anesthesia unnecessary. But the latter (anesthesia) has the advantage that the patient sees nothing and is not disturbed by the idea of a nail driven through the bone.

The danger of a primary infection through the insertion of the nail is not likely with correct management of a very simple asepsis, and I have seen no inflammatory reaction with the aforementioned boiling of the nail. Also, the danger of secondary infection cannot be great. In a dirty patient, I have left the entry point without antiseptic protection for a week without an inflammatory reaction occurring. In spite of this, I always indicate that the point of entry of the nail be covered with some collodion or wind a loose strip of iodoform gauze around the nail.

By means of a bandage or a cotton compress, the attachment of the traction can be concealed from the patient if one wishes to do so.

I consider that a chief advantage of my traction method is that it is entirely painless, even with the strongest pull. Of course, the latter need not be always as great as with adhesive plaster extension, since there is less loss through friction in the underlying supporting tissues of the joint segment and

*(Two rather similar nails with minor differences in their heads are illustrated in the paper.)

therefore more intensive effect on the fragment.

Our method knows nothing of irritation of the skin, eczema, circulatory disturbance through bands, ischemic muscle paralysis, decubitus, gangrene and all the other difficulties and dangers associated with adhesive plaster traction bindings. Therefore, it does not require such intensive supervision as the other and may be left all day with the greatest weights without the above-noted difficulties occurring.

Nail traction leaves the entire periphery of the extremity free and unhindered for every movement, thereby permitting early and plentiful gymnastic management. As for the most distinctive advantage of my traction, especially in compound fractures only two skin-piercing apertures are necessary. Such fractures often prevented the use of traction, and the wounds healed horribly. Our method permits suitable traction even in these cases and at the same time free approach to the treatment of the wounds.

Our procedure can have a great influence on the management of the distal fragment, especially in reference to rotation, and thereby avoid the use of many corded rotation pulleys.

When the traction has fulfilled its objective the nail may be withdrawn easily, since in time it becomes loose. The loosening, often the result of a certain pressure atrophy of the bones, makes a transverse drive of the nail necessary. I press the fragments to lessen the loosening. The nail does not penetrate extremely compact bone. However, where it does enter one does not fear splintering.

After the removal of the nail the entry wounds close quickly under a collodion or adhesive plaster band.

As for the clinical use of nail traction it can replace adhesive plaster almost altogether. First of all, it is suitable where heavily weighted traction must be used and can be applied easily in areas where large bone structures are found covered with little soft tissue, for example at the lower end of the femur in fractures of the shaft.

If the physician knows a little anatomy, a serious soft-tissue injury is impossible. I have tried by now the method in fractures of the thigh and the leg, in the latter placing the nail at the upper end of the malleoli.

I sought different places for nail traction in all bones, for example the lower end of the humerus where from a 3-cm. long nail driven through epicondyles 3 to 5 Kg. hung for a week. In fractures of the femoral neck, the traction would be attached to a nail driven into the trochanteric mass, and this would convert a fracture, according to Lauenstein the most difficult for the application of traction, into an advantageous situation. Also a nail driven in the correct place can bring over a short displaced fragment unmanageable by adhesive plaster traction. (Displaced proximal fragment in subtrochanteric fractures of the femur, displaced head in fractures of the upper end of the humerus, and so forth.) In general, accessible areas broaden with each closer study. A fixation of a dislocated acromioclavicular joint which I treated by means of a transversely driven nail through skin, soft tissue and joint showed an application of the method other than traction.

These are the principal characteristics of my nail traction. It requires a certain aseptic precaution, some anatomic knowledge and frequently a short anesthesia; but on the other hand it is managed more simply and more quickly than adhesive plaster traction; it allows prompt application of greater and more effective weight; the strongest traction is painless for the patient; it completely eliminates every irritation of the skin, circulatory interference, decubitus and gangrene and therefore requires no extensive supervision. The immediate possibility of gymnastic management is noted, and it is equally useful in

complicated compound fractures as it is in uncomplicated.

The method is still new and certainly capable of many improvements. I believe that a useful procedure is presented, and it seems to me that whoever has seen it work on a femoral fracture would agree.

A somewhat more detailed report will appear shortly in the *Korrespondenzblatt für Schweizer Artze.*

Bern, Juli 1907

FRITZ STEINMANN

Fritz Steinmann of Bern, Switzerland (1872-1932) described a new method for the reduction and the treatment of fractures by the use of a specially designed nail to be inserted through a distal fragment and to be controlled by direct skeletal traction. This was published in 1907 when the fear of introducing infection into bone was a matter of nightmare concern to all surgeons. Its rapid acceptance in spite of the fears the method engendered is a tribute to that decade of surgeons. The Steinmann pin was one of the half dozen important contributions to fracture therapy in over 2,000 years of its practice.

CLASSIC 21 Essays and Observations on Natural History, Anatomy, Kysiology, Psychilogy and Geology

JOHN HUNTER (1728–1793)

The hardest or firmest parts of an animal, whose use in the machine is to give support and form to the whole, and attachment to the moving powers, may be called the 'skeleton:' or if only to a part, then it is the skeleton of that part. Some consist of only one piece[1], others are made up of several pieces, having motion on each other, which at the same time directs and determines the places for motion.

A skeleton respecting the internal economy of the animal is of no use, having no action within itself so as to influence others; it is passive, as a wheel in a machine, and must be acted upon. However, its use is not so essential as that of a wheel; for wheels make a part of the internal economy of the machine. But wheels neither give support nor shape, which are two very essential uses of the skeleton.

Skeletons are composed of different kinds of substances suited to the necessity; some being extremely hard, others soft, yet of sufficient firmness to give support, and afford fixed points for muscular attachments. These substances may be membrane, cartilage, horn, and bone. The first three are animal substances, the last is a kind of mixture of animal matter and earth. These different substances are not entirely peculiar to particular classes of animals; some having two kinds, others three, and probably there may be some which have all the four. We find, too, that some animals may have one kind at one period of life, while they have another kind at another period. Some skeletons contain the whole animal, as in the oyster; others are in different parts of the body (as in the tortoise). We may observe that, upon the whole, when the skeleton contains the whole or a part of the animal, it consists of fewer parts, with the least motion on each other. Of this shell-fish are the strongest instance, and next the lobster, turtle, tortoise, &c. And even in the quadruped, bird, &c., where the bones are in great numbers,

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* Edited by Richard Owen. Published by John vanVoorst, London, 1861. Chapter 11 pp. (373-378) from a treatise on animals from Hunter's notes deposited with the Royal College of Surgeons (Eng.) and apparently intended for a large treatise on comparative anatomy and physiology. No date.

(Hunt. Preps. Phys. Series, Nos. 225, 226.)

[1] (Hunter here refers to his "Croonian Lectures on Muscular Motion." See my edition of the 'Animal Economy,' 8vo. 1837, p. 229.)

having motion on each other, yet we find the skull to accord with the above-stated principle. The cuttle-fish (*Sepia*) might be cited as an exception to this, for it has only one bone for its skeleton, which is not on the outside, and in some kinds (*Loligo*) the internal skeleton is a horny substance.

I shall begin my history of the different kinds of skeleton with the most simple in regard to use, which may be as simple in regard to substance and construction. I conceive that where the skeleton has the least rigidity, it is least complicated in its uses; and this idea is verified in those animals where the skeleton is found to be of most varied use. For in those at the age where this part of the animal can be of little use, the most rigid skeleton does not exist; but only the soft, or that which I conceive to be of least use: and as the actions of the animal increase, rigidity becomes more and more requisite or useful; and the soft is changed to the rigid, as will be observed when on the skeleton of each class of animals. The membranous skeleton must have the fewest parts; and we find that the most inferior animals have only this kind.

The membranous skeleton is the first, and appears to be more of a tendinous than membranous nature: it is to be considered rather as a medium for muscular union, so as to give fixed points of action to distinct muscles in the flexible animals of the lowest order; a worm may be given as an illustration. Every ring in this animal may be considered as a bone, or fixed point, from which muscles pass to the other ring. The same substance is carried to different parts in higher animals, so as to supersede bone, where it can answer the same purpose; and either where no harder substance is wanted, or would be hurtful; thus tendons of muscles and ligaments of bone are to be considered as a part of the skeleton; they certainly make part of the skeleton of the animal.* In the head of the infant, as at a period when the contents are in no danger of being injured, the skeleton is only a membrane, the function being simply that of a containing part: its becoming bone afterwards is to answer the purpose of a defence from external violence to the contained parts.

As the membranous skeleton is not stretchable, or has a sufficient firmness in texture not to yield beyond a necessary extent to the natural actions of the animal, and as, in such, the sections of motion are short, a pretty regular form is preserved; for in every natural action there is such a relationship depending upon it, that no distortion of parts takes place, and only external violence deranges the form. A worm is just as regularly a formed animal as any other, although it varies more than those whose forms are more determined by (the harder nature of) the skeleton.

The cartilaginous skeleton differs from the former in the nature of its substance, as in the consistence whereby it retains its form; but there are considerable differences in the degree of consistence, and of course in the power of retaining form. This substance is introduced in various ways, but seldom alone, as we find in the membranous skeleton; in some animals there is more of it, and in some less, when the skeleton approaches nearer to the membranous. Cartilage is used as an external covering, like a shell, as in those (*Salpa, Ascidia*) which I have called the 'soft-shelled animals[1].'

Cartilage is used in the body of some animals as a fixed point for the muscles to act from. And as it is not so yielding as the membranous skeleton, it is composed of parts which are united to each other, admitting of motion in those parts, and determining with more exactness the places of motion; although not perfectly, as it is elastic, yielding

* In my history of muscles, in which I treated on tendons, I considered them more as a part of the skelton than muscles[1].

[1] (They answer to the *Mollusca tunicata* of Lamarck and Cuvier. The external skeleton, shown in the Hunt. Prep. Phys. Series, No. 76, is a dense gelatinous membrane, containing 'cellulose:' not true cartilage, but resembling it in physical properties.)

and recovering without the aid of antagonizing muscles. These unions mostly consist of membranes filling up the space between each cartilage; although in some the membrane makes a capsule.

This mode of introduction of cartilage is principally in fishs; and in some parts of other animals, such as the cartilages of the ribs in man. It gives more stability to the shape than membrane could, and admits of more variety of shape in animals.

Cartilage.—This is semitransparent; of various consistence according to its use; and is commonly of a determined shape or outline, seldom losing itself insensibly in the surrounding parts. Cartilages are of two kinds respecting the power of being changed for bone; one where it is forming the skeleton of many animals only before birth; the other where it is not, becoming the skeleton of some animals throughout life[1],—that of both kinds is a very uniform mass, breaking equally in every direction. The one which is changed for bone is vascular, and when going to be changed becomes more so, these vessels having now more to do[2].

The horny skeleton is truly animal, and is placed principally on the outside of the animal, by which means it is kept dry, which renders it stronger under the same quantity of matter. In the spade-tailed cuttle (*Loligo*) there is a horny or tortoiseshell blade that runs through the whole back[3]; besides which there is a cartilage on the anterior end of the back. In the common horny skeleton the muscles are placed on the inside, by which means it becomes a compound part of the animal, serving equally as skin and skeleton, and often other purposes. It is common but not peculiar to the insect: it constitutes the scales (rings) or external covering of every flying insect, to which the muscles are attached; besides which it sends inward horny processes for the further attachment of muscles; just as bones send out processes for the same purpose. I believe in the insect this substance is almost the sole, having very little of the ligamentous, and, I believe, none of the cartilaginous (substance combined with it). We have no generic term for this substance[4]. I believe it is fibrous in all; growing from an end like hair, or from the edge like scales, according to its form. But when it acts simply as a cuticle, I believe it grows from a centre, or all round the edge, as in the shell[5] of the tortoise or turtle.

The bony skeleton belongs commonly to the higher orders of animals; although it is introduced into some of the lower, where firmness, strength and determinate motion, with great variety, are wanted. As it is internal, and of course always kept moist, it is a fitter substance for those purposes than horn; for horn, when moist, is elastic and yielding, and therefore when used is external. Bone is not the original skeleton in any animal, but only of the adult; for in the first formation of any animal, which afterwards is to have bone, the skeleton is either membrane or cartilage, which is changed *for* bone, but not *into* bone.

The gradations of this change are beautiful. When the animal has no locomotion, nothing to support, no action of parts but such as immediately concern life, we find no bone. But as the young animal advances towards that period in which it is to take a scope of bodily action beyond its own internal economy, when one part is to act upon and to sustain another, then rigidity becomes requisite, and bone begins to be formed in preparation for this period. This is similar to what goes on in every other part which is to come into action after birth, with a new mode of the continuance of life. Thus the lungs, stomach, intestines, with every thing relative to them, the brain, nerves, senses, and extremities are forming, from an early period, so far as to be useful when the animal comes, as it is calculated, into the world. The sub-

[1] (Hunt. Preps. Phys. Series, Nos. 78, 230—237.)

[2] (Ib. Nos. 133—162. The above is an outline sketch of a histological chapter on cartilage, which appears not to have been written.)

[3] (Ib. No. 77.)

[4] (It is now called 'chitine,' having a different composition from horn.)

[5] (This is true 'horn.')

stitutes for bone at those early periods are cartilage and membrane, but cartilage chiefly. And this varies in consistence according to the age. It is, at first, almost a jelly, and becomes firmer and firmer as the fœtus may move upon itself. But as it is not wholly changed for bone at birth, what cartilage remains is become, by this time, fit to act as bone. Where the least power of resistance is wanted, where no action can take place, there we have only membrane; and this membrane is only to contain, and to allow itself to be changed for bone; such as what covers the brain; for, while in the state of a fœtus, the brain requires only to be covered, similar to the abdominal viscera; but, by the time of birth, it wants something more.

I shall here observe that the cartilage of those animals where there is bone, is of two kinds: the one that is changed for bone is a uniform mass, but that which does not is fibrous, and is placed on the ends of bones, forming the cavity of the joint; and as it is for the purpose of the motion of the joint, it remains a cartilage through the life of the animal. The cartilage that is changed for bone is of two kinds respecting the time of change: one is where the change is complete when the animal has arrived at its full growth, forming what are commonly called the 'bones.' The other is where the period of change is uncertain, seldom until considerably after that of full growth. Such commonly retain their original name of cartilage, and when they do become bone, are said to be ossified: such are the cartilages of the larynx, and of the ribs or sternum. The earth in bones is not to be considered as a part of the animal; it is like the fat; for it can be diminished or increased by simple absorption or deposition. It is a secreted substance, and, as it were, thrown out of the machine simply for a mechanical purpose. It is not required to be of the nature of the machine, for it can be made up of parts, *e.g.* madder, that are not altered by the stomachic process.

The stone in the bladder, which cannot be considered as part of the animal, is coloured in the same manner as bone; the urine being the carrier of the madder out of the blood.

As those cells that contain oil are called 'adipose membrane,' *cellulæ adiposæ,* I think the animal parts of the bone should be called 'calcose membrane,' *cellulæ terrestres seu calcareæ.*

Young bone may always be said to grow, even the part that seems to be already formed; for at first it is growing longer, thicker and denser; so that there is always new matter added until it is at its full growth. But in the full-grown state, it would appear from the circumstance of reddening a whole bone by feeding the animal with madder, that a bone, although completely formed, yet is changing its earth, and probably every other part. This effect, however, is much slower than in the growing bone. This would show that the madder does not act as a dye upon the earth which is already deposited in the bone, but only upon that matter that is every day deposited; and as there is a great deal more deposited in a young bone than in an old one in a given time, in the same proportion must it dye sooner than an old one. The new matter that is deposited in an old bone is to make up for the waste that is daily going on in it; but in a very old bone the waste is more than the repair[1].

Bones would seem to have but very little sensibility. This is best known in the fractured patella; where generally there is no contusion, no splinters to run into sensible parts, and nothing torn but what is also insensible. People who meet with such an accident, seldom complain of pain when it happens. It is similar in this respect to the rupture of the tendo Achillis[2].

The number of bones should be reckoned according to the number of distinct cartilages

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[1] (The preparations resulting from the experiments on the growth of bone are Nos. 188—201, Phys. Series. See also the memoir on the same subject "From the Papers of the late Mr. Hunter," communicated by Home to the "Transactions of a Society for the Improvement of Medical and Chirurgical Knowledge," vol. ii. p. 277, 1798.)

[2] (An injury of which Hunter had personal experience.)

which ossify; for, in general, wherever Nature intended a bone, she first made a cartilage of the shape of the intended bone. Yet this is not universal; for I believe in none of the bones of the head, except the occipital and sphenoid bones, is there a cartilage: the others being formed in membrane; and even in the exceptions above mentioned it is only at the union of the ossifications that we find cartilage: in their circumference we find the bony rays shooting out into membrane. From this mode of numbering bones, we see that the bones called 'occipitale' and 'sphenoides' are but one bone. However, as a general principle, it appears the best; for we find it almost everywhere else in the body. Therefore it seems improper to give the parts of one bone in the adult two, three, or four different names, because it was formed of two, three, or four different ossifications. It would be much more proper to give the bone only one name, as, for instance, the 'os innominatum,' for two reasons; because the whole is really but one bone, and because it was formed in one cartilage[1]. This last would be no reason if we found that Nature sometimes formed two bones in one cartilage, and that they remained so through life; but this is never the case. However, we have an exception to distinct cartilages forming distinct bones; for the sacrum is one bone, although formed in several distinct cartilages, these being closely united together by substances which readily ossify.

Bones in young animals are often so soft, that they are not able to support the perpendicular weight of body; therefore they generally bend; those that soonest give way are the tibiæ and fibulæ. The direction in which they do bend is not constant; being sometimes forward, and often outward. When forward, it is generally higher up than when outward; for when outward it is generally just above the ankle: but this bend forward is not altogether from perpendicular pressure; the tendency to it is assisted by the contraction of the muscles behind. This bend, in the human subject, is produced gradually by pressure from above. That it is from pressure or some power applied beyond the strength of the animal or part, is evident from the case of a young leopard. It was chained by a chain about a yard long, and had always a vast desire to go out of the door: in all its efforts to get loose it pulled in one direction, pulling with one fore-leg, and pushing with the other, by which means the bones of the leg that he pushed with were bent outwards, exactly answering these two motions of the legs, and the motion of the animal.

Ossification of the cylindrical bones is supposed to begin like a ring in the middle of the cartilage; and this ring becoming broader, makes the length of the bone. But I have reason to believe this is only conjecture, arising from what a section of a cylindrical bone would show. For in a very young bone we never find the end of it hollow, although the middle of it may be so; but as the end increases in length, from being solid, it becomes hollow; this scooping out or excavation following the growth.

Cut off from the end of an older bone the proportion by which it exceeds the length of a younger one, and we shall find the cut end of the older bone hollow. From this then we see that the greatest part of the bone is solid, and afterwards becomes hollow; therefore it is reasonable to think that the first ossification was solid, and then became hollow.

The bones are such parts that do not grow or increase in any part while that part is exposed to the air; therefore Nature has taken care to cover bones that are sound as soon as possible (if they are by any accidental circumstance exposed).

Bones are commonly hard in proportion to their length; for, in proportion to their length they are obliged to make the greater resistance. Any lateral bias, wrench, blow, &c.

[1] (Hunter, it will be seen, fails to appreciate the signification and value assigned in homological anatomy to the distinct points of ossification in the common cartilage of the compound bones which he cites. It is interesting, however, to find this approach to the verge of considerations which have subsequently exercised so strongly the anatomical mind.)

more easily breaks a long bone than a short one. It in all cases acts with a longer lever.

Animals whose bases of support and motion are formed of hard and solid parts, have them so joined as to allow of motion between them; which joints, in the formation of their parts, are so related to the application of the powers of motion, as to constitute what are called the mechanical powers or levers. A lever has the moving power, the centre of motion, and the resistance. And as these may be so placed with respect to each other as to vary their relative position as much as three numbers can, so are the joints in an animal variously formed. The joint of the foot upon the tibia is of all the three sorts. It is a lever of the first kind when we push anything with our toes; of the second kind when we raise anything with them; and of the third when we raise our body upon them.

In mechanics, without resistance there could be no such thing as motion; but in animals, where there is a self-moving power, this can act without any resisting point. But this self-moving power cannot be applied to other parts, even in the animal, without a fixed point of resistance. However, these self-moving powers, by their simple action within themselves, may produce immediately the effect, without one point resisting more than another; as (in the instance of) a worm simply contracting and bringing its two ends together, or contracting laterally, so as to push itself out, by which means it is elongated; but even here the one half of the worm may be said to be the fixed point or point of resistance to the other; but a worm can fix any part of its body to whatever it lies upon, and move towards that point. A circular muscle would appear to have no fixed point, only the power of contraction, or shortening itself; and from the figure the muscle is thrown into, it produces its effects; each portion becomes a fixed point to the other all round; therefore every moving body which acts mechanically, acts from some resisting power which may be called the fixed point, or centre of motion. But animals, more especially the compound ones, having a number of points or movements (of parts of the skeleton) on each other, have so many fixed points; the larger portion becoming the fixed point to the smaller; until, at last, the whole body has its fixed point, or point of resistance to move upon. Animals that move upon the earth, have that for their fixed point; birds that fly have the air for their fixed point; and fishes have the water for their fixed point.

Besides these general fixed points of motion for the whole animal, each animal has a fixed point within itself from which the parts of the body take their principal motion. In the human body this fixed point seems to be in the joints of the thigh-bones; and being in the middle of the body, it must be common to the extremities; therefore we see that the trunk either moves on the legs, or the legs on the trunk. Besides this there are as many fixed points as there are joints; so that the body is to be looked upon as a chain of joints whose general centre of motion is in the joints of the thighs; but each has its centre of motion, which is always on that side next to the general.

The greater the motion in any joint, the less nice it is; therefore, where correctness and nicety is wanted, the parts of motion are divided into smaller movements; as, for instance, the bones of the fingers become shorter and shorter towards their terminations.

Of the Spine.—The spine in animals is that which is the basis of the whole body, on which everything is built. It gives support to the whole, and may be said to be like the keel of a ship—the first thing laid down, from which the whole superstructure is to arise. From its great length, it is necessary to have motion within itself; and, as it would be improper for it to bend at one part sufficiently for the required motion, more especially on account of the ribs and viscera, it is made up of a number of bones, that it might have an easy motion through the

whole: this also protects the spinal marrow from being hurt by too quick a bend.

The other joints have no parts save for their simple motion; but the trunk has a great many, which prevents such motion.

The spine is straight in a fore view, because the two sides of the body are similar parts; but the back and fore parts not being similar, the spine is bent accordingly, to be able to support the different weights applied to it. However, this is observable principally in the human subject, owing to his erect position. That part of the spine to which the other bones of the pelvis are attached (the sacrum), is commonly nearly in the same line with the rest of the chain of bones; although, in most, it is a little bent so as to give space to the pelvis; but in the human it is thrown further back, in order that the thigh-bones might be brought perpendicularly under the spine, and at the same time the cavity of the pelvis not at all diminished: both could not have been done in any other way.

The canal of the spine is largest in the neck and loins[1]. This answers two purposes; first, it allows a greater motion in those parts without the medulla being hurt; secondly, it makes the parts stronger with the same quantity of matter: this is most remarkable in the loins.

In man the crooks of the spine vary in different parts, at different ages, of the same person. In the child it is most in the back, and is backward; owing, perhaps, to the weight of head; in the adult it is as much in the loins and is forward. This, perhaps, is owing to the weight of the thorax and head, and the loins being the most moveable part.

The ligaments between the vertebræ are stronger externally in proportion as they are removed from the centre of motion.

The trunk is made up of three parts, the head, thorax, and pelvis—all at a distance from one another; and this is common to all quadrupeds. It was necessary that these parts should have motion; therefore they are placed at some distance from one another, which makes the necessity for the neck and the loins.

The back-bones of animals differ very much respecting motion, and especially the degree of curving; they might be divided into the straight and curved. Horses, elephants, rhinoceroses, and ruminating quadrupeds, which only stand or lie, have spines of the straight kind. However, there is a gradation between the straight and the curved spine. The curved or bendible spine belongs to those animals which can sit, either upright, as in man, or bowed forward; the monkey, dog, &c. forming the gradation between the one and the other.

Animals that have very long bodies, and are small[2], generally have their backs bent upwards, archways: the use of this must be to support the body as an arch is supported.

In quadrupeds and birds the ilium is a long bone, situated nearly at right angles with the thigh-bone, crossing its head like the upper part of the letter T; giving origin, along its whole sweep, but principally at its ends, to muscles which flex and extend the thigh-bone. The middle part of the ilium is so near the joint as to give but a small surface for muscular attachment; therefore there is produced but little lateral motion. This position and formation of the ilium with respect to the thigh-bone is remarkable in the bird.

The reason for the great difference between the shape of the pelvis in man and other animals, is to give a circular sweep of

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1 (*Vide* Mr. Henry Earle's paper thirty years after Mr. Hunter's death, for this single fact, Phil. Trans. 1822 or 1823.—W. C. Mr. Earle also regarded the expansion at the ends of the neural canal in the neck-vertebræ of birds as an important element of his paper.—R. O.)

2 (See the skeleton of the marten (*Mustela Martes*), No. 4152, and that of the sable (*Mustela zibelline*), No. 4168, Hunterian Osteol. Series.)

origin to the muscles of the human thigh-bones; the pelvis being adapted to this purpose by the circular spreading position of the iliac bones, making a cone, the base of which expands over the thigh-bones. The acetabulum is to be considered as the apex: it is placed laterally, looking downwards and outwards, and gives a free scope to the motions of the thigh-bone. This position of the bone obliges the thigh-bone to be of a peculiar shape; at first it comes out nearly in the direction of the cone, forming what is called 'head' and 'neck;' it then bends down so as to give the legs a proper position for the support of the body.

This position of the head and neck gives principally a rotatory motion, upwards and downwards, which brings the body of the bone outwards and inwards; so that the rotatory motion of the head and neck, joined with the up and down motion, produces the conoid motion in the body of the bone.

The body of the thigh-bone makes with the neck an angle of 56°. This angle confines in some degree the motion of the thigh; for, on account of it, the body of the bone has not the quantity of motion that the neck has; or would have, if the neck were continued out in a straight line from the body.

The perpendicular column of the leg of a fowl is thrown under the centre of gravity (by the forward bend of the femur). For, although the joint of the thigh is not, that of the knees is, under the centre. The thigh-bone is supported in that oblique position by muscles.

The scapula and clavicle generally move together; but sometimes the scapula moves without the clavicle. When both move together, they may be compared to a pair of compasses.

The motion of the wrist is chiefly flexion and extension: the flexion is between the radius and first row of the bones of the carpus; the extension is between the first and second.

The metacarpus is to be considered as the first set of bones; for they make the basis for the others to bend upon. The second set of bones, or first row of the fingers, becomes the basis of the other two; and the second row of bones of the fingers becomes the basis of the last of all. In proportion as these bones become shorter, they describe, in their movements, the section of a smaller circle. The tails of some animals are constructed upon this principle.

Of Ligaments.—Ligaments are parts commonly composed of strong materials which are flexible. Their strength has to be equal to the accidental force applied, tending to dislocate the parts which they unite. Most of our muscles, with their tendons, become, indeed, principally the ligaments in the motions of the joint, arising from their own action. But every joint is not sufficiently surrounded with muscles and tendons to guard it in every direction; therefore it must have ligaments as a substitute. The thigh-bone at the union with the pelvis, and the humerus at the union with the scapula, are so surrounded with muscles that it is hardly necessary for them to have ligaments, excepting to retain the synovia. However, as those large joints are subject to various motions, not produced by their muscles, it was necessary they should have ligaments of some strength; although these are not always equal to the force of such motions, which are commonly called accidental. The ligaments of joints are inserted at a distance from the moving point, in a proportion equal to the quantity of motion, which motion is always from the received bone, viz. the thigh-bone and the humerus. It is equally so in the ginglymus and conoid joints; for, in the ginglymus, the ligament is inserted at a great distance from the point of motion on the flexing and extending sides, but is much nearer to the lateral, and in the true conoid the ligaments are inserted at equal distances all round.

The vertebræ of the quadruped are never, in any action of the animal, in danger of

being pulled asunder, but they are liable to be broken asunder; therefore the union of the two is such as is a hindrance to their being broken, the strong part of the union being exterior, and the weak one in the centre.

The simple motion in every joint is the sliding one; but from the difference in the articulations, and the different directions of the bones, different effects are produced, which have given rise to different classes of joints, and of course to different names for them.

JOHN HUNTER

John Hunter (1728-1793) spent many years teaching in the private school of anatomy maintained with his brother William in London. His lectures influenced several generations of Anglo-Scottish surgeons who customarily kept notes. Hunter wrote prolifically, but many of his manuscripts were still in the formative stage when he died. These came into the possession of the Royal College of Surgeons (Eng). Richard Owen, a leading investigator in the basic sciences of surgery and natural history, was closely associated with the College. Among his other contributions was the edition of Hunter's works in 1861. Among the manuscripts was a collection of notes and fully written passages apparently intended for a large treatise on compartive anatomy and physiology.

One section bore the title *A treatise on animals*. Chapter 2 of this treatise summarizes Hunter's many years of study on osteogeny, far in advance of his contemporaries. His note (Par. 12-13) concerning the nature of replacement of cartilaginous anlage in the vertebrate skeleton by invasion from an osseous centrum was singularly perceptive in his day. Other osteologic observations of Hunter's during the second half of the 18th century will equally amaze the reader. The actual date of the manuscript is not given, but as lecture material during his teaching period, and as notes of his students carried widely through England, Scotland and early United States, this material was Classic in its influence. Richard Owen referred to John Hunter as "the founder of philosophical surgery."

CLASSIC 22 En epidemi af infantil paralysi

(An Epidemic of Infantile Paralysis)

PROFESSOR DOCTOR O. MEDIN (1874–1928)

In 1887, I had an occasion to make the observation that the well-known disease infantile paralysis may occur epidemically, and in certain cases assume forms which I have never before observed. For a long time I have been certain about the infectious nature of this disease, but I knew very little about an epidemic dissemination. I knew that a Swedish colleague, Dr. Bergenholtz in Umeå, in 1881 had submitted to the Royal Medical Board an account of a small epidemic of infantile paralysis seen by him in the vicinity of Umeå (at about latitude 64 north). Dr. Bergenholtz had seen 13 cases in a very short time. His account is highly interesting, but it is quite short and has not yet been published. A statement by Seeligmüller (according to a quotation from Vogt), that a Dr. Colmann had seen 17 cases in children under age 2 within 3 to 4 months is not at all correct. It is true that a statement to this effect exists in the *London Medical Gazette* and in the *American Journal of Medical Science,* 1843, submitted, however, not by Colmann but by G. Colmer. He had not seen 17 cases but only a single one toward the end of 1841. It was the parents of the diseased child who told Dr. Colmer that in the area where they lived, West Feliciana, La., U.S.A., within a radius of only a few English miles in the course of 3 to 4 months 8 to 10 other cases of acute paralysis had occurred in small children. This is all that Colmer stated. Of great interest is an account by Cordier that a small epidemic of 13 cases in the vicinity of Lyon occurred during June and July of 1885. Not less than 4 cases ended in death. Cordier did not see any of these cases in the acute stage, not even any of the cases that lead to death. It was in the Fall of 1886 that Cordier heard of this epidemic and thereafter collected information about it. Cordier's account became known to me only one year after I had observed the epidemic in Stockholm in 1887. I should finally add Eichhorsts' remark that it had been observed that occasionally several cases had occurred at the same time and in the same area. Other than that I do not know of any information on the possible epidemic occurrence of infantile paralysis. This disease occurs in Sweden as in Stockholm, the capital, rather rarely, and an epidemic has certainly not occurred in Stockholm in the last 50 years. My own experience in the Pediatric Department and the outpatient clinic in Stockholm extends through 15 years. During this period only a couple or only a few isolated cases

* Translated by Göran C. H. Bauer, M.D.

† Presented in German to the Pediatric Section at the International Medical Congress in Berlin, August 7, 1890. A more thorough account will soon be available in Nord. Med. Arkiv and in Jahrb. f. Kinderheilk.

have occurred, usually older cases in the atrophic stage.

Conditions became quite different in 1887. Already in the month of May 2 cases occurred, in June 1, and in the month of July another 2 cases. All 5 were typical cases of poliomyelitis anterior acuta, which came under observation only after the acute stage had passed. On August 1, there occurred a new case which came under my treatment on the 10th of August, but it was only from August 9 that the occurrence of the disease assumed epidemic character. The cases became numerous and particularly violent. From August 9 until September 23, that is in 46 days, 29 cases occurred observed by me, most of them in the city of Stockholm proper, and only a few cases from the surroundings of the city. I saw most of these cases during the acute phase. They showed unusually severe symptoms from the start of the disease, and this is the probable explanation why the help of a physician was sought so early.

During the months of September, October and November another 9 cases occurred. From the month of November until May not less than 44 children had succumbed to infantile paralysis. It was not only the frequency of cases during August and September which was so remarkable. I became very surprised to see the violent and severe symptoms which many of the cases showed at the same time, especially during the acute stage, and I was even more surprised when a 3-year-old girl, who became ill on September 3, died after 6 days of illness on September 9, with symptoms of increasing general paralysis. On that same day another child died, a 1½-year-old boy, but this case I did not see myself. This case came to my attention because a 3-year-old brother who had fallen ill with infantile paralysis was seen in the outpatient clinic the same day that the younger brother had died with symptoms which, according to the report of the mother and of the physician who had treated the boy, in all essentials agreed with the picture of an infantile paralysis.

The other death which I observed myself occurred on September 28. It was a 5-month-old girl who fell ill on September 23 and died the 28th. A 4th child died from diphtheria in the 7th week of infantile paralysis when the condition still was very poor from this disease. Thus of 44 children who fell ill during this year, 3 died of acute infantile paralysis and 1 of diphtheria.

The epidemic observed here has been highly instructive. The observations made have further broadened our knowledge of the fever stage and of its symptoms; they have taught us to know new, peculiar forms of the infantile paralysis; they have given important contributions to our knowledge of which parts of the nervous symptoms may be affected by this disease; and, finally, given us a rather good idea of the pathologic changes in the organism when death occurs in the acute stage. I hope to have an opportunity to describe these observations in a more thorough publication. The 20 minutes force me to touch only the most important points.

First a few words concerning the symptoms. In descriptions of infantile paralysis one talks of predisposing causes and of premonitory symptoms. I have found neither one nor the other. Only in a single case have I observed obvious premonitory symptoms during 4 to 5 days. Otherwise, the disease usually has all of a sudden attacked previously completely healthy children without any trace of any external cause. Tender age seems to be the only predisposing factor. Five children were less than half a year, 9 were in the 2nd half of the 1st year of age, 9 in the 2nd, 11 in the 3rd, 6 in the 4th, 2 in the 5th and 1 in the 6th year of age. Twenty-two were boys, and 21 were girls. Most of the children belonged to the working classes, but a few cases occurred even in better-to-do families. The season seems to have etiologic influence. As is known,

even the single cases occur most commonly during the summer, and as I have already mentioned, it was in August and in September that the real epidemic reigned, even though the climatic conditions at this season in 1887 were not in any sense unusual.

As regards the fever stage the characteristic symptoms have been fever, somnolescence and dyspeptic symptoms, in a few cases vomiting, in some diarrhea, and in several cases obstipation. Fretting, anxiousness and pains in the body have further been noticed. The fever was irregular, the temperature seldom over 39° (C.); in one case a few hours before death 41.4°. The somnolescence in the acute fever stage is very characteristic. A slight drowsiness in many cases is increased in others even to deep stupor. In the cases which ended in death, coma ensued. As regards the obstipation and the retention of urine in the fever stage, when the children suffer from obstipation it may last several days, sometimes 4 to 5 days, whereas retention of urine usually lasts only 1 day. In one case the bladder had to be emptied by catheter during 3 days. Obstipation for several days, like retention of urine, suggests a real but transient paralysis of the bowels and bladder toward the end of the fever stage in infantile paralysis. I believe the somnolescence is due to a transient malfunction of the cerebral cortex. The pains and tenderness on touch suggest some mild affection even of the sensory nervous system at the start of the disease. I have observed convulsions during the fever stage only twice: in one case of polio encephalitis and in one case with 8 days of sopor and paralysis of almost all of the body.

In general the fever stage lasts for 2 to 4 days; only in 2 cases was no trace of a fever stage observed, whereas in some others it lasted 8 days. In a couple of cases a 5-to-6 day remission free of fever occurred, whereafter the fever reappeared with considerable spreading of the paralytic symptoms.

As mentioned already, the paralytic symptoms appeared during the fever stage. After paralysis has occurred, fever and sopor may last for several days. After the fever stage has terminated, no new paralysis appeared. The restitution starts in the initially affected parts of the nervous system during the fever stage; in rare cases it may lead to full health, in some to almost full health, but in most of the cases it has left one or another area permanently paralyzed and atrophic.

The general features of the picture of this disease in most of the cases have been those which constantly characterize poliomyelitis anterior acuta. However, not less than 17 cases presented as regards localization more or less uncommon symptoms from the nervous system. Yes, I would hardly have included many of these with this disease unless they had occurred exactly simultaneously with the cases of poliomyelitis, and unless they had had so much similarity with these as regards the fever stage. Transitional forms are not lacking either.

As we observe the outline of the symptoms in the table shown here, we first see among the atypical cases 3 cases of monoplegia facialis. Had these occurred alone, I would have had difficulties in thinking about any connection between them and the infantile paralysis. In passing, I wish to recall that it is very seldom that previously completely healthy children are affected with facialis paralysis. However, I had occasion during August to October 1887, that is during the on-going epidemic of infantile paralysis, to observe not less than 3 cases. Already this temporal concurrence proves to a certain extent the etiologic connection between these cases of facialis paralysis and the other cases of infantile paralysis. But even more clearly 2 other observations suggest this relation; one is the fever stage which preceded the facial paralysis and in at least 2 cases was exactly like that in infantile paralysis; and the other is the fact

Outline of Symptoms in an Epidemic of Infantile Paralysis Observed in Stockholm 1887.

	Maj.	Juni.	Juli.	Aug.	Sept.	Okt.	Nov.	Summa.
Poliomyelit. anter. acut. c. pares extremitat.	2	1	2	8	8	4	2	27
Monoplegia facialis	—	—	—	1	1	1	—	3
Polyneurit. acuta	—	—	—	2	—	—	—	2
" " + pares. n. abducent. et hypoglossi	—	—	—	1	—	—	—	1
" " ?, (ataktiska o. spastiska symptom + pares. n. facialis)	—	—	—	—	1	—	—	1
" " ?, (ataktiska o. spastiska symptom + nephritis acuta)	—	—	—	—	1	—	—	1
" " (+ poliomyelit. anter. acut.) + pares. n. facialis.	—	—	—	1	—	—	—	1
Poliomyelit. anter. ac. + pares. n. abducentis	—	—	—	—	2	—	—	2
" " " + " " facialis et oculomotorii	—	—	—	1	—	—	—	1
" " " + " " oculomotorii et vagi	—	—	—	—	1	—	—	1
" " " + " " facialis, vagi et accessorii	—	—	—	—	1	—	—	1
" " " + " " accessorii et hypoglossi	—	—	—	—	1	—	—	1
" " " + " " oculomotor., abducent. (ophthalmoplegia extern.), facialis, trigemini, vagi, accessor. et hypoglossi	—	—	—	—	1	—	—	1
Poliencephalitis acuta + pares. n. abducentis	—	—	—	1	—	—	—	1
	2	1	2	15	17	5	2	44

that a mother had found that the child during the fever stage was not able to stand on his legs, a weakness in the lower extremities reminiscent of the rapidly transient paralysis which one often observes in this disease. In addition, in not less than 5 cases the facial paralysis occurred in connection with poliomyelitis and polyneuritis; it is thus certain that the facial nerves in several cases of true infantile paralysis had been affected. This nerve just as much as the tibialis anticus nerve alone can be paralyzed in this disease. I must leave it an open question whether these facial paralyses have been caused by neuritis or by an affection of the facial nucleus. I adhere to the latter possibility as the most probable.

I cannot refrain from mentioning a very interesting case which I had occasion to observe in the Spring of 1888. In this case both the facial and the abducens nerves on one side were the only paralyzed nerves. How could one better explain such a coincidence than by assuming an affection of the nucleii of these nerves which as we know lie quite close to each other. One has hitherto believed that the cranial nerves were very rarely, if ever, affected by infantile paralysis. My experience from the epidemic of the year 1887 has taught me that this belief is not correct. I have mentioned the 3 cases of monoplegia facialis (and especially mentioned combined facial and abducens paralysis). During this epidemic I have observed in 11 other cases symptoms of paralysis from the cranial nerve in addition to simultaneous poliomyelitis, polyneuritis or polioencephalitis. With nervus facialis this has occurred 5 times, so that the number of cases of infantile paralysis with affection of the facial nerve observed by me amounts to 10. Abducens paralysis has occurred 5 times during this epidemic; twice simultaneously with otherwise common poliomyelitis, once combined with polyneuritis, once in one of the cases which terminated in death, and finally in one case of polioencephalitis. As regards the hypoglossus nerve I have observed in a couple of cases a considerable disturbance of the speech (atactic aphasia); yes, in one case one could see the paralyzed tongue dangle to and fro in the mouth. In

this latter case the child died, and after death a degeneration of the hypoglossus nucleus was observed in the microscope. The same observation was made after the other case of death, even though no symptoms of hypoglossus paralysis were observed during life. The accessorius spinalis nerve has been paralyzed in 3 or 4 cases. Not even the nervi vagi nucleii escape from infantile paralysis. In the 2 cases of death which I observed myself, the children died with symptoms of rapid onset of dyspnea and cyanosis. It is of course possible that these symptoms were caused by the inflammatory degeneration which after death was observed in one of the nucleii of the vagus nerve in each case. However, it is certain that a vagal nucleus may be affected in infantile paralysis. I believe that even the vagal nerve, like other parts of the nervous apparatus, can be affected by a rapidly transient functional disturbance. In one case of poliomyelitis in which the entire body of the child was paralyzed with the exception of one half of the face, the child one day toward the end of the fever stage contracted dyspnea with superficial rapid respiration, 56 breaths per minute, the pulse was small, rapid, 120 per minute. I thought immediately of vagal affection and expected a lethal outcome, but the following day respiration was more calm, 24 per minute, the pulse was 100; even other symptoms showed signs of starting improvement. In one of the sick children, the voice became aphonic; possibly this symptom could be ascribed to paralysis of the vagal recurrent nerve. In this same child, a 5-month-old girl who later died, the masticatory muscles were obviously paralyzed; she could not catch the nipple, nor could she suck, possibly because of trigeminal paralysis.

I was especially surprised by the observed disturbance in innervation of the oculomotoric nerve. The first time I saw these they were of transient nature. They appeared for a few days during the fever stage in a 1-year-old boy as deficient coordination of the movement of the eyes when the child was to focus on an object, furthermore as nystagmus, especially evident in the left eye, and finally as sluggishness in reaction of the left pupil. In the same case the left facial nerve and the left upper arm were paralyzed with the usual symptoms of poliomyelitis. In both of the children who died, disturbances in the oculomotor nerve had been observed: in the one nystagmus and pupils of unequal size, in the other just 2 days before death completely motionless eyes, that is, an ophthalmoplegia externa which obviously can be explained only by paralysis of all the muscles of the eye. Thus from my observations it would appear that probably all the nucleii in medulla oblongata and in pons which morphologically and physiologically are equivalent to the nervous nucleii in the anterior gray horn of the spinal medulla could like these be affected by the disease process. The microscopic slides made by Dr. Rissler completely support these observations made during life.

The polyneuritides earn special attention. All occurred during August through September, that is, simultaneously as many cases of poliomyelitis. Already this suggests a genetic identity between these cases of poliomyelitis and polyneuritis. Leyden, Eisenlohr, Strümpell and probably many others previously thought about such a relationship. During the epidemic discussed here without doubt the same disease seed has caused both poliomyelitis and polyneuritis. In addition to the simultaneous occurrence this relationship is suggested by the fact that the polyneuritis' affected children between 2 and 3 years old, that the children fell ill suddenly with fever, somnolescence and so on, that the fever stage in several respects resembled the usual in poliomyelitis, and that it lasted only a few days. In other respects, however, the symptoms were different. In the poly-

neuritis the children complained about severe pains in the body in general, in the arms, but especially in the lower extremities which were quite tender on palpation. This tenderness stayed even after the fever stage. The passive range of motion was diminished, probably because of the pain. No paralysis occurred in any separate group of muscles of the extremities. In one case the unusual occurred in that motion of the lower extremities, tendon reflexes and so on were restituted which very rarely happens in poliomyelitis anterior acuta. In 3 cases of polyneuritis in which in addition to other symptoms cramps and tremors were observed in the extremities during the fever stage, a pronounced ataxie locomotrice appeared during convalescence, a very uncommon phenomenon in infants. It is true that the uncertain, tottering, atactic gait could be explained by changes in spinal marrow because Dr. Rissler's microscopic examinations have shown that even other parts of the spinal marrow than the anterior horns—in one case the Clarke's columns, in another the posterior horns—may be affected by the disease process. However, it seems to me, less farfetched to explain the atactic phenomenon as directly caused by the polyneuritis. Déjerine ("le nervo-tabes périphérique") and others have proved that this may be the state of the matter.

In the polyneuritis cases no atrophies were observed. The patella reflex and the electric excitability which are so uniformly and always disturbed in the same fashion in the usual poliomyelitis were quite different in the polyneuritis cases. Thus I have seen not only diminished tendon reflexes and partial disturbance of the entartungs reaction (sensibility of a nerve when irritated by the electric current inverse reaction) but even in other cases of polyneuritis, diminished tendon reflexes without such signs. I have also seen lively tendon reflexes and at the same time the entartungs reaction. In a couple of cases, which by the way had much similarity with the polyneuritis cases, some mild spastic symptoms have appeared with lively, even stronger than normal tendon reflexes, and in spite of this a fully developed reaction occurred in one of these cases. These phenomena obviously contradict each other, and I am quite doubtful as to the correct localization in the last-mentioned cases. In polyneuritis, as in poliomyelitis, simultaneous paralysis of the cranial nerves has occurred a few times.

As we know, Strümpell has emphasized regarding the polioencephalitis that polioencephalitis acuta in children probably may develop for the same reason as poliomyelitis. The case of polioencephalitis acuta, in all respects characteristic, but which occurred during the ongoing epidemic of infantile paralysis, gives a beautiful proof for the correctness of Strümpell's contention. That the polioencephalitis was complicated by an abducens paralysis could not seem strange by a comparison with similar symptoms in polyneuritis and poliomyelitis.

Finally, a few words concerning the results of autopsy in two of the children who died in the acute stage. A girl, 3 years and 4 months old, died 6 days after onset of the disease; another, 5 months old, died 5 days after onset of the disease. In the first the following abnormalities were observed: dark viscid blood, small ecchymoses under the pleura and the endocardium, parenchymatous "trübe Schwellung" in the myocardium, in the spleen, in the liver, in the cortical substance of the kidneys, in the solitary follicles and in the Peyer plaques of the bowels, and in the mesenterial glands, changes identical with those in violent acute infectious diseases. In the other case almost exactly the same lesions were observed. From the nervous system hyperemia of the brain was recorded in one case; in the other, hyperemia in the gray substance of the bulb. In both cases hyperemia in the spinal canal was

recorded, hyperemia of the dura with bleeding on top, in the first case hyperemia, swelling, and some dotlike bleedings in the anterior horn of the spinal marrow, especially in the cervical and lumbar tumescence; in the other case, the same, but in addition loosening of the white substance and hyperemia in the posterior horns. Nervus cruralis showed a diffuse reddening of the nerve sheath.

Doctor Rissler has done very beautiful microscopic investigations of the spinal cord in both these cases. I have time only to refer to his work in Nordiskt medicinskt arkiv, XX, nr 22. He has found an intensive acute parenchymatous inflammatory process in the anterior horns with from the very start observable degeneration of the ganglion cells, and with secondary degeneration of the nervous fibers of the association tracts in the "Vorderseitenströngen" and in the anterior nerve root. Rissler confirms Charcot's opinions concerning the pathogenesis of the disease. I have already mentioned that Rissler has found inflammatory and degenerative changes in the hypoglossi, the vagi, the facialis and the abducens nucleii.

Final Statement: The infantile paralysis no doubt is a specific acute infectious disease. It may appear epidemically, as has been shown by some observations during the last decade. Cordier considers this disease to be contagious, but I have not found any certain proof for this opinion, even though I have seen twice how 2 siblings in one and the same family have fallen ill with infantile paralysis within a few days.

My observations have thus demonstrated that it is not only the anterior gray horn of the spinal cord which is affected in this disease. In the acute stage all the organism is affected, as has been shown at autopsy of children who died at this stage. In some cases an at least functional disturbance was widespread in the nervous system during the acute stage. It is true that the main attack involved the gray anterior horns of the spinal cord, but in several cases a similar degree of affection appeared in the peripheral nerves and in the cerebral cortex. Most, probably all, nervus nucleii in medulla and pons may be affected by infantile paralysis as in severe cases in connection with poliomyelitis, polyneuritis and polioencephalitis. However, it has happened even in mild cases as mentioned above.

However different the symptomatology, whatever part of the nervous system that is mainly affected, whether the disease appears as poliomyelitis, as polyneuritis, as monoplegia or as polioencephalitis, all these somewhat differently localized diseases in genetic respect belong to one and the same disease.

As regards treatment, I have nothing of positive value to contribute. Cordier has advised us to separate healthy children from the focus of the disease, if one is apparent, and to isolate the diseased children. If this is necessary or useful, I cannot say. I have tried antipyretic and antiseptic remedies in the fight against the disease in the acute stage, but hitherto without any appreciable effect.



OSCAR MEDIN

Although the effects of poliomyelitis have been known from ancient times the first recognizable case of "infantile paralysis" is that described by Underwood of London in 1784. From that time on, individual cases were reported until Jacob Heine of Constatt in 1840 recognized these cases as variable effects of a single disease process. In 1860 he pointed to the spinal cord as the seat of the lesion. As yet its etiology was unknown.

The first recognized epidemic of the disease occurred in the Scandinavian countries in 1855 and was reported by Bergenholz. However, the first serious epidemiologic study was that of Oscar Medin of Stockholm (1874-1928), who described in detail the Stockholm epidemic of 1887. The influence of Heine and of Medin on the subject was such that for many years at the turn of the century poliomyelitis was known in the literature as Heine-Medin's disease.

The paper here presented is, as far as I know, the first epidemiologic study in the area of orthopaedic interest and became classic in its day. I believe that this is its first translation into English.

CLASSIC 23

On the Influence of Abnormal Parturition, Difficult Labours, Premature Birth, and Asphyxia Neonatorum on the Mental and Physical Condition of the Child, Especially in Relation to Deformities

W. J. LITTLE, M.D. (1810–1894)

Senior-Physician to the London Hospital; Founder of the Royal Orthopaedic Hospital; Visiting-Physician to Asylum For Idiots, Earlswood; etc.

Pathology has gradually taught that the fœtus in utero is subject to similar diseases to those which afflict the economy at later periods of existence. This is especially true if we turn to the study of the special class of abnormal conditions, which are termed deformities. We are acquainted, for example, with abundant instances of deformities arising after birth from disorders of the nervous system-disorders of nutrition, affecting the muscular and osseous structures, disorders from malposition and violence. Each of these classes of deformity has its representative amongst the deformities which originate before birth, viz., congenital clubfoot, congenital rickets, congenital degenerations of muscles, amputations in utero from strangulation by umbilical cord or adventitious bands, intra-uterine fractures, &c.

There is, however, an epoch of existence, viz., the period of birth, during which, at first sight, we might consider that the fœtal organism is subjected to conditions so different to those of its earlier and of its prospective later existence, that any untoward influences applied at this important juncture would affect the economy in a manner different to the influences at work during the periods ordinarily characterised as those of before birth and after birth.

The object of this communication is to show that the act of birth does occasionally imprint upon the nervous and muscular sys-

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tems of the nascent infantile organism very serious and peculiar evils. When we investigate the evils in question, and their causative influences, we find that the same laws of pathology apply to diseases incidental to the act of birth as to those which originate before and after birth. We are, in fact, afforded another illustration that there exists no such thing as exceptional or special pathology.

Thirty-five years ago the pathology of deformities, if not invested with fable, was wrapped in obscurity; it was then scarcely perceived that the materials for extensive inductive observation existed.

Nearly twenty years ago, in a course of lectures published in the 'Lancet,' and more fully in a 'Treatise on Deformities,' published in 1853, I showed that premature birth, difficult labours, mechanical injuries during parturition to head and neck, where life had been saved, convulsions following the act of birth, were apt to be succeeded by a determinate affection of the limbs of the child, which I designated spastic rigidity of the limbs of new-born children, spastic rigidity from asphyxia neonatorum, and assimilated it to the trismus nascentium and the universal spastic rigidity sometimes produced at later periods of existence.

Dugès, Cruveilhier, Smellie, Davis, Evory Kennedy, Doherty, Weber and Hecker, who have described the condition of stillborn children, suspended animation, asphyxia neonatorum and apoplexy of new-born children, are almost entirely silent respecting the after consequences to the infant, when not fatal. The first named is the only one who distinctly enunciates that hemiplegia and idiocy may follow injury received at birth. The others seem quite unaware that abnormal parturition, besides ending in death or recovery, not unfrequently has another termination, *i. e.* in the language of medical writers, has a third termination "in other diseases." My friends, Drs. West, Tyler Smith, and Barnes, have informed me that instances of such a termination of abnormal labour have not fallen under their notice. Dr. Ramsbotham says he can remember two instances. It is obvious that the great majority of apparently stillborn infants, whose lives are saved by the attendant accoucheur, recover unharmed from that condition. I have, however, witnessed so many cases of deformity, mental and physical, traceable to causes operative at birth, that I consider the subject worthy the notice of the Obstetrical Society. In orthopædic practice alone, during about twenty years, I have met with probably two hundred cases of spastic rigidity from this cause. I omit reckoning the subjects of idiot and other asylums, in which probably such cases abound, but of which I have been able to obtain no history. I revert to the subject at the present moment because I believe I am now enabled to form an opinion of the nature of the anatomical lesions and the particular abnormal event at birth on which the symptoms depend. Moreover, as the study of the proximate cause of the affections which I shall describe requires the light of such facts as the members of this Society have peculiar opportunities of supplying, I make no further apology for occupying the Society's time.

Before I describe the mental and physical derangements of the infant which can be referred to the effects of abnormal parturition and asphyxia at birth, I may be permitted to dwell upon the principal phenomena which occur in the fœtal organism immediately before, during, and immediately after, the act of normal parturition.

The fœtus, during the long nine months of its abode in the uterus, has been justly regarded as being plunged into a deep sleep, giving no signs of existence as a semi-independent organism but by an occasional strictly reflex or convulsive movement of the limbs, and the pulsation of its heart during the later months of gestation. The materials for its nutrition, oxygenation of its blood, and the carrying off of the carbon, and prob-

ably of other residues of the metamorphosis of its tissues, being provided for by the intercourse which takes place between its blood and that of the mother at the placenta. With the commencement of normal parturition the long repose of the fœtus is broken in upon. The fœtus, during the uterine contractions, especially after evacuation of liquor amnii, is subjected, together with the placenta and umbilical cord, to a gradually increasing amount of pressure, through which it may reasonably be conjectured that the circulatory system, and consequently the capillary system, as of the lungs and nervous centres, are gradually prepared for the altered offices which are about to devolve upon them. This pressure is at first intermittent, the duration of the period of repose at first greatly exceeding the period of disturbance; as the final exit approaches, the pressure simply remits, until at length it is so considerable that prompt escape from the mother alone prevents mischievous results to the nascent organism. During the uterine contractions a certain amount of impediment to placental respiration or to placental interchange of material is unavoidable, so much of undecarbonized or deteriorated blood is contained in the fœtal tissues—amongst other tissues, in those of the excitor of respiratory acts, the medulla oblongata—as suffices to give notice to the medulla oblongata of the need of inspiratory movements and of the admission of air into the lungs. Hence is explained the first-observed phenomenon of normal, independent, extra-uterine existence, the effectual act of inspiration, accompanied with the welcomed, characteristic, expressive cry of the new-born child. The normal impediment to placental interchange reaches its maximum at the moment of birth. Should any departure from the normal act of birth take place, should the act of normal respiration not be established at the moment of birth, the child presents itself in a state either of manifest death (stillborn), apparently stillborn, or in a state of more or less completely suspended animation, and does not utter the characteristic expressive cry of the new-born child.

The new-born child that has not yet attained to thorough independent existence tolerates a longer duration of suspended animation than the child in which pulmonary respiration has been thoroughly established or than the adult; yet reflection on the nature of a delay of only a few moments in the substitution of pulmonary for the ceased placental respiration would lead to the apprehension that even the want of a few breathings, if not fatal to the economy, many imprint a lasting injury upon it. The observations I have recorded of the direct connection between suspended animation at birth and mental and physical impairment of the individual, prove that the proportion of entire recoveries from the effects of asphyxia neonatorum is smaller than has hitherto been supposed.

It will be acknowledged that the state of things in the fœtus at the moment of birth, at the moment of entire withdrawal of placental or maternal circulatory influence, is one of imminent failure in decarbonization of the blood. If pulmonary respiration be not immediately established, the state of suspended animation—asphyxia neonatorum—takes place. From analogy with other forms of suffocation in later life, as from drowning, when the air-passages are suddenly and forcibly obstructed, suffocation also from inhalation of certain gases which exclude oxygen from the lungs, we may infer that the want of respiration in the new-born child is followed by stagnation of blood in all the large venous channels. We may direct our thoughts to the necessary consequences of blood stagnation in the sinuses of the brain, the venous plexuses surrounding the spinal cord, the venæ cavæ, the right side of heart, and the pulmonary system. We can apprehend the inevitable congestions of the capil-

lary system of the brain and spinal cord, and a prompt result in death, if the mischievous circle of affairs is not relieved by suitable respiration.

The forms of abnormal parturition which I have observed to precede certain mental and physical derangements of the infant consisted of difficult labours, *i. e.* unnatural presentations, tedious labours from rigidity of maternal passages or apertures, instrumental labours, labours in which turning was had recourse to, breech presentations, premature labours, and cases in which the umbilical cord had been entangled around the infant's neck or had fallen down before the head. To these abnormal forms of labour I believe Cases LII and LIII justify me in adding labours in which, from want of due attention immediately after birth or after expulsion from the mother, the child has been partially suffocated in the maternal secretions or under her clothes.

Doubtless in some of the instances I have recorded sufficient mechanical injury to head and neck was inflicted to account for whatever unfavorable consequences, whether these were fatal or not, may have ensued, but the more the facts I shall adduce are studied the more apparent, in my opinion, it will be that a larger proportion of infants, either dead, stillborn, apoplectic, or asphyxiated at birth, have been rendered so by interruption of the proper placental relation of the fœtus to the mother, and non-substitution of pulmonary respiration, than from direct mechanical injury to the brain and spinal cord.

Until quite recently the morbid anatomy of children dead at birth or shortly afterwards had been little recorded. Jadelot ('Traité des Maladies des Enfants de Michael Underwood', 1823, p. 67) says—"We never find effusion of blood, but only very considerable engorgement." Cruveilhier ('Anat. Pathol. sur l'Apoplexie des Nouveaux-nés') and Dr. Evory Kennedy ("On Cerebral Apoplexy of New-born Infants," 'Dublin Journal,' vol. x, p. 425) agree that effusion of blood takes place commonly on the surface or base of brain, never into the substance itself, and that in the majority even of fatal cases only intense turgescence of sinuses and veins, with extreme congestion of the capillary system, are found. Cruveilhier found in all cases the dura mater of spinal canal distended with fluid blood. The fullest contributions to the morbid anatomy of stillborn children have recently been made by C. Hecker, of Berlin, and F. Weber, of Kiel. Hecker (Verhandlungen der Gesellschaft von Geburtskunde,' Berlin, 1853), after quoting Schmidt, Ritgen, Litzmann, and Krahmer, to the effect that children dying at birth or subsequently asphyxiated present numerous dotted, petechiæ-like ecchymoses on the surface of the lungs and diaphragm, gives a large number of his own dissections, proving beyond a doubt that punctiform ecchymoses are present, as a rule, on the serous surfaces of chest and abdomen, sometimes on the skin, besides intense congestion of viscera of chest and abdomen, blood extravasations between pericranium and cranium, the vessels and sinuses of brain gorged with blood, in children born dead, whether from interruption of placental or insufficient pulmonary respiration, *caused by pressure on umbilical cord, premature separation of placenta, and uterine hæmorrhage.* Hecker also found several times *in prematurely born* children, who had lived a longer or shorter time after birth, *similar ecchymoses on surfaces of lungs and heart.*

F. Weber ('Beiträge zur Pathologischen Anatomie der Neugebornen,' Kiel, 1851-54) found laceration of dura mater and effusion of blood between it and the bones, rupture of longitudinal and transverse sinuses of brain and considerable hæmorrhage on the surface and base of brain, sometimes sufficient to envelop cerebellum and oblongata in cases in which mechanical injury to bones of the head had occurred, whether or no

instruments had been used to complete the delivery. But Weber found pretty generally the same tendency to punctated, capillary apoplexies, especially on the serous membranes of lungs, heart, brain, and spinal cord, as were first described by Hecker as a cause of death of new-born infants. The class of lesser injuries uniformly met with in death of child from abnormal labour was, according to Weber, great congestion of all the large veins and sinuses, intense congestion of surfaces of brain and spinal cord. In the spinal cord the small extravasations of blood and the congestion of pia mater were always greatest in the cervical and lumbar portions. Weber rationally accounts for the comparative unfrequency of capillary apoplexy of the brain in these dissections, on the ground that capillary apoplexy is usually recovered from, whilst extravasated blood oftener kills. The sequel will show that capillary apoplexies of the nervous centres are probably the cause of, at least, one form of persistent deformity of limbs—generally spastic rigidity, and that although capillary apoplexy may not commonly destroy life, its consequences seriously impair the organism.

Weber describes an autopsy similar to some of those of Hecker, in which the results of great congestion, apoplexy of the pleura, congestion of brain, bloody serum in ventricles, the cerebellum and medulla oblongata swimming in it, in a case of death through descent of umbilical cord, *no pelvic obstruction having existed.*

The detailed autopsies of Hecker and Weber, with the carefully appended histories of the nature of the fatal impediment at birth, have greatly facilitated an explanation of the spastic rigidity and paralysis of limbs, which appeared from my observations to be produced by so many different forms of unnatural parturition. The dissections of these obstetricians show the important fact that mechanical injury of the fœtal head, neck, or trunk, is not necessary for the production of intense congestion and blood extravasation of serous surfaces of chest, brain, and spinal cord. The other phenomenon commonly observed in difficult and abnormal parturition is that of interruption of placental respiration and circulation with non-substitution of pulmonary breathing and circulation. To this phenomenon alone, when mechanical injury or impediment has not existed, can we attribute the internal congestions, capillary extravasations, serous effusions which correspond with, or produce the symptoms of asphyxia, suspended animation, apoplexy, torpidity, tetanic spasms, convulsions of new-born children, and the spastic rigidity, paralysis, and idiocy subsequently witnessed. I am justified in regarding the dissections of Hecker and Weber as confirmatory of the opinion emitted by me, that asphyxia neonatorum, through resulting injury to nervous centres, is the cause of the commonest contractions which originate at the moment of birth, namely, more or less general sphastic rigidity, and sometimes of paralytic contraction.

The former class of affections may be described as impairment of volition, with tonic rigidity and ultimately structural shortening, in varying degrees, of a few or many of the muscles of the body. Both lower extremities are more or less generally involved. (See plate.) Sometimes the affection of one limb only is observed by the parent, but examination usually shows a smaller degree of affection in the limb supposed to be sound. The contraction in the hips, knees, and ankles, is often considerable. The flexors and adductors of thighs, the flexors of knees, and the gastrocnemii, preponderate. In most cases, after a time, owing to structural shortening of the muscles and of the articular ligaments, and perhaps to some change of form of articular surfaces, the thighs cannot be completely abducted or extended, the knees cannot be straightened, nor can the heels be properly applied to the ground. The upper extremities are sometimes held down by preponderating action of pectorals, teres major and teres

minor, and latissimus dorsi; the elbows are semi-flexed, the wrists partially flexed, pronated, and the fingers incapable of perfect voluntary direction. Sometimes the upper extremities appear unaffected with spasm or want of volition, sometimes a mere awkwardness in using them exists. Not unfrequently the parent reports that the hands were formerly affected. Participation of the muscles of trunk is sometimes shown by the shortened, flattened aspect of pectoral and abdominal surfaces, as compared with the more elongated and rounded form of the back. The prominence of back partially disappears on recumbency, but the greater weakness of muscles on dorsal aspect of trunk is obvious when the individual again attempts to sit upright. The muscles feel harder than natural to the age. Micturition is sometimes observed to be rare, and the bowels usually confined, either from deficient exercise of voluntary expulsive power or from implication of the sphincters. The muscles of speech are commonly involved, varying in degree from inability to utter correctly particular letters up to entire loss of articulating power. Sometimes articulation is only slow and difficult, like other acts of volition, the child or adult reminding us of a tardigrade animal. Sometimes the speech is nervous, impulsive, or stuttering. Often during the earliest months of life deglutition is impaired, and the power of carrying saliva into the fauces is not acquired until late. The intellectual functions are sometimes quite unaffected, but in the majority of cases the intellect suffers—from the slightest impairment which the parent unwillingly acknowledges or fails to perceive up to entire imbecility. The functions of organic life are unexceptionably performed, except, perhaps, that of development of caloric, although the depression of temperature in later life is more probably dependent upon the want of proper exercise. The frame is often lean and wiry, but not wasted. On the contrary, it is generally well nourished. The appetite is good, the child is often described as the healthiest of the family. These subjects often lead a more precarious existence during the first weeks after birth, at first even vegetative existence languishes, sometimes, perhaps, because premature birth or difficult labour, by impairing the maternal supply of nutriment, renders more difficult the infant's recovery from the shock its system received at birth. However, in the majority of instances, after restoration of the vegetative functions, a gradual but slow amelioration of all the functions of animal life is perceived. Some cases present distinct convulsive twitchings of face or limbs during first days after birth, open or suppressed convulsions, opisthotonos, or laryngismus. In some instances the persistent rigidity of muscles commences or is observed shortly after birth, in others it escapes observation until the lapse of some weeks or months. The child's limbs are sometimes reported to have been simply weaker, to have shared in the general debility, the question of viability having alone occupied the attention of the attendants during the first month. Occasionally the weakness of the limbs has been recognised as a genuine paralysis in the first instance, of which the rigidity of muscles has been the sequel. Before the age of three or four months, though sometimes in slight cases not until ordinary time for walking arrives, the nurse perceives that the infant never thoroughly straightens the knees, that these cannot be properly depressed or separated, that she is unable to wash and dress the infant with the ordinary facility, that the hands are not properly used. The upper extremities recover before the lower limbs. Sometimes the trunk is habitually stiffened, so that the infant is turned over in the lap "all of a piece," as the nurse expresses it. Occasionally the head is habitually retracted. Where the symptom of convulsions or "inward convulsions" exists, the rigidity is attributed to the convulsions. In many cases convulsions have been absent. As the child approaches the period

at which the first attempts at standing and progression should be made, it is observed to make no use of the limbs, or he is incapable of standing except on the toes, or the feet are disposed to cross each other. Even children slightly affected rarely "go alone" before three or four years of age, many are unable to raise themselves from the ground at that age, and others do not walk, even indifferently, at puberty. On examination, the surgeon finds that the soles of the feet are not properly applied to the ground, that the knees always incline inwardly, and continue bent. When locomotion is accomplished, the movements are characterised by inability to stand still and balance the body in erect attitude. In the best recoveries from *general* spastic rigidity, even in the adult, the gait is shuffling, stiff; each knee, by forcible spastic rubbing against its fellow, obstructs progression.

The external form of cranium occasionally exhibits departure from the normal or average type, such as general smallness of skull, depression of frontal or occipital region only, sometimes one lateral half of skull, sometimes of one half of occiput, or forehead only. In slight cases the head has been well developed.

In cases even with great inertia as to exercise of volition in any part of the body, common sensibility appears little, if at all, deficient. The child often, indeed, manifests uncommon sensitiveness to external impressions, even when approaching adolescence he is alarmed at trifling noises. The sleep after the first weeks of life is light, easily disturbed. Often there is extreme sensibility to touch, the whole condition reminding the observer of tetanus. In a few cases a distinct resemblance to severe chorea is perceptible. It is probable that some of the cases designated by authors congenital chorea have been cases of the affection I have described.

Amongst the more uncommon consequences of difficult or premature labour and asphyxia, I may refer to Cases XLVIII and XLIX, in which wry-neck apparently resulted from one or other of these causes, and Cases VII, X, XX, and others, in which a distinct hemiplegic contraction resulted. I have occasionally met with the slightest amount of single spastic talipes equinus referable to this cause. Such a case has commonly been attributed to dentition, a fit or illness during infancy, the first link in the pathological chain of nervous susceptibility caused by the asphyxia having been disregarded or overlooked.

A survey of the history of forty-seven cases, appended, shows that one fact is common to all the cases of persistent spastic rigidity of new-born children, namely, that some abnormal circumstance attended the act of parturition, or rather, the several processes concerned in separating the fœtus from the parent and its establishment in the world as an independent being. I cannot recall positively to mind, or find recorded in my journals, more than a single case in which this persistent *spastic* rigidity affected a numerous series of muscles of the trunk and extremities which could be unequivocally referred to any illness subsequent to the establishment of proper pulmonary respiration as its starting-point. Often it has been found that convulsions in infancy had occurred, to which the disease had been attributed. Spastic contraction of a single set of muscles, as the gastrocnemii of one or both limbs, commonly of one limb only, or of the muscles of the forearm and calf on one side, is certainly an everyday occurrence after infantile convulsions, convulsions *during* dentition, and during early childhood without convulsions or other marked illness. But general spastic rigidity I have, with one exception, found to have been preceded by some abnormal act connected with mode of birth. Occasionally several causes, either of which may be competent to produce cerebro-spinal disorder and deformity, may coexist. Thus, in Case XLIII uterine hæmorrhage occurred two months before labour; labour was tedious, accoucheur was absent at birth, the

child was born with navel-string around neck and legs, and did not cry for an hour afterwards, and a large, hard substance, as large as another child—possibly a blasted twin conception—was discharged with the afterbirth. I may remark that asphyxia neonatorum, from whatever amount of disturbance in separation of fœtus from the uterus it may have resulted, is, as might be surmised, very apt to be accompanied with, and to be succeeded by, convulsions at variable periods after birth. It will be borne in mind that convulsions at birth, or subsequently to it, are but a symptom of lesion of nervous centre, and that we cannot refer one symptom of disorder of the nervous system to another symptom of the kind. The convulsions may doubtless react upon the nervous centres, upon the lungs and heart, and probably aggravate the disorder. North ('Practical Observations on the Convulsions of Infants,' 1826, p. 52)—says "It cannot be doubted that convulsions occasionally arise from excessive and long-continued pressure of the head during protracted labour. . . . They generally pass off in a very short time after birth." But he adds, speaking of asphyxia, "If such an infant only partially recover, and convulsions succeed, the death of the child almost inevitably follows." Cases II, IV, XVII, XXII, XXXIV, and XLVI, in Appendix, are instances of recovery from such convulsions, and of production of subsequent spastic rigidity. North quotes Dr. Clark, to the effect that such children, if saved from immediate death, are liable to die suddenly in a fit of convulsions. I have witnessed several confirmations of this statement. Case III is an example of the kind. Baume ('Convulsions dans l'Enfance,' 1805, p. 69) makes a similar observation; and Smellie ('Midwifery,' 1772, vol. i, p. 230) alludes to convulsions before or soon after delivery from compression of head, to the danger, and oftimes the destruction, of the child. Billard ('Diseases of Children,' translation of third French edition, 1839, p. 472), speaking of the morbid anatomy of diseases of cerebro-spinal apparatus developed after birth, says —"The length of the labour, the necessary tractions in certain manœuvres, the difficulty with which respiration is established, the changes which the circulation undergoes, explain why the cerebro-spinal system is so often the seat of sanguineous congestions, varying from simple injection of the meninges to true apoplexy." At page 477 he remarks that in two thirds of the cases of convulsions in new-born children, examined post mortem, spinal meningitis was found; myelitis was less frequently met with. Billard was not aware that cerebro-spinal congestions and apoplexy occur in infants where the labour had not been difficult, tedious, or involved mechanical aid—after descent of and pressure upon umbilical cord only, for example. The Appendix shows that Brachet ('Traité des Convulsions des Enfans,' 1837, p. 97) is too absolute in the statement that "all the infants who are born after difficult and protracted labour are all, without exception, doomed to frequent convulsions."

It is impossible not to connect the persistent affections of the intellect, of volition, and of organic life, with the injury the several nervous centres suffered in some instances before the fœtus had reached the maternal pelvis, in others whilst in transit through it; and in a third set of cases, where the fœtus was exposed to neither of these kinds of injury, it suffered from asphyxia neonatorum, suspended animation, and its concomitant congestions, effusions, capillary apoplexies of brain, medulla oblongata, and spinal cord. Hitherto I have been afforded only one opportunity of learning the post-mortem condition of any of the cases of spastic rigidity which I have referred to asphyxia at birth, viz., Case LX, kindly furnished by my colleague, Dr. Down. It is certain that if, examined after death, after living many years, and such cases I find may live at least past the meridian of life, an anatomical condition very different from that present at or soon after birth would be found. Without going so far as Weber, as

to assert that capillary apoplexies are necessarily absorbed when immediate death does not result from them, we may conclude that although the effused blood-particles may be absorbed, permanent lesion—atrophy of the nervous tissue—results (see Case LX). Possibly a state of chronic meningitis, with effusion, or of chronic meningeal hyperæmia or congestion, or a certain amount of chronic myelitis, may maintain the spastic excitable tetanoid, sometimes choreal contractions, with rigidity of the trunk and extremities. My experience as Physician to the London Hospital has afforded me some facts which support the idea that spinal meningitic and myelitic affections may play a considerable part in the phenomena of spastic rigidity. Thus the only case of persistent general spastic rigidity of upper and lower extremities, commencing after adult age, which I had the opportunity of seeing at intervals during twenty years, and the general appearance of which appeared to me similar in many respects to spastic rigidity from asphyxia neonatorum, was found by me after death to have depended upon chronic spinal meningitis and myelitis. A case related by Cruveilhier, of pus found in medulla spinalis, in a case of death of infant on the fifth day, after difficult labour, supports this view.

The greater or smaller impairment of intellect may safely be attributed to the greater or less mischief inflicted upon the cerebrum. As already observed, the considerable extravasations of blood on the surface of the brain are usually fatal. The autopsy, Case LX, showing cicatrized apoplexies on surface and interior of brain, is an exception. The only fatal instance of partially stillborn infant, which I have had the opportunity of post-mortem examination, was one which came rapidly into the world, preceded by uterine hæmorrhage, nearly at full time, owing to fright to which the mother was exposed. Death of child ensued seventy hours after birth. In this case considerable effusion of blood was discovered in both ventricles of brain—a true apoplexy in the new-born child without mechanical injury. The autopsy, Case XLI, illustrates congestive apoplexy, no pelvic obstruction having existed.

I formerly found much difficulty in the analysis of various symptoms met with in different cases of spastic rigidity traceable to something abnormal in the act of birth. It soon became apparent that the symptoms, *of the living* at least, attributable to mechanical injury of head were a minority of the whole. This is consistent with the remark of Ollivier ('Traité sur les Maladies de la Moelle Epinière,' vol. i, p. 152), that whilst at natural birth the spinal cord is perfectly developed, the brain is still in a very rudimentary state, and consequently able to bear considerable disturbance without ultimate injury to its functions. In fact, in the new-born child brain-life is entirely absent; any injury it may have received at birth is at that period unaccompanied with special brain-symptoms, and, if not too severe, the child may entirely recover. Ollivier says (p. 244) "the brain of the new-born child is often found softened and destroyed without any external sign having permitted the practitioner to suspect it during life." In the present day, with the experience we now possess of the causes of death at or shortly after birth, the accoucheur will suspect the existence of some form of apoplexy in every case.

The severe lesions caused by mechanical compression and laceration, and extensive hæmorrhages within the skull, when they do not destroy life, give rise to permanent deformity of cranium, to atrophy of injured portions of brain, and are the cause of many cases erroneously described as *congenital* idiocy. Dr. J. Crichton Browne ("Psychical Diseases of Early Life," 'Journal of Mental Science,' April, 1860) is one of the few observers who have traced idiocy to difficult labours (see also Dr. Howe, 'Causes of Idiocy,' Edinburgh, 1858). But in addition to the undoubted instances in which cranial injury and some imperfect development of intellect stand in the relation of cause and effect, the Appendix shows impaired intellect

in Cases IV and VIII, in which no mechanical injury had taken place, but in which suspended animation, asphyxia neonatorum, and probably its consequent general and capillary congestion and ecchymoses—capillary apoplexies of the brain as well as of the spinal cord—perhaps even a moderate amount of larger apoplectic extravasation, had taken place, and had been imperfectly recovered from. I have observed that in impaired intellect from abnormal birth the degree of impairment met with in private practice often does not exceed feebleness of intellect; it varies much in degree, as elsewhere mentioned; it is often not sufficient to exclude the individual from family society. The individual may acquire a fair knowledge of music, the memory is good, the constructive tendency may exist, a fair capacity for arithmetic and languages may be displayed, but there commonly exists a great want of application, a slowness of intellect similar to the slowness of volition. In other cases, where intellectual powers are good, a preternatural impulsive nervous condition of mind exists, combined with an agitated, eager, anxious mode of performing acts of volition. Making every allowance for family peculiarities, there undoubtedly exists a considerable pathological resemblance, even in intellectual character and physiognomical expression, in these subjects of more or less general spastic rigidity. The occurrence of this feeble intellect in those who have not been exposed to mechanical injury of head, but in whom premature birth or pressure on umbilical cord has been recorded, appears explicable only on the supposition that the asphyxia and feebleness at birth had been followed by the usual capillary or larger hæmorrhage or effusions in brain, and their transformations and consequences to the nervous tissue; and the degree and variety of impaired function of brain may be due to the degree and variety of situation of these hæmorrhages.

The affections of the functions of organic life, the protracted inability to suck and swallow in a natural way, often observed during the first few weeks of life, the liability to "choking noises in the throat" and other signs of what may be classed under the name laryngismus stridulus, and the affections of speech dependent upon impaired innervation of glottis, pharynx, tongue, and lips, and consequent arrested development of some of these parts (larynx), may be referred to injury at base of brain and medulla oblongata. An occasional choke and gasp for breath, succeeded by a sigh, was described by the nurse of Miss N. (Case XXX) as having continued to the date of the report, when the patient was twelve years old. Occasionally the injury to base of brain or medulla oblongata may have resulted from mechanical displacement of part of the occipital bone, as in some cases described by Dr. J. Marion Sims ('American Journal of Medical Science,' April 1846) under the title of Tetanus of New-born Children; in Case LV of my own in Appendix the injury was consequent upon violent traction exercised to extricate head in breech presentation. But as in the explanation I have given of the causes of impaired intellect in relation to supposed injury to brain at birth, so I can show by reference to Cases IV, VI, XI, XII, and others, in Appendix, that mechanical injury to base of cranium and neck in those who survive is only exceptionally the cause of difficult deglutition, respiration, and speech, but that these important symptoms occur in practice oftenest, in cases in which suspended animation or asphyxia at birth took place without previous violence to head and neck rendering it probable that capillary apoplexy, serous or sanguineous effusion towards base of brain and in and around medulla oblongata, resulted from the general blood-stasis accompanying the asphyxia. Joerg (Kinderkrankheiten,' p. 387) says that immediate death, although the heart continues to pulsate for several minutes after birth, follows mechanical injury, such as stretching or twisting, of cervical vertebrae. Case LV, with which I was favoured by Dr. M'Intyre, of

Odiham, and probably Cases XLVIII, by Mr. Brown, of Camberwell, and XLIX, show that children recover from the immediate consequences of considerable injury in this situation. Dr. Marion Sims (opus cit.) describes, under the head of Trismus nascentium, well-marked instances of spastic rigidity of new-born children. One case was that of a negro, a twin, the second born; labour was tedious, the child stillborn, several minutes having elapsed before respiration was established. Tetanic symptoms were discovered on the sixth day, succeeded by death in ninety-six hours. At the autopsy "coagulum of blood was found occupying the whole length of spine, perfectly enveloping the medulla spinalis, thicker as it approached the brain. Spinal veins full of black blood." Dr. Sims attaches no importance to the tedious labour nor to the asphyxia at birth. Of six cases of trismus of new-born children reported by him incidental mention is made of two of them having ensued after difficult labours. In some later cases of trismus nascentium published by Dr. Sims (opus cit., 1848), either inability to suck or stridulous breathing were observed soon after birth. It appears probable that the usually fatal disorder denominated trismus nascentium is often induced by the same causes—asphyxia at birth, and when recovered from has constituted the early stage of the condition which I have so often met with in older children, and have denominated spastic rigidity from asphyxia at birth. Abercrombie ('Diseases of Children,' sect. iv, Case 150) describes a case of spinal apoplexy of an infant who had been unable to suck and died with trismus and convulsions on the eleventh day. At Case 147 he speaks of hematorachis causing tetanus of new-born child. Weber (opus cit.), in death from trismus nascentium, always found the principal morbid appearances in spinal cord. Dr. Evory Kennedy (On Cerebral Apoplexy of New-born Infants, 'Dublin Journal,' vol. x, p. 429) relates a case of an infant which, after protracted birth and difficulty in establishment of its respiration, was seized on the second day after birth with general convulsions, hands clenched, screaming, abdominal muscles tense, respiration diaphragmatic, death on third day. At the autopsy, the vessels on hemispheres were much loaded, serous fluid abounded in spinal canal. The veins and membranes of medulla oblongata were excessively turgid and congested. Amongst some interesting cases reported by Dr. Doherty ('Dublin Journal,' vol. xxv) of asphyxia of new-born children (a title to which he objects because the individuals have never breathed), are several which I recognise as belonging to the more numerous class of recovered asphyxia cases which present themselves in later life. Thus Dr. Doherty's Case 19, asphyxia of two hours' duration, resulted from prolapse of funis. Fifteen hours after birth convulsions set in; death on the fifth day. At autopsy—infiltration of blood into cellular tissue about dura mater of the cord, dura mater congested, vessels in spinal canal gorged, serous effusion in theca; sinuses of brain distended. *Blood between dura mater and parietal bones.* Dr. Doherty relates another case (Case 4) in which labour lasted three hours, funis expelled before head. Asphyxia reported, "followed by general tendency to spasm," said to have gradually recovered. The case, however, reappears as Case 28 a year afterwards, the child "never having been able since birth to hold up head." Dr. Doherty, however, doubts whether the symptoms were connected with the original transient apoplexy, as he properly designates the primary state. It was doubtless a case of asphyxia from descent of cord before head, accompanied with capillary or more extensive apoplexy or other effusion in nervous centres, followed by debility, paralysis, and spastic rigidity, similar to several of the cases I have appended. (Cases XIX, XLIII, XLV.)

Brachet, the author of the most complete work on the convulsions of children, relates a case of what he designates hereditary convulsions, overlooking the fact, which he inci-

dentally mentions, that the child was semi-asphyxiated for half an hour after birth. He adds (p. 102), "I confess I could discover no exciting cause of the convulsions unless it were that M. Montain, the accoucheur, had been obliged to give the child some slaps on the buttocks to recall it to life." He adds, "Quelque peu de confiance que j'ajoute à ce cause, elle est la seule probable, surtout chez un enfant qui y etat disposé par sa constitution." Brachet also relates (p. 106) the case of a female child coming into the world after the mother had suffered two or three frights. The child's weakness was so great that the child did not cry for a fortnight, and swallowed with difficulty. This was succeeded by "convulsions neophytes de sauvages." She recovered, but he says, "pour la moindre cause elle tressaille et parait menacée de convulsions."

It will be remembered that early in this paper I described this great susceptibility to impressions, almost tetanic, as a common accompaniment of spastic rigidity from asphyxia neonatorum.

Reference to more than fifty case of injury of mind or body from abnormal parturition which are appended, will show that whilst in many cases the subsequent symptoms indicated that the brain and medulla oblongata had permanently suffered, the only one of the nervous centres which invariably presented symptoms of lesion was the medulla spinalis.

If—from analogy with the contractions of limbs observed to follow well-known diseases of spinal cord in later life, and from the fact of capillary apoplexy, larger blood-extravasations, and serous effusions being met with after death in spinal cord of infants who have died still-born from premature birth, descent of funis before head, &c., without mechanical injury to head and neck—I am justified in referring the spastic rigidity which follows asphyxia at birth to lesion of spinal cord, and not to lesion of brain or medulla oblongata, it is obvious, from the greater frequency of this evidence of lesion of spinal cord than of lesion of brain and medulla oblongata, that from some cause this nervous centre suffers most often from the asphyxia, or least frequently recovers its integrity. It seems almost superfluous to add, as a further proof of non-dependence of spastic rigidity of limbs upon mechanical injury at birth, that the lower extremities are oftenest affected and are the slowest to recover, although they derive their nerve-power from the lower part of the spinal column, which is assuredly the part of the cerebro-spinal axis least obnoxious to mechanical injury.

When we consider the intimate pathological connection between spasm and paralysis it is remarkable that these cases of spastic rigidity from asphyxia at birth do not offer a decided combination of spasm and paralysis, such as is observed after ordinary cerebro-spinal disease in childhood. It is common, after such diseases, to find a child with one limb affected with paralysis or paralytic contraction and the opposite limb with spasmodic contraction.

As additional evidence of the dependence of the several states of brain, medulla oblongata, and medulla spinalis upon the asphyxia which so often attends abnormal parturition, I may recall to mind that recovery from asphyxia from choke-damp, asphyxia from suspension, are apt to be followed by cerebro-spinal disease; and I may add that at several autopsies after the asphyxia of Asiatic cholera, I have witnessed small blood-extravasations on serous surfaces of lungs and heart. Experiments of submersion of animals show internal congestion and ecchymoses of serous surfaces as a consequence of that form of suffocation.

Joerg ('Kinderkrankheiten,' 1828, pp. 402—438) is the only author I have met with who distinctly enunciates that too early and unripe-born fœtuses present a state of weakness, persisting in the muscles until puberty or later. He says it interrupts use of muscles during first and second periods of life, as well in limbs as in carriage of head

and trunk, often thereby causing curvatures of spine and legs. Ollivier was aware of the liability of the spinal cord to suffer after difficult labour, for he says (opus cit., p. 240), "The greater influence of the spinal cord at birth appears to continue during the first portion of extra-uterine existence, for affections of the spinal cord and its membranes sont assez communs dans les enfans *naissans*." Ollivier also distinctly attributes the marked injection of membranes of spinal cord in new-born children examined by him to the embarrassment which respiration and circulation undergo at this period of life.

It will be observed that I have in this paper often employed the term asphyxia neonatorum nosologically, in its widest sense, embracing in it all the conditions of suspended animation in the new-born infant which have for their result to prevent the immediate establishment of proper respiration and circulation, whether or no the colour of the infant be pale or dark. It is probable, from analogy with the asphyxias of later life, that the dark colour of the surface is a measure of the embarrassment of the pulmonic and cardiac functions, the pallor indicating greater prostration and greater tendency to cessation of nerve-life and death. D. D. Davis ('Principles and Practice of Obstetric Medicine,' vol. ii, p. 1212) endeavours in vain to establish a difference in in the aspect of the infant, according to whether the state of suspended animation arises from asphyxia, asthenia, or apoplexy. C. A. Struve ('On Physical Education of Children,' translated by Willich, 1800) makes two kinds of apparently still-born, the adynamic and apoplectic. Joerg (opus cit., p. 402) recognises that the suspended animation is sometimes composed of two states, injury (mechanical) to head and want of air. It is apparent that the phenomena of suspended animation of infants after birth will permit of more extended observation by the members of the Obstetrical Society. Davis's view, that three states occur, asphyxia, asthenia, and apoplexy, is doubtless correct. It is, however, evident from that which I have already stated, that it is not yet possible before death to point out upon which of these three conditions the suspended animation depends. The want of breathing is manifest in all cases, asthenia may be present as a complication, and if the suspended animation terminates in death or in cerebro-spinal disorder, we may infer the existence of sanguineous congestions and apoplexies in the nervous centres.

This is the class of cases which, during the "Sensation" times of the promulgation of subcutaneous tenotomy, furnished opportunity to an able French orthopædic surgeon triumphantly to divide sixty or more muscles at one sitting. Happily, Stromeyer's operation of subcutaneous tenotomy rested upon a more secure foundation than could be overthrown by so great an abuse of it.

I trust the views of the pathology of the lesions of mind and body referable to the influence of the act of birth upon the child which I hope to have somewhat unravelled will promote the beneficial treatment of the disorders when detected in the early stages. In the later stages, the general principles of orthopædy, and mental training when the intellect is affected, are successfully applicable in the inverse proportion to the extent of the permanent disorganization of the nervous centres and of peripheral structures. The length to which this paper has already extended prevents my dwelling upon the subject of treatment. I have had many of these cases under observation from one to twenty years, and may mention as an encouragement to other practitioners that treatment based upon physiology and rational therapeutics effects an amelioration surprising to those who have not watched such cases. Many of the most helpless have been restored to considerable activity and enjoyment of life. Even cases which exhibit impaired intellect may be benefited in mind and body to an unexpected extent.

When we reflect on the frequency of pulmonary engorgement and ecchymosis as well

in the interior of the lungs as upon their surface, also the distention of venæ cavæ, the right side of heart, and the ecchymoses on pericardium, in the bodies of still-born children, it will appear not improbable that since one of the members of the tripod of life—the cerebro-spinal system—manifests defects in after-life referable to injury received at birth or to asphyxia neonatorum, in like manner partially still-born infants who recover with atalectasia pulmonum or with strained and injured hearts, may in after-life present anomalous affections of, or be prone to, pulmonary or cardiac disorder.

I would therefore suggest for inquiry, whether, for example, some cases of "congenital" cyanosis may not be induced at birth through impediment at this period to the normal substitution of infantile for the fœtal circulatory route, causing, for example, interruption of development and non-closure of foramen ovale. I am indebted to Mr. Curling for the following case. A youth, æt. 12 years, the second child born of parents not liable to asthmatic or other pulmonary complaints, did not cry immediately at birth, but received several vigorous slaps from the hand of the accoucheur before respiration was established. The child has from an early period of infancy been subject to considerable difficulty of breathing, and to attacks of acute dyspnœa on slightest cause. His asthmatic condition has puzzled several distinguished physicians who have seen him. Refuge has been taken in "*congenital* asthma." May not the starting point of the complaint have been injury to the capillary system or larger vessels of heart and lungs at the moment of birth?

The researches of Weber and Hecker into the morbid anatomy of still-born children testify also that the vascular system of the abdominal viscera undergoes disturbance, causing ecchymosis in those organs from the accidents attending birth.

It is further suggested, therefore, whether some of the ailments in these viscera, occasionally presenting themselves in the earliest periods of life, may not be due to causes similar to those which I have shown undoubtedly influence the cerebro-spinal system and its dependent organs. And lastly, as the general capillary system cannot be independent of that which affects the circulation of the brain, chest, and abdomen, there remains for consideration whether the nutrition and development of the muscles and peripheral nerves are not directly affected, independently of the influence of the nervous centres upon them, by the proved abnormal congestions sometimes accompanying the act of birth.*

Dr. BARNES said, that although not able, from his own observation, to produce any facts in confirmation or negation of Dr. Little's theory, this might be due to his not having studied the subsequent history of children in connexion with the phenomena attending their birth. He was now, however, able to look back upon a considerable number of children who had been born semi-asphyxiated, in consequence of difficulty involving resort to the forceps, or turning. Many of these children he knew were healthy, and did not appear to bear any trace of the difficulties that attended their birth. He had, like most obstetricians, observed that occasionally children born with difficulty were liable to convulsions for a short time; but if these survived, they commonly did well. The difficulty there appeared to be in discussing this excellent paper, arose, no doubt, from the entire novelty and originality of the subject. Dr. Little had brought before the obstetric world new matter for inquiry of the highest interest. It was closely related to the question of the causes of still-birth—a subject, also, of which little was known, at least in this country. One reason was, that there existed

* EDITOR'S NOTE: At this point, the original paper presented 63 brief case reports (24 pages of text) under the covering title of "Abstract of ... of Spastic Rigidity." Space limitations have made it necessary to omit this section. Anyone who desires to refer to this abstract may consult the files of a medical library.

no large lying-in hospitals in England, for there could be no doubt that the lying-in hospitals of the Continent lent greater opportunities for investigations of this kind than existed here. Hence Dr. Little has been obliged to look to German authors for information. He (Dr. Barnes), however, hoped that the study of the causes of still-birth would be more closely prosecuted by post-mortem examinations in this country. There was a case of which Dr. Little might be glad to avail himself. It is recorded of Samuel Johnson that "he was born almost dead, and did not cry for some time." The name of Samuel Johnson was almost synonymous with intellectual grandeur, but he was well known to be affected with certain nervous disorders which Dr. Little could better interpret than the speaker.

Dr. TYLER SMITH expressed the great obligation of the Society to Dr. Little for his valuable paper. There could be no doubt the author had directed attention to an original field of observation in pointing out the injuries to which the nervous system was liable during, and immediately after, birth. Cases of early paralysis and contraction had not fallen under his (Dr. Smith's) observation, but he quite agreed with the possibility of their occurrence from the causes stated. In cases of spasm of the limbs, especially the lower extremities, shortly after birth, he had attributed the condition of the limbs to an excess of the tonic contraction of the muscles natural to the fœtus in utero, and which gradually disappeared under the influence of volition and the use of the limbs. He thought dentition the great source of paraplegia and hemiplegia in young children. The irritation of teething sometimes caused paralysis by exciting convulsions, during which the nervous centres were damaged. At other times reflex paraplegia ensued, without fits, during dentition. These forms of disease were very commonly met with, especially in hospital practice, in children from six months to two years of age. The great point was to prevent these seizures by relieving the irritation of dentition, by timely scarification of the gums, and attention to the secretions.

Dr. GIBB said he was reminded of an instance that came under his observation some years ago, but which, perhaps, hardly came within the same category as those described by the author of the paper. After a lingering labour, a child was born with spastic rigidity of all the muscles on one side of the body; in fact, it was an instance of conjunctive hemiplegia. Suspecting that the cause existed in the brain, he was allowed to make an examination of the body of the infant, and found a clot in the substance of the brain on the side opposite to that on which the hemiplegia existed. The vessels generally were very much congested about the head, and, no doubt, had the child lived, it would have remained palsied. The case was recorded at the time in one of the medical journals.[1]

Dr. LITTLE said he quite agreed with the President that the majority of infantile spastic and paralytic contractions arose between the ages of six months and two years from cerebro-spinal disorders, and that, perhaps, for one that depended on abnormal or premature labour there were twenty or more from other causes incidental to later life. He mentioned that, not having found any reference to the affections consequent on abnormal and premature parturition in the works of English medical writers, he had referred, with some confidence, to Shakespeare, to ascertain whether any notions on the subject were contained in his works. He said, the description of the physical character of Richard III was exactly that of an individual afflicted with one kind of deformity originating at birth.

"I that am curtailed of this fair proportion,
Cheated of feature by dissembling Nature,
Deform'd, unfinish'd, sent before my time
Into this breathing world, scarce half made up,
And that so lamely and unfashionable
That dogs bark at me as I halt by them."

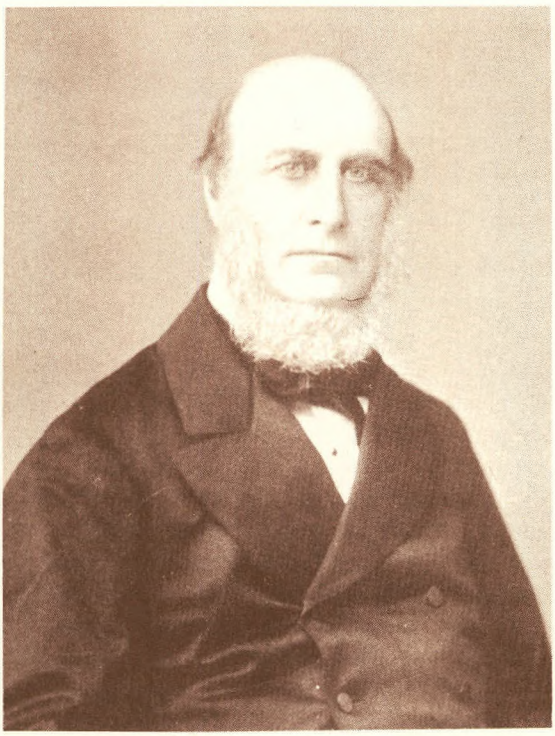
[1] 'Lancet,' Nov. 13th, 1858.

In the following lines Shakespeare has used more poetic licence. The great dramatist has here probably intensified some popular notions on the subject:

"If ever he have child, abortive be it;
Prodigious and untimely brought to light,
Whose ugly and unnatural aspect
May fright the hopeful mother at the view;
And that be heir to his unhappiness."

He was convinced Shakespeare had drawn the first picture from an individual who had suffered through asphyxia at birth. He, probably, was aware of the fact mentioned by Sir Thomas More, that "the Duchess of Gloster had much ado in her travail, he (Richard III) being born the feet forward."

[1] 'Lancet,' Nov. 13th, 1858.



WILLIAM JOHN LITTLE

William John Little of London (1810-1894) a founder of The Royal Orthopaedic Hospital, published this fullsome report in 1862 after some years of studying a then-well-known but little-understood group of deformed and at times mentally retarded children and young adults. Although certain aspects of spastic paralysis had been described in isolated reports before then, this paper became the definitive and classic beginning of all subsequent work in this field. For many years in the orthopaedic and pediatric literature, the type of spastic paralysis with paraplegia of both lower extremities was known as Little's disease.

CLASSIC 24

Cerebral Birth Injuries

Their Orthopaedic Classification and Subsequent Treatment

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The classification of cerebral birth injuries has always been made on a neurological basis. Lesions are described as occurring in various parts of the brain. The mechanism of production of these lesions has had much careful study. The remote causes have been considered and include such factors as prematurity, primiparity, icterus neonatorum, congenital syphilis, dystocia, and obstetrical difficulties. Classifications, distinguishing the actual birth-injury group from congenital anomalies of the nervous system, have been made. All of these studies have aroused the interest and cooperation of the obstetricians in an increased effort to prevent the injuries, in many cases unjustly attributed to them. Nevertheless, children continue to suffer from this type of dyskinaesia, whatever the cause, and treatment must be carried out. An exact definition of the term "cerebral birth injury" would strictly imply only an obstetrical injury, but the late results of many types of disturbance to the child during the last month of pregnancy and the first two or three weeks of life are, in many instances, identical with actual obstetrical damage. Hemorrhage in the cranial cavity, which is the most common cause of the types of dyskinaesia to be described, will produce the same picture, whether or not it is the result of actual obstetrical injury. Therefore as the types of dyskinaesia come naturally to the orthopaedic surgeon for treatment, all being crippled in one way or another, a classification must be made, which can be used as a basis for treatment. Such a classification must be made on a functional basis, and must take into consideration the total function of the individual, rather than that of an arm or leg alone. Total function includes, of course, both mental and physical ability.

Little,[1] in 1862, described these cases first in an article bearing the following title: "On the Influence of Abnormal Parturition, Difficult Labors, Premature Birth, Asphyxia Neonatorum, on the Mental and Physical

Read before the Section of Orthopaedic Surgery, New York Academy of Medicine, January 15, 1932.

Condition of the Child, Especially in Relation to Deformities". For years, Little's disease covered the whole group, of which a typical example was the feeble-minded, drooling child, with scissors gait and marked general spasticity. But further study has shown that there are many physically handicapped types, with or without mental deficiency. These individuals may often be wrongly classified as mentally deficient, because of lack of motor control of the facial muscles, or physical inability to speak or perform the usual intelligence tests. Therefore, it is important to determine the mental level in these cases as accurately as possible, while allowing for the physical handicap. A recent survey of a large feeble-minded institution has shown approximately six per cent with motor disturbance and a definite history of birth injury. It is probable that actual mental deficiency is not present in some of these, but that retardation has resulted from environmental difficulties. Study of mental level evaluation in children showing physical handicaps is showing, more and more, that there is behind the mask of dyskinaesia a trainable mind in a large percentage of the birth-injured.

Confusion in late diagnosis of these conditions is certain to occur because of the many acquired physical handicaps which resembled closely, at first glance, the birth-injury group. It is not sufficient to classify these cases as "spastics" or as "Little's disease". Treatment obviously will be of no avail, even in the group in which the mentality is good, if the lesion is progressive. Many cases of epidemic encephalitis result in a physical handicap which is identical with certain types of birth injury and, if the history is not available, a differential diagnosis is difficult. However, most, if not all, of the postencephalitic group show a progressive picture and observation over a period of time will demonstrate this fact. The same is true of Wilson's disease. Confusion arises also in cases of congenital anomalies of the central nervous system, especially in regard to the diplegic group, described by Ford, Crothers, and Putnam.[2] If there is the slightest tendency toward an asymmetrical distribution, the cases are regarded as probable birth injuries, all other factors being equal. Slowly growing brain neoplasms may also occasionally be confused with birth injuries, but in these cases their progressive nature soon becomes apparent.

Having determined that the intelligence is sufficiently great to make treatment worth while, and that the lesion is static and not progressive, the exact type of dyskinaesia must be studied, in order to carry out a rational form of treatment. Originally, all cases not showing flaccid paralysis, as in poliomy tis, were grouped as spastic. Later, it was seen that some showed a predominance of incoordination and uncontrolled movements, and the group was divided into those with spasticity and those with athetosis. Further study of the motor disturbances demonstrates that there are many varieties of dyskinaesia, which, in order to carry out rational and intelligent the- py, must be distinguished and treated as es.

There are two chief methods of study of these disturbances. In many cases, the movements are too rapid to be caught by the eye, but the use of slow-motion pictures will reveal the difficulty exactly. The second method, which will only be mentioned at this time, is the laborator procedure of oscillographic records of m le-ac curr-ents. Much information can be gained concerning rate of contraction, sequence of contraction, shape of curve, etc. As a result of these two methods, definite entities become observable. These may be considered under five main headings,—namely, (1) Spasticity, (2) Athetosis, (3) Overflow or Synkinaesia, (4) Incoordination or Ataxia, (5) Tremor. It is significant that these practically never appear in pure form, but rather one type will dominate the picture, with evidences of other disturbances present to a lesser degree.

1. *Spasticity*

Spasticity represents a hyperirritability of muscle to any stimulus. Tapping on the patellar tendon produces a markedly increased violence of contraction of the quadriceps. But any stimulus will likewise produce this contraction. Clapping the hands loudly causes sudden response, or any local disturbance of the muscle, such as rubbing or striking. Stretching the muscle is, of course, a distinct stimulus to contraction. This is seen especially on attempted passive motion. The muscles seem to resist the pull, which is clearly the result of the stimulus to contraction caused by the attempted passive motion. The typical disturbance in the spastic individual is thus explained. For example, the patient voluntarily attempts to flex the knee by contracting the hamstrings. The motion of the knee in the direction of flexion tends to stretch the quadriceps extensor. This stimulus causes a contraction of the extensor reflexly. Therefore, the result is a contraction (voluntary) of the flexors, almost simultaneous with a contraction (reflex) of the extensors, resulting either in no motion at all or markedly impeded motion. This mechanism becomes obvious in the slow-motion picture. Spasticity, therefore, is dyskinaesia found in muscles which are hypersensitive to contractile stimuli and in which voluntary contraction of a given group produces reflex contraction in the antagonistic group.

2. *Athetosis*

A study of the literature brings to light an extremely confused picture. Many use the word interchangeably with choreiform movements, incoordination, etc. An attempt to determine this condition as an entity is greatly simplified with slow-motion pictures. It is seen as an involuntary, more or less constant contraction of successive muscles, without regard to function in antagonistic or reciprocal groups. It may be rapid or slow and is not affected by voluntary contraction. When voluntary contraction is willed, it becomes superimposed on the athetoid movement, the result resembling closely other forms of incoordination. Careful observation of the films will show definitely this superimposition. Athetosis, then, can be defined as involuntary motion of unrelated muscles which produces incoordination as a result of superimposed normal voluntary contraction.

3. *Overflow or Synkinaesia*

Overflow represents another separate entity of dyskinaesia. It is involuntary motion resulting from voluntary attempts at motion. It is an example of the difference between neurological and orthopaedic classification. For overflow is often not a pathological neurological entity. Very little is known about it, yet it is very important therapeutically. Overflow is seen as motion of the legs or feet, on attempts at voluntary motion of the hand or arm. It is seen as involuntary motion of the hands on attempted use of the legs. The overflow may be limited to the face on use of either the arms or legs. The degree of overflow varies within wide limits. It is seen in normal individuals occasionally. Sticking out the tongue or grimacing while writing or untying knots represents a more or less normal overflow reaction. The amount of overflow usually increases with the difficulty or complexity of the motion. It may be associated, therefore, with any form of dyskinaesia. Severe facial overflow frequently causes the patient to appear feeble-minded because of the grimaces on attempts to walk or use the arms. It is misleading, especially when it results from voluntary attempts at speech, but it is more important from a therapeutic view-point when it occurs in the arms or legs and interferes with motor control.

4. *Incoordination or Ataxia*

The term has been used to describe so many different entities that it is probably inadvisable to use it unmodified. In the dis-

cussion of athetosis, for example, it was seen that incoordination resulted from the superimposition of normal voluntary efforts upon athetotic motion. This would differ markedly from voluntary incoordination. Voluntary incoordination would be represented by the inability to direct movement in the desired direction. Again, careful observation aided by slow-motion pictures will identify this entity. It is seen in its pure form in the ataxias and is to be distinguished especially from athetosis and overflow. Incoordination, thus resulting when a voluntary effort is made to perform a given motion, may result from a variety of causes, which include loss of muscle sense, loss of equilibrium, etc., or, more rarely, interference with muscle balance of peripheral nerve or muscle origin. Passive incoordination represents such combinations of conditions as result from athetosis and voluntary effort, but can be reduced to more fundamental difficulties.

5. *Tremor*

Tremors can be classed as fine or coarse, and as intentional or non-intentional. There is no confusion concerning this type of dyskinaesia, except in cases of very coarse intention tremor where the condition suggests an incoordination. It can be distinguished, however, by its rhythmical and recurrent nature.

The five above entities or varieties of dyskinaesia are those which are found in birth injuries or in conditions which are likely to be mistaken for birth injuries. Other varieties of disturbance of motor function are usually well defined. Chorea may be mistaken for a fairly rapid athetosis. Choreic motions are spontaneous, involuntary motions, not constant in character but presenting a much more definite pattern than athetosis. These motions are so rapid that they often appear purposeless. If they are slowed down by means of a slow-motion picture, the pattern becomes obvious in nearly all cases. In athetosis this is not true. Habit spasms or tics are not likely to be mistaken for other conditions. Convulsions are usually unmistakable, although in severe cases of athetosis a momentary impression of a convulsion may be given. Decerebrate rigidity needs no comment here.

The five varieties of dyskinaesia described seldom occur in pure form. They are seen combined in various degrees and must be distinguished in every case. The relation to attempted voluntary motion must be carefully studied with the idea of therapy in mind. The aim of the whole orthopaedic study is to supplement the neurological diagnosis in such a way as to determine the practicability and advisability of treatment. It is for the same reason that the orthopaedic surgeon must make, or have made, a careful evaluation of the mental status. This cannot be done successfully without a clear understanding of the physical handicap, involving, as it may, the muscles of speech and face. Of course, many other factors, social and individual, must aid in determining the practicability of treatment, as many years are necessary to bring about satisfactory results and interruptions of treatment during this time frequently cause loss of all previous benefit.

Having completed the study of dyskinaesia, it is necessary, especially in older individuals, to determine the habit factor which is complicating the picture. The ability of these patients to perform their daily routine acts is sometimes extraordinary, but these acts are carried out in bizarre ways which have been stumbled on and which, when repeated, become habits. One patient with only a mild athetosis could only pick up objects from the table with his back to the table. When much younger, he had found that he could do this, and always afterward he repeated it. After a very short period of treatment, he was trained to accomplish this act in the usual way. The result was very great in his general welfare, as he could

eat at a table after this and his social life consequently was much simplified.

The presence of any actual contractures must be determined. In the spastic type, apparent contractures are often mistakenly operated on. The toe-walking due to extreme spasticity of the gastrocnemius-soleus suggests contracture, but, in the examination, care and patience will prove that the foot often may be dorsiflexed the full amount. Real contractures are seen most frequently in the knees, but here again the joint may often be fully extended slowly. The adductors are often tenotomized unnecessarily, thus preventing any normal power of adduction later. The same general principles hold for the arm.

A study of the muscle balance must be made. Hyperactivity of one group is compared to another should be noted for therapeutic reasons. This is most strikingly seen in the abductor-adductor hip antagonists in the spastic group. The "scissors gait" seldom actually represents a contracture, but the power of the adductors, being normally greater than that of the abductors, results in this position when both groups are spastic. It is, therefore, more difficult for these patients to perform abduction than adduction.

TREATMENT

1. *Relaxation. Primary Treatment*

The principles are based on the actual difficulties found in the examination. In the spastic, the hyperirritability of muscles, resulting in almost simultaneous contraction of antagonists, is the important factor. Thus, voluntary relaxation should be one of the first aims. In the athetoid, voluntary relaxation is desirable in order to produce volitional motions later, uncomplicated by athetoid movements. The abolition of synkinaesia or overflow can only result from relaxation as a first principle. In pure incoordination, the principle of relaxation is less important, as is the case with tremors. The ability to relax is important to normal individuals. It relieves tension, mental and physical, and is essential in skilled activities. This is stressed in sport. Golfers are constantly adjured to relax. Skilled musicians must keep the body relaxed while playing. In the birth-injured, its importance is very great, and it can be taught successfully if cooperation can be obtained. In babies and youngsters, relaxation is a more normal finding and here it is taught to be maintained in the presence of more and more disturbing factors. The clap of the hands will throw many of these into spasm, but a process of conditioning will result in much benefit. In older children and adults, of course, it can be taught more directly. This part of the treatment should precede all other forms and should last until relaxation can be instituted at will and maintained at will for a long time. Aids to relaxation should be used with caution and, when used, the reason must be kept clearly in mind. Warm baths, sedatives, etc., are the chief aids. But there is great danger of bringing the patient to depend on these aids and to be unable to relax without them. The whole aim of the treatment is thus vitiated as the relaxation is obtained, but is no longer voluntary. Massage may be of help; it should be tried. In some cases the effect will be beneficial and in others it will be an irritant.

2. *Treatment of the Neck and Trunk*

In patients who cannot stand, sit, or balance, and who have difficulty in holding up the head, general training must be started on the trunk and neck. The head can often be held up more quickly if a Thomas collar is worn for a time and muscle strengthening given daily for the neck. The collar acts to limit the extreme overstretching which results from the head falling in any direction whenever the patient is lifted. Massage and strengthening exercises of the usual type are used for the neck and back muscles, and balance is gradually attained, in the sitting position, by daily practice beginning with assistance. Often the patient will learn to

balance much more quickly while wearing the Thomas collar because of the stabilization afforded the head. The work on the extremities, most of which is done lying down, can be begun simultaneously with the strengthening of the neck and trunk.

3. *Reciprocal Motion. Treatment of the Extremities*

Treatment should always begin with the proximal joints. A highly trained hand or foot is of no use if there is marked dyskinaesia in the shoulder or hip. The work should begin with these joints and extend gradually to the more distal parts. Often a year or more is necessary on the hips and shoulders alone, and at the end of this time very little improvement will be actually apparent. This must be stressed in the treatment, especially to relatives. The length of treatment, of course, is great,—five years usually being the minimum.

As has been seen, the inability to carry out reciprocal motion results from a variety of different causes. In spasticity, it is due to the reflex contraction of the antagonist on attempted voluntary contraction of the protagonist. In athetosis, it is due to the distortion produced by the underlying athetoid motion when a volitional motion is superimposed. In incoordination, it is due to the inability to direct the motion itself, either through loss of joint sense, as in tabes, or loss of equilibrium, as in cerebellar lesions, or through local muscle imbalance. There is less difficulty with reciprocation in overflow or in the various tremors. The reestablishment of reciprocation must depend on an understanding of the particular disturbance in the individual case.

In spasticity, the previous training in relaxation is basic. Then, while in as complete relaxation as possible, minimal passive reciprocal motion may be attempted. These motions should be of very small amplitude and be carried out very slowly, in order not to disturb the relaxation or produce reflex spasm. Later the motion should become active assisted motion. The amplitude should remain small, the rhythm be marked, and the speed of reciprocation slow. No attempt should be made to emphasize the motion in one direction more than another. Thus, if the patient is a spastic and the motion being given is abduction-adduction of the hip, the greatest pull is in the adductors, because of their greater strength. If the motion toward abduction should be emphasized, the tendency to resulting spasm in the adductors will be increased and the treatment vitiated. Therefore, the motion should be balanced in amplitude, speed, and rhythm. Some method of eliminating gravity must be used. The exercises may be given with the patient supine on a polished board, covered with talcum, or they may be given under water. Finally, active reciprocal motion may be begun by the patient himself, when it has been demonstrated that it can be done without spasm. Gradually the amplitude of motion can be increased and, much later, the speed increased. Rhythm must always be kept constant and should be equal in both directions. Passive stretching in spasticity is always entirely useless.

In athetosis, the essentials are somewhat different. Here, the athetoid movements underly essentially normal reciprocation. If the athetosis is pure, the training in reciprocation can proceed more rapidly, but the preliminary training in relaxation will be found to take a much longer time. The work is begun as passive reciprocal motion, carried through active assisted reciprocation to active reciprocation. The amplitude of the motions can be increased more rapidly than in the spastic and the rhythm must be very regular. The speed should only be increased very slowly.

In overflow or synkinaesia, the work is again different. Here, the passive reciprocal motion will be easy, as the overflow only results from attempts at active motion. The treatment, therefore, will emphasize the stage of active assisted reciprocation, and this

phase will be the longest. Here, the amplitude and speed must be extremely slow, as any attempt to hurry will produce a recurrence of the difficulty.

In incoordination of the pure type, the training in reciprocation resembles closely the training for any skilled activity, as in sport. But, again, it should be begun cautiously. If joint-posture sense is absent, then there is no point in passive reciprocation, and training can be begun directly with the active phase. In cerebellar lesions, the passive phase is necessary, but of shorter duration than the assisted and active phases.

In tremors, there is very little to be accomplished when they are of the non-intention type, but, in the intention tremor, reciprocal exercise is often very effective. It should be emphasized again here that these conditions represent static lesions, the progressive ones having been eliminated, and that the attempts at controlling intention tremor are thus more successful.

The conditions described seldom occur in pure form, but one or another predominate in a given case. The reciprocal motion must be given according to the indications of all of the conditions found in the individual under treatment. Thus an athetoid patient with overflow will necessitate taking both of these conditions into consideration. Any element of spasticity seen in an otherwise athetoid patient must also be given special attention according to the principles of the treatment of spasticity. This brief summary of the use of passive, assisted, and active reciprocal motion illustrates the necessity for orthopaedic classification of these patients.

The indications for surgery should never be immediate. A period of training is often productive of surprising results, making certain operative procedures unnecessary. In any case, the procedures should be used only as incidents in, and aids to, the training program. A conservative attitude should be adopted. (a). Tenotomies are usually unnecessary as the results are irreparable. They can occasionally be used to reduce total power where one of a group is tenotomized. For example, the adductor longus, when tenotomized alone, leaves the pectineus, adductor brevis, and adductor magnus to perform the motion. A better balance may be obtained in this way. (b). Tendon lengthening is not usually necessary or advisable, as the muscle will sooner or later contract sufficiently to produce the same deformity. However, it cannot be said that it should never be used. (c). Tendon or muscle-stripping operations are used essentially to give better contractile leverage. Thus, the Soutter operation will decrease the mechanical advantage of the rectus femoris and sartorius, and consequently increase the mechanical advantage of the hip extensors. Training in hip-extension motions may thus be facilitated. (d). Novocain injections of nerve trunks are used occasionally to determine the effect of throwing them temporarily out of function. There may be doubt occasionally about the advisability of alcohol injections or Stoffel operations. A preliminary novocain injection of the nerves in question may be of great help in this determination. (e). Alcohol injections will throw a muscle or group of muscles out of function for a period of months by the paralysis of their motor nerves. This may be desirable in order to facilitate a period of training of the antagonists so that, when power returns to the paralyzed group, a balance can be effected. (f). Stoffel operations are valuable aids to the treatment. These procedures cannot be expected to effect a cure, but, in carefully selected cases, will enable a balance of power to be brought about which results in much greater ease of training. The most common nerves used in this procedure are the branches of the obturator and of the internal or external popliteal. Of course, the procedure may be applied to the nerves of any desired muscles. (g). Sympathetic ramisection has not proven of much value. In those cases showing the "plastic rigidity" described by Hunter and Royle, it is occasionally of

benefit. (h). Tendon transplantations may very occasionally help in improving balance.

4. *Advanced Treatment*

The further treatment, when relaxation and reciprocation have been established, consists of combining motions which have been learned into action patterns. At first, it is wise to combine only two simple motions, such as hip and knee flexion, or bilateral abduction-adduction of the legs, or elbow flexion with supination. As these combinations are learned, more combinations may be added. Motion under weight-bearing gives rise to difficulties due to reflex stimulation of muscles by gravity. Thus, the motions of walking may be learned perfectly lying down and no change in the gait observed in walking. Here, the gravitational effect has not been simulated in the treatment. It can be thus simulated in the treatment by making resistance to the motions while they are being learned and the results are gratifying. The best form of record of improvement is the motion picture record, taken at definite intervals. It is impossible to remember the performance from year to year, but a comparison of films will show the rate of gain, and act as a guide to further treatment.

It may be seen, therefore, that the treatment described is not easy, and that it covers a long period of time. It requires the careful study of the individual from all standpoints, —mental, physical, and social. The cases which are accepted for treatment require very constant care. The treatments should constitute a regular part of the daily routine and the average length of time is an hour a day. The rest of the day, the condition should be forgotten. Patients become "stale" as in too prolonged or constant training for any reason. It is advisable to skip one day a week and to allow about a month's vacation each year. Greater advances will be made by this method. The greatest gains can be made only if these patients are institutionalized. There are very few institutions at present with facilities for handling the mentally normal, birth-injured individuals. It is hoped in the future that more will incorporate these facilities and that more institutions for the care of these patients will be available.

SUMMARY

1. Cerebral birth injuries are described and the handicaps, both physical and mental, classified from an orthopaedic rather than a neurological point of view in order to facilitate therapy.

2. A neurological diagnosis is nevertheless essential in the survey of the patient in order to rule out other conditions which may be progressive.

3. A careful mental capacity evaluation must be made, taking into consideration the physical handicap as an added factor in determining the advisability of treatment.

4. Treatment is briefly outlined for the various types of dyskinaesia.

5. The use of slow-motion pictures is recommended as a great aid in distinguishing the various types of dyskinaesia encountered and as an aid in recording improvement.

6. Slow-motion pictures were shown illustrating the types described and comparative films as used for record.

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WINTHROP MORGAN PHELPS

Winthrop Morgan Phelps (1894-) published this paper on cerebral birth injuries in the *Journal of Bone and Joint Surgery* in 1932, having read it before the Orthopaedic Section of the New York Academy of Medicine in January of that year. At that time, Phelps was professor of orthopaedic surgery at Yale University Medical. He subsequently moved to Baltimore to become the director of the Children's Rehabilitation Center devoted to the care of cerebral palsy patients.

This paper was, in my opinion, the first major classic on the subject since Little's publication of 1862 (see Vol. 46, *Clinical Orthopaedics and Related Research*). Little's contribution was chiefly that of an understanding of its pathology and to some extent its etiology. The classification of its different types, the variability in its etiology and above all the modern approach to management of these cases began with this remarkable paper by Phelps.

CLASSIC 25

Ueber die Verbiegung des Schenkelhalses im Wachstumsalter. Eine neues Krankheitsbild

(On the Deflection of the Femoral Neck in Childhood. A New Syndrome)

ERNST MÜLLER

In this paper I describe an affection of the upper end of the femur of which I have found no notice in the literature. In past years in the Surgical Clinic at Tübingen I have seen and carefully examined increasing numbers of cases, including one autopsy, and besides in individual cases found so closely conforming characteristic features that it seemed proper to describe a special pathologic process.

The course of the affection is as follows: In young individuals from 14 to 18 years there occurs without special cause or the result of any preceding painful trauma of the hip a limp, a weariness and a gradual shortening of the affected limb.

The symptoms develop quite gradually and attain no special intensity that might confine the individual to extended bed rest. The patients are in other respects, except for fortuitous affections, healthy, specifically without evidence of other joint or bone disease.

On objective investigation there is found an absolute shortening of the diseased limb in a manner that shows equal measurements from the trochanter to the external malleolus with the trochanter moved 2 to 3 cm. higher. There is no swelling; instead, with further progress, atrophy sets in. The limb in addition outwardly rotated to a limited degree with some contraction at the hip; movement at the hip, especially flexion is but little diminished, rotation and abduction is somewhat more restricted. The mobility at any rate is so good that one must assume that the head will be found in its socket (observing that the whole appearance of the limb was not that found in a dislocation) and that no serious changes would be found in the joint itself such as a wandering acetabulum due to destruction from caries. In one case an examination was made under anesthesia, and thereby one was convinced that the flexion and the extension which had previously appeared to be somewhat restricted had disappeared and that these movements were completely free and without crepitus, so that the femoral head must be in a healthy joint. Abduction and rotation remained somewhat limited even under anesthesia.

The shortening of the limb depends on the fact that the diaphysis is shifted on the epiphysis so that the angle between the shaft and the neck of the femur is lessened. That

Translated by Edgar M. Bick.

no separation of the epiphyseal line exists is demonstrated by the rotatory restriction of the arc of motion of the greater trochanter. Based on the evidence in the living subject, one must conclude that the symptom complex must lie in the femoral head. A more exact insight into the changes is gained by a specimen of femoral neck and head prepared from a case of resection of the hip joint (S. W. Hauber). The changes in this specimen are quite remarkable, as the sawed cross section of the head and the neck seen in Figure 1 Table V is compared with the adjacent normal femoral neck (Fig. 2). The femoral neck gives the impression of being molded by pressure from above downward. In accordance with this is the circumstance of the neck's being strongly extended in the longitudinal direction. The distance from the tip of the greater trochanter to the line of the cartilaginous articular surface measured point to point is 7 cm., while that of the normal gross specimen measures only 3.5 cm. The superior surface of the neck, after the drop from the tip of the trochanter, follows a horizontal, lightly upward convex curve, while the normal line after the drop (from the tip of the trochanter) follows a concave line to the cartilage border.

The circumstances along the inferior border from the lesser trochanter to the inferior rim of the cartilaginous border are the opposite. This distance in the pathologic specimen amounts to somewhat more than 1½ against nearly 4 cm. in the normal. In the latter the line runs outward in a quite easy convex curve, in the altered specimen; on the other hand, it rises in a less steep direction, thereupon near to the cartilaginous rim it suddenly turns downward until that border is reached.

The cartilaginous joint surface is entirely healthy. The epiphyseal line is clearly seen as a narrow band. A cartilaginous epiphyseal line is no longer present; nevertheless, the border between the epiphysis and the diaphysis is clearly recognized in the arrangement of the bone trabeculae; the network of the diaphyseal trabeculae in the border facing the epiphysis is much finer meshwork than in the adjacent layer of the epiphysis; the trabeculae of the diaphyses are thinner than those in the epiphysis. The border is set fairly sharply and is clearly marked in that the trabeculae along the margin are arranged in a line. The part of the diaphysis adjoining the epiphyseal line differs from the rest of the bone by a more grayish opaque tinge; the width of this tinted layer averages 3 mm. Worthy of note is the course of this border: it forms a sharp convex curve toward the joint surface, giving the epiphysis a distinctly crescent shape, and lies like a cap over the diaphysis; if one draws a line from both end points of the epiphysis in a frontal plane, the greatest distance of this from the epiphyseal line is 1.2 cm. The diaphysis simulates an impacted fracture driven into the epiphysis.

With this changed direction of the femoral neck, the femoral head by its constant relationship to the extremity must accommodate itself to an extreme position of abduction, or rather in a position of abduction that it could not attain in a normal relationship; one can only think that a larger part of the upper extent of the femoral neck was being drawn into the socket.

Therefore, it is easily understood that abduction was restricted even under narcosis.

The inner architecture of the bones changes, corresponding to this altered form. At first the very significant thickening of the Adams' rich arch is striking. The compact bony mass has attained the considerable thickness of 1½ cm. The thickness is the most remarkable along the inferior border of the specimen; that of the superior border of the neck is comparable with the shaft. Toward its upper part it diminishes a bit in circumference suddenly to split into several trabeculae, in contrast with normal bone in which the trabeculae of the cortex quite gradually split off, flowing into the spongiosa. On the surface of the bones the compact substance reaches to the under end of

the epiphyseal line. The compact bone is carried into the marrow spaces in a manner that makes it possible to follow the bone lamellae quite far, so that these appear only as a thick dense arrangement of individual lamellae.

This thickening of Adams' arch is, as an expression of the changing form of the bone, an essential part of the greater load on the inner circumference of the bone.

From this compacta (cortex) a system of bone trabeculae radiates upward and inward separately, thereby differentiating it from the normal in that the individual trabeculae are of considerable thickness and remain distinct in the large marrow spaces. It follows therefore that because of the considerable enlargement of the proximal circumference of the femoral neck, the trabeculae must be distributed over a larger surface.

A further difference in the arrangement of the trabeculae between our specimen and the normal bone is the fact that the most strongly developed trabeculae lie in the neck and the head. In the normal specimen the densest network of trabeculae is drawn from Adams' arch through the inferior medial part of the femoral neck toward the superior periphery of the joint surface of the femoral head. Beyond this strong trabecular network a less dense area lies in the upper and the medial portions of the neck.

In our pathologic specimen it is different. Here the strongest and thickest set of trabeculae is found at the upper and the medial portions of the neck, in the part still covered by the slipped epiphysis but also in its uncovered area. The inferior medial part of the femoral neck, where normally the dense spongiosa lies, a more loosely arranged trabecular system is now found.

This dissimilar distribution of dense and loose trabecular webs corresponds to the demands placed upon them by the weight supported. Normally, the weight falls first on the upper circumference of the femoral head and from this it passes slanting outward and downward through the spongiosa of the femoral head and the lower medial parts of the neck through the cortex of Adams' arch. In our case on the other hand, the lower medial part of the neck does not receive the burden while its superior medial part, still in line with the joint socket, lies in the direction of the greatest pressure.

There is no change in the consistency of the bone and nothing abnormal on the surface of the bone or the joint cartilage, such as hypertrophy, erosion of cartilage or other perceptible evidence.

On microscopic study there is no evidence of specific changes; the bone and the marrow have a normal construction throughout. In the epiphyseal line zone, which macroscopically is distinct by its opacity, cartilage is absent; on the contrary, a large mass of osteoclasts and osteoblasts appears; nothing specific is observed except that a lively metamorphosis of the bone goes on, necessitating that the trabeculae of the head and the neck be continuous. In the trabeculae of the neck osteoclasts and osteoblasts are also seen, but much more scarce than at the epiphyseal line; here the bone has already come to rest, and if not completely so, the trabeculae have adjusted to the new demands which were described above.

If we ask about the process which has taken place in the bone and has led to its deformity, we have a group of bone affections to choose from which could lead to the bending of the femoral neck. The diseases that come to mind are rickets, osteomalacia, osteitis deformans and deformity of the neck following inflammatory softening from an adjacent osseous focus.

Schede and Stahl have observed a deformity of the latter type in a live individual and have described and portrayed a specimen from the Halle collection. In both cases osteomyelitis of the femur was found involving the upper end of the bone. I introduce this only for the sake of completion, since no such inflammatory process appeared in any of our cases.

Also the picture of osteitis deformans de-

scribed by Czerny and by Paget does not apply to our cases. Bending of the femoral neck occurs also in this disease, but this is only a partial aspect of an extensive disease of the skeleton. In osteitis deformans there is increased density and broadening, especially involving the medullary canals of the lower extremity and the skull; the structure of the bones is changed, the canaliculae widened and the cancellous tissues in a state of chronic inflammation; apart from this new bone is deposited. One finds nothing of this in our cases; it is a completely isolated disease of the femoral neck; anatomically, except for the change in shape, no deviation from the normal can be identified in the specimen macroscopically or microscopically. Besides, osteitis deformans in the cases described appears in older individuals mostly on the far side of 40, while in our cases individuals are affected during the years of puberty.

Osteomalacia by the manner of its appearance is also excluded, and so only rickets remains. This cannot be accepted in its usual form but only in a late form, as for example Mikulicz accepted it for genu valgum. But genu valgum in its described clinical process recalls many relationships. If one observes the basic anatomic changes, it may be said that here as in genu valgum, because of a considerable pliancy and softness of the bones, they may be deformed by the high stress of the body weight, that in both instances deformity proceeds from body weight. Both lesions affect patients during puberty, and the lesion affects individuals who are otherwise healthy and well. In both instances, there is a chronic noninflammatory process which after a certain time reaches its end-point and then proceeds no further except to attain complete healing at its final state of deformity. By this similarity of the lesions it might well be believed that both are parallel, and the same pathologic anatomic process could be assumed for both. Miculicz has wisely assumed rickets as the basis for genu valgum. His investigations produced much in favor of rickets, such as the presence of osteoid substance and increased resorption in the bone; from these changes which he described let it appear very probable, though not proved, that indeed rickets is the basis of genu valgum. Our specimen shows no changes that could denote rickets, but it is a process that led to deformity, already run its course leaving nothing recognizable in the specimen. This end-result cannot contradict the hypothesis of rickets, because it is well known that its healed state may leave no disturbance in the finer structure of bone.

That it is rickets which gives rise to the described typical softening and bending of the femoral neck allows no direct proof, but it appears to me that it represents the most plausible explanation with no known facts in contradiction.

Translator's Note. There follows clinical description of four cases: 1, Matilde Faulhaver, age 17, of Gollsdorf; 2, Wendelin Birkle, age 16, of Trillfingen; 3, Friedrich Renz, age 19 of Emmingen; and 4, August Hauber, age 18 of Schopflock. Treatment by present concepts was chiefly observational, and the clinical findings correspond to presently accepted standards.

Slipped Capital Femoral Epiphysis

At various times known as coxa vara, slipped epiphysis, fracture of the epiphysis of the femoral neck, epiphyseolysis and epiphyseolisthesis, the definitive clinical and pathologic description of the lesion of slipped epiphysis was first developed and brought to notice by Ernst Müller of Tübingen in his report published in the then widely read *Beiträge zur klinischen Chirurgie*. To the best of my knowledge this is its first published English translation.

CLASSIC 26 On a Form of Chronic Inflammation of Bones (Osteitis Deformans)

SIR JAMES PAGET, BART., D.C.L., LL.D., F.R.S. (1814–1899)
Consulting Surgeon to St. Bartholomew's Hospital, etc.

I HOPE it will be agreeable to the Society if I make known some of the results of a study of a rare disease of bones.

The patient on whom I was able to study it was a gentleman of good family, whose parents and grandparents lived to old age with apparently sound health, and among whose relatives no disease was known to have prevailed. Especially, gout and rheumatism, I was told, were not known among them; but one of his sisters died with chronic cancer of the breast.

Till 1854, when he was forty-six years old, the patient had no sign of disease, either general or local. He was a tall, thin, well-formed man, father of healthy children, very active in both mind and body. He lived very temperately, could digest, as he said, anything, and slept always soundly.

At forty-six, from no assigned cause, unless it were that he lived in a rather cold and damp place in the North of England, he began to be subject to aching pains in his thighs and legs. They were felt chiefly after active exercise, but were never severe; yet the limbs became less agile or, as he called them, "less serviceable," and after about a year he noticed that his left shin was misshapen. His general health was, however, quite unaffected.

I first saw this gentleman in 1856, when these things had been observed for about two years. Except that he was very grey and looked rather old for his age, he might have been considered as in perfect health. He walked with full strength and power, but somewhat stiffly. His left tibia, especially in its lower half, was broad, and felt nodular and uneven, as if not only itself but its periosteum and the integuments over it were thickened. In a much less degree similar changes could be felt in the lower half of the left femur. This limb was occasionally but never severely painful, and there was no tenderness on pressure. Every function appeared well discharged, except that the urine showed rather frequent deposits of lithates. Regarding the case as one of chronic periostitis, I advised iodide of potassium and Liquor Potassæ; but they did no good.

Three years later I saw the patient with Mr. Stanley. He was in the same good general health, but the left tibia had become larger, and had a well-marked anterior curve, as if lengthened while its ends were held in place by their attachments to the

unchanged fibula. The left femur also was now distinctly enlarged, and felt tuberous at the junction of its upper and middle thirds, and was arched forwards and outwards, so that he could not bring the left knee into contact with the right. There was also some appearance of widening of the left side of the pelvis, the nates on this side being flattened and lowered, and the great trochanter projecting nearly half an inch further from the middle line. The left limb was about a quarter of an inch shorter than the right. The patient believed that the right side of his skull was enlarged, for his hats had become too tight; but the change was not clearly visible.

Notwithstanding these progressive changes, the patient suffered very little; he had lived actively, walking, riding, and engaging in all the usual pursuits of a country gentleman, and, except that his limb was clumsy, he might have been indifferent to it. He had taken various medicines, but none had done any good, and iodine, in whatever form, had always done harm.

In the next seventeen years of his life I rarely saw him, but the story of his disease, of which I often heard, may be briefly told and with few dates, for its progress was nearly uniform and very slow. The left femur and tibia became larger, heavier, and somewhat more curved. Very slowly those of the right limb followed the same course, till they gained very nearly the same size and shape. The limbs thus became nearly symmetrical in their deformity, the curving of the left being only a little more outward than that of the right. At the same time, or later, the knees became gradually bent, and, as if by rigidity of their fibrous tissues, lost much of their natural range and movement.

The skull became gradually larger, so that nearly every year, for many years, his hat, and the helmet that he wore as a member of a Yeomanry Corps needed to be enlarged. In 1844 he wore a shako measuring twenty-two and a half inches inside; in 1876 his hat measured twenty-seven and a quarter inches inside (Pl. I, fig. 4). In its enlargement, however, the head retained its natural shape and, to the last, looked intellectual, though with some exaggeration.

The changes of shape and size in both the limbs and the head were arrested, or increased only imperceptibly, in the last three or four years of life.

The spine very slowly became curved and almost rigid. The whole of the cervical vertebræ and the upper dorsal formed a strong posterior, not angular, curve; and an anterior curve, of similar shape, was formed by the lower dorsal and lumbar vertebræ. The length of the spine thus seemed lessened, and from a height of six feet one inch he sank to about five feet nine inches. At the same time the chest became contracted, narrow, flattened laterally, deep from before backwards, and the movements of the ribs and of the spine were lessened. There was no complete rigidity, as if by union of bones, but all the movements were very restrained, as if by shortening and rigidity of the fibrous connections of the vertebræ and ribs.

The shape and habitual posture of the patient were thus made strange and peculiar. His head was advanced and lowered, so that the neck was very short, and the chin, when he held his head at ease, was more than an inch lower than the top of the sternum.

The short narrow chest suddenly widened into a much shorter and broad abdomen, and the pelvis was wide and low. The arms appeared unnaturally long, and, though the shoulders were very high, the hands hung low down by the thighs and in front of them. Altogether, the attitude in standing looked simian, strangely in contrast with the large head and handsome features.*

* An attitude somewhat similar is given by a rare form of what I suppose to be general chronic rheumatic arthritis of the spine involving its articulations with the ribs. The spine droops and is stiff, the chest is narrow, the ribs scarcely move, the abdomen is low and broad, but there is no deformity of head or limbs.

All the changes of shape and attitude are well shown in sketches from photographs taken six months before death (see Pl. I, figs. 1 to 3). Only the lowering of the necks of the femora is not shown. In measurement after death the axes of the shaft and neck of the right femur formed an angle of only 100° instead of 120° or 125°, and this change of shape added to the appearance of increased width of the pelvis.

But with all these changes in shape and mobility of the head, spine, and lower limbs, the upper limbs remained perfect, and there was no disturbance of the general health.

In 1870, when the disease had existed sixteen years, the left knee-joint was, for a time, actively inflamed and its cavity was distended with fluid. But the inflammation soon subsided, only leaving the joint stiffer and more bent.

About this time some signs of insufficiency of the mitral valve were observed, but the patient now lived so quietly, and moved with so little speed, that this defect gave him no considerable distress.

In December, 1872, sight was partially destroyed by retinal hæmorrhage, first in one eye, then in the other,* and at nearly the same time he began to be somewhat deaf. In the summer of 1874 he had frequent cramps in the legs, and neuralgic pains, which were described as "jumping over all the upper part of the body except the head," but change of air seemed to cure them.

In January, 1876, he began to complain of pain in his left forearm and elbow which, at first, was thought to be neuralgic. But it grew worse, and swelling appeared about the upper third of the radius and increased rapidly, so that, when I saw him in the middle of February, it seemed certain that a firm medullary or osteoid cancerous growth was forming round the radius.

Still the general health was good. Auscultation could detect mitral disease, but the appetite and digestion were unimpaired, the urine was healthy, the mind as clear, patient, and calm as ever. As letters about him at this time said "his general health has been excellent;" "he is free from pain except in the left arm; he sleeps well, enjoys himself, and does not know what a headache is."

After this time, however, together with rapid increase of the growth upon the radius, there were gradual failure of strength and emaciation, and on the 24th of March, after two days of distress with pleural effusion on the right side, he died.

The body was examined five days after death, and showed no marked signs of decomposition. As it lay on a flat board its posture was remarkable, for the head was upraised to the level of the sternum, being supported by the rigid and arched spine, and the lower limbs, with the knees bent and stiff, rested on the heels and nates.

The pericranium, dura mater and all the substance of the brain appeared healthy.

The right pleural cavity contained at least a pint of pale serous fluid, with flakes and strings of inflammatory exudation. The lung was compressed, and in its pleural covering were numerous small nodular masses of pale cancerous substance. The proper pulmonary structure appeared healthy, and so did the left lung and its pleura, except that in the pleura and anterior mediastinum there were many small masses of cancer.

The heart was enlarged but thin-walled. The tricuspid and pulmonary valves and artery were healthy; the mitral valve was opaque, contracted, stiffened with atheromatous and calcareous deposits.

The aortic valves were slightly opaque but pliant, and both in them and in the first part of the aorta were numerous small patches of atheroma.

* Mr. Brudenell Carter saw him in January, 1873, and observed "the right retina sprinkled with small dots of arterial hæmorrhage, chiefly in parts remote from the centre;" and "there was no other change." The left retina was at this time healthy, but in February Dr. Clifford Allbutt found "several little plugs" in its vessels.

The liver and digestive canal and kidneys, examined externally, appeared healthy.

The right femur, the left tibia, the patellæ, and the upper part of the skull, were taken for separate examination, and will be separately described.

In the other bones of the skeleton, except the left radius, no signs of disease appeared externally, but I regret that they were not all more carefully examined, for I think that, at least in the clavicles and pelvis, some changes like those in the long bones of the lower limbs would have been found.

The upper third of the left radius was involved in a large ovoid mass of pale grey and white soft cancerous substance, similar to that of the nodules in the pleuræ and mediastinum, but with growths of bone extending into it. The rest of the radius and the ulna appeared quite healthy.

Some nodules of similar cancerous substance were imbedded in the bones of the vault of the skull.

Microscopic sketches of these structures by Mr. Butlin are appended (Plate II, figs. 1–3).

The curvatures of the spine and its rigidity appeared due to shortening and hardening of its fibrous structures. The vertebræ appeared healthy; there was no appearance of overgrowth or anchylosis among them.

In no part, whether near or far from the diseased bones, was there an indication of any change of structure in skin, muscle, tendon, or fascia; but in the right hip-joint and in the left knee-joint there was some thinning and wasting of articular cartilage, such as one sees in chronic rheumatic arthritis. The other hip- and knee-joints and both ankle-joints were healthy.

In the arteries of the lower limbs there was extensive atheromatous and calcareous degeneration.

The enlargement of the skull may be estimated by comparison of the following measurements:

	Diseased skull.	Average skull.
Circumference at the level of the middle of the temporal fossa	26½ in.	21 in.
From occipital spine to base of nasal bones	15 in.	13¼ in.
From mastoid to mastoid process	18½ in.	15¼ in.

All the sutures, at least all those of the vertex, were obliterated. The outer surface of the upper part of the skull was lowly bossed by the predominant thickening of the hinder part of the parietal bones. The thickness was in every part increased to the extent shown in these following measurements.

In a median vertical section the thickness of the frontal bone was	11—13 lines.
" parietal	14—16 "
" occipital	8—12 "
In a horizontal section, through the middle of the temporal fossa, the thickness of the frontal bone was	8—9 "
" temporal "	6—9 "
" at their junction	2 "
" of the occipital bone was	10—12 "

Comparing these measurements with those of average healthy skulls, it may be said that the bones of the vault of this skull were in every part increased to about four times the normal thickness.

The whole outer surface of the skull-cap was finely porous; in the least changed parts, such as the squamous bone, perforated with innumerable apertures for blood-vessels; in the most changed, finely reticulate, as with delicate cancellous and medullary texture.

The inner surface was comparatively smooth and appeared little changed, except by the enlargement of all channels and apertures for blood-vessels, and especially by the deepening of all the grooves for the middle meningeal artery and its branches.

On the cut surface, in the median vertical section, that which might be regarded as the altered internal table of the skull was a layer, having a very unequal thickness varying from two to six lines, consisting of hard white

bone, close-textured, in some parts porous or finely reticulate, in more looking compact and dense like limestone or white brick (Pl. V).

The rest of the thickness of this part of the skull, representing probably the altered diploë and outer table, was made up of bone in various degrees porous, cancellous, or cavernous, with spaces filled with soft reddish substance, a kind of medulla. Its surface was covered with a very thin layer, a mere coating of more finely porous bone.

In the horizontal section, at the level of the upper part of the squamous bone, the same altered characters were observable, but a larger proportion of the substance of the skull was finely porous or reticulate.

By the cavities in the skull-cap in which cancerous growths were lodged the structure of the bone was neither more nor less altered than in other parts.

A portion of sphenoid bone showed changes of structure very similar to those already described, but with a much more uniform and regular finely porous condition.

The bones of the face were not uncovered, but they showed, neither to sight nor touch, any appearance of disease; not a feature was unnatural.

The conditions of all the long bones were so similar that one description may serve for the altered structure of both femora and tibiæ.*

The periosteum was not visibly changed, not thicker or more than usually adherent.

The outer surface of the walls of the bones was irregularly and finely nodular, as with external deposits or outgrowths of bone, deeply grooved with channels for the larger periosteal blood-vessels, finely but visibly perforated in every part for transmission of the enlarged small vessels. Everything seemed to indicate a greatly increased quantity of blood in the vessels of the bone.†

The medullary structures appeared to the naked eye as little changed as the periosteum. The medullary spaces were filled with soft, yellow, ruddy, and bright crimson medulla, of apparently healthy consistence. The medullary laminæ and cancelli had a normal aspect and arrangement, and in the shafts of the long bones the medullary spaces were not encroached upon.

The compact substance of the bones was, in every part, increased in thickness. Taking, for example, the femur, the thicknesses of its walls and those of a healthy femur of about the same length and age are compared in the following tables.

	Healthy — Lines.	Diseased — Lines.
Thickest parts of the wall . .	3—6	6—10
Articular covering of head, about	¼	3—10
Wall of neck, about	¼—3	4—6
Wall of the trochanter major, about	¼—½	3—5
Articular covering of the condyles, about	¼—⅓	3—5
Lateral walls of the condyles	⅙—¼	2 and more.

Changes in similar proportions were found in the walls of the tibia. In the patellæ the walls were from three to five lines thick.

The thickening of the walls of the shafts of the bones appeared due chiefly to outward expansion and some superficial outgrowth. In some places there were faint appearances of separation of parts of the outer layers of the walls, and of these becoming thick and porous, while the corresponding parts of the inner layers were less changed; but in the greater part of the walls the whole construction of the bone was altered into a hard, porous or finely reticulate substance, like very fine coral. In some places, especially in the walls of the femur, there were small,

* Their changes are shown in Pl. IV. The specimens are in the Museums of the Royal College of Surgeons and of St. Bartholomew's Hospital.

† But see p. 47 in the account of the microscopic examination.

ill-defined patches of pale, dense, and hard bone looking as solid as brick.

In the compact covering of the articular ends of the long bones, and in those of the neck and great trochanter of the femur, and in the patellæ the increase of thickness was due to encroachment on the cancellous texture, as if by filling of its spaces with compact porous, new-formed bone.

Mr. Butlin was so good as to make careful microscopic examination of the diseased bones, and to give me the following report on them, together with the annexed drawings of their minute structure.

"Microscopical examination was made of sections cut from the skull and from the tibia, some of them from the recent bones, but the majority of them from portions of bone deprived of earthy salts and rendered sufficiently soft to be cut with a razor. The appearances observed were essentially the same in both bones, but most of the drawings and description were taken from the tibia, the sections of which were much clearer than those of the skull.

"The examination was conducted from a two-fold point of view: first, to discover the changes which the bone had undergone; second, to discover, if possible, the nature of the process which had led to such changes.

"With a low power the number of Haversian systems and canals in any given section was seen to be much diminished (Plate II, fig. 8; Plate III, fig. 9). The space between the Haversian canals was occupied by ordinary bone-substance, containing numerous lacunæ and canaliculi. The Haversian canals were enormously widened, many of them were confluent, and thus the appearance of a number of communicating medullary spaces was obtained, an appearance which was rendered still more striking by the presence in the canals of a large quantity of ill-developed tissue in addition to the blood-vessels (Plate II, figs. 4—6). With a high power the contents of the Haversian canals were seen to consist generally of a homogeneous or granular basis, containing cells of round or oval form about the size and having much the appearance of leucocytes. Larger nucleated cells were also present, and fibres or fibro-cells, sometimes in considerable quantity. Myeloid cells were occasionally observed, but they were not plentiful; fat also existed in many of the larger spaces, especially in the skull. The vessels were usually small compared with the channels in which they ran; indeed, they did not seem to be much larger than those of normal bone (Plate II, fig. 6). The walls of some of the canals were lined by a single layer of osteoblasts, a condition precisely similar to that observed in the normal ossification of bone in membrane. The presence of new bone was most evident in the periosteum of the tibia, external to the ordinary compact layer of the shaft (Plate II, fig. 7). This external layer was, of course, but thin, and was much softer and less developed than the cortex of the bone from which it sprung; it evidently was not nearly sufficient to account for the great increase in the diameter of the tibia. From the diminution in size of the medullary canal it was thought that a similar recent formation of bone would be found on its outskirts, but this expectation was not justified by observation.

"With a medium power the number of (Plate III, fig. 12) lamellæ surrounding the Haversian canals was easily seen to be not larger than in normal bone, whilst the arrangement of the intervening space was most complex and totally different from that of healthy bone. The lacunæ and canaliculi throughout the sections did not strikingly differ from those of ordinary bone."

I am indebted to Dr. Russell for the following chemical analysis of portions of the diseased skull and tibia, and of a healthy tibia in comparison with them.

	Skull.	Tibia.	Normal tibia.
Inorganic constituents (Ash)	60.59	61.22	63.62
Organic "	39.41	38.78	36.38
Phosphoric acid (P_2O_5) ...	22.76	25.45	25.50
Carbonic " (CO_2) ...	3.59	3.95	3.59
Fat	6.83	3.45	—
Moisture in the sample (dried at 115° C.).....	15.49	11.83	9.73
The CO_2 calculated as calcium carbonate ($CaCO_3$)	8.17	8.99	8.16
The P_2O_5 calculated as calcium phosphate (Ca_32PO_4)	49.70	55.56	55.66
Specific gravity	1.895	1.889	1.886*

* Specific gravity of normal skull 1.990.

Cases of the disease which I have described are so rare that I believe no one has

seen a sufficient number of them to enable him to distinguish this disease, either clinically or anatomically, from some which seem like it. Specimens illustrating it are commonly included under a general name of hyperostosis, osteoporosis, senile rachitis, or the like. But I hope that, if I add to the description I have just given some notes of similar cases which I have seen or found on record, the disease may be so distinguished as to deserve in pathology a separate place and name.

CASE 2.—Some ten years ago I saw a gentleman, between fifty and sixty, very active, tall, thin, and muscular, a master of hounds. For many years before his death he had curvature of the thighs and legs, exactly like that already described, and stooping of the spine. The changes of the limbs were attended with severe pains, which he used to relieve with hard rubbing, but the general health was unimpaired. In the last years of his life the upper part of his right humerus became very large, and as he was riding and suddenly raised his arm the bone broke near the shoulder. The evidence of large tumour now became clear, and I amputated the arm at the shoulder-joint. The tumour was well marked and very vascular medullary cancer investing and infiltrating the upper part of the humerus. The rest of the humerus was healthy, and the fracture, which was just below its neck, was evidently due to muscular force acting on its structures spoiled by the cancerous growth. He died a few days after the operation, but was not examined after death. The similarity of his case with that which I have described is, I think, certain.

CASE 3.—I saw, with the late Dr. Brinton, a gentleman between forty and fifty who may be still living. He was a sturdy and quite healthy man; his tibiæ were curved and enlarged exactly like those in the first case and he had similar pains, but there was more thickening of periosteum and an appearance of more external formation of bone. He was treated with iodide of potassium and many other things as for periostitis, but without avail.

CASE 4.—A case is recorded by Dr. Wilks in the 'Transactions' of the Pathological Society,* and through the kindness of Sir William Gull, whom the patient occasionally consulted, I am enabled to add some facts to those in Dr. Wilks's report, and to show photographic portraits.

A summary of Dr. Wilks's report is that the patient was sixty when he died. Signs of the disease, beginning with pains like those of rheumatism in the legs, were first observed fourteen years before his death. It was soon found that the tibiæ were enlarged, and in subsequent years the cranium and nearly all the bones of the skeleton underwent similar changes. About a year before death the general health began to suffer from the thorax having become implicated in the disease. Gradually the chest became more contracted and at last quite fixed; the breathing became more difficult until at last the respiratory apparatus altogether stopped.

Sir William Gull's notes tell that the patient consulted him when fifty-six years old, and said that he first noticed enlargement in the left tibia when he was forty-five years old; that he had seven brothers well and strong, and was eldest in the family. He complained chiefly of weakness, inability to make exertion, feeling of nervousness with occasional vertigo, shortness of breath, stiffness in neck, hoarseness and feebleness of voice. His general health was good; he was not much troubled with pain anywhere; but had occasional strange sensations about the head, and much cough. His height, when a young man, was five feet three and a half inches, now four feet eleven and a half inches. The urine was normal and of normal colour. The cranium was enlarged and thick-

* Vol. xx, p. 273, 1869.

ened; the clavicles much thickened, as also the long bones; the phalanges and facial bones and perhaps the lower jaw were not altered. The ribs were thick and immovable, as was also the sternum. There was general dulness over the chest on percussion. The respiration was chiefly diaphragmatic.

Less than a year before the patient's death Sir William Gull recorded that he was breathless, and had occasional attacks of mental confusion in which he remarked that he could not understand the sense of words. His voice was hoarse and feeble, and the hyoid bone seemed thickened. The head had continued to enlarge, and he maintained that he was still losing in height. The neck was fixed, and somewhat forward. All the viscera appeared normal. The urine, repeatedly examined, was always found normal, and of normal colour.

The record of the post-mortem examination by Dr. Goodhart leaves no doubt that the disease in this case was the same as that which I have described, and it may be important that this patient also had cancerous disease. "A growth . . . . corresponding to the growth described as epithelioma of the arachnoid surface of dura mater," grew from the inner surface of the dura mater, was as large as a chestnut and made a pit in the brain near the left Sylvian fissure.

The description of the changed structure of the bones, for which I may refer to the 'Pathological Transactions,' seems to me to indicate that the disease was more advanced in the direction of degeneracy than that which I have described, or that it had not been in any degree repaired.

CASE 5.—I owe to Mr. Bryant the opportunity of seeing a similar case which was under his care in Guy's Hospital, and of which Mr. Viney was so good as to give me notes.

The patient was a carpenter, sixty years old, a hard-working married man, and had seven children. When about sixteen years old he had a slight attack of gonorrhœa, but without sores, and no history of syphilis could be learned. When thirty-five years old he received an injury to his pelvis. Shortly after this he had trouble with his bladder, which became much distended; a large quantity of clotted blood was washed out. He lay in bed for this six weeks, and at the end of three months was able to go to work again.

For the last five years he had been troubled with gout in his left great toe. His father suffered from this. The attacks had been short; a few days' rest always sufficed for recovery.

About three years before admission he first felt pains of a shooting description about the tendons of the popliteal space, whenever he straightened his legs. At this time also he first noticed a swelling of the legs, which began at the ankles. These symptoms, without his taking any special notice of them, continued for about a year.

In the last year and a half the tibiæ had become much swollen and curved forwards, and on account of the pain he had in them from standing he had been obliged to give up his regular work. Until admission he did not notice anything wrong with his other bones, but he had lost about half an inch in height.

The tibiæ presented a marked curve forwards. The anterior border of each was rounded to a very marked degree, so that it could not be felt at all distinctly. The right tibia was slightly larger than the left. The inner surface of each measured about four inches at its widest part. The veins above the ankle were in a varicose condition.

The fibulæ were very much enlarged; the femora enlarged in their shafts and bowed outwards. The great trochanter was drawn up to the level of a vertical line drawn from the anterior superior spinous process of the ilium to the horizontal line of the body, instead of being about two and a half inches below this line. The patellæ were little larger than natural.

The bones of the upper extremity were enlarged, but not to so marked a degree as those of the lower. The enlargement was most marked in the humeri and the left was thicker than the right. He could not straighten his arms, probably owing to the enlargement of the olecranon. In the clavicles the natural curves were very much increased and the bones thickened, the left more so than the right. In the scapulæ the spines and acromion processes were very much enlarged.

The chest was slightly flattened from side to side, but moved fairly whilst breathing. The ribs on the right side were slightly larger than those on the left.

There was a general curve backwards from the cervical to the dorsal vertebræ, so that the patient's usual position in bed was with his head bent forwards, and his legs in a semi-extended position.

The bones of the hands and feet did not seem to have shared in the general thickening.

There seemed to be a slight thickening about the external protuberance of the occipital bone, but there was no other evidence of the cranial bones being involved.

The patient had cold perspirations over his legs in the evening. His urine had a specific gravity of 1014, was strongly acid, contained a little albumen but no excess of phosphates.

[Six months later Mr. Bryant told me that this patient's bones were still enlarging, and that there were evidences of enlargement of the skull.]

I have looked for records of cases similar to these in nearly every work that seemed likely to contain them, but in vain. I have found only three cases, and the first two of these are doubtful.

Saucerotte* relates the case of a man who died at forty and in whom all the bones, those of the head, face, orbits, ribs, vertebræ and limbs had begun to enlarge about seven years before death. He increased in weight from 119 livres to 168, wholly from increase of bones; he had rheumatic pains; for a time sleepiness, oppression at the chest, and very small pulse; but these passed-by and he died with some acute illness. No examination was made.

Rullier† tells of a man, aged seventy-eight, who died in the Hôtel Dieu of empyema. He had previously been in good health, and nothing had indicated any derangement of cerebral function. The skull was very large, osteoporotic, and heavy, and, except the lower jaw, all the bones of the face were healthy. The ribs were thicker and larger than usual; the sternum narrow and very thick; the pelvic bones changed like those of the skull. The clavicles were thick, curved, and solid. The other bones were healthy.

Wraný‡ has fully described the condition of the bones in a case of spongy hyperostosis of the skull, pelvis, and left femur, taken from a woman fifty years old, of whom, however, nothing is told but that she died of pyæmia, and that she had "spongy hyperostosis of the skull with atrophy of the facial skeleton, spongy hyperostosis of the vertebral column, pelvis, and left femur, with elongation of the latter bone; kyphoscoliosis of the upper dorsal part of the spine; pelvic abscess; emphysema and œdema of both lungs, abscess of the left; marasmus."

I cannot doubt that this disease was the same as I have here described, and the paper is valuable, both for the many signs indicated in it that the bones softened and yielded to pressure in the early part of the disease, and for the careful comparison of the distortion of the pelvis with the dissimilar distortions in rickets and mollities ossium. The spine was very curved; the chest small and too arched; the whole trunk very short.

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* 'Mélanges de Chirurgie,' Paris, 1801.

† 'Bulletin de l'École de Médecine de Paris,' t. ii, p. 94, 1812.

‡ 'Prager Vierteljahrschrift,' 1867, B. i, p. 79.

From these cases which, though few, are well marked and in some chief points uniform, as well as from a recollection of two more of which I have no notes, I think we may believe that we have to do with a disease of bones of which the following are the most frequent characters:—It begins in middle age or later, is very slow in progress, may continue for many years without influence on the general health, and may give no other trouble than those which are due to the changes of shape, size, and direction of the diseased bones. Even when the skull is hugely thickened, and all its bones exceedingly altered in structure, the mind remains unaffected.

The disease affects most frequently the long bones of the lower extremities and the skull, and is usually symmetrical. The bones enlarge and soften, and those bearing weight yield and become unnaturally curved and misshapen. The spine, whether by yielding to the weight of the overgrown skull, or by change in its own structures, may sink and seem to shorten with greatly increased dorsal and lumbar curves; the pelvis may become wide; the necks of the femora may become nearly horizontal, but the limbs, however misshapen, remain strong and fit to support the trunk.

In its earlier periods, and sometimes through all its course, the disease is attended with pains in the affected bones, pains widely various in severity and variously described as rheumatic, gouty, or neuralgic, not especially nocturnal or periodical. It is not attended with fever. No characteristic conditions of urine or fæces have been found in it. It is not associated with syphilis* or any other known constitutional disease, unless it be cancer.

In three out of the five well-marked cases that I have seen or read-of cancer appeared late in life; a remarkable proportion, possibly not more than might have occurred in accidental coincidences, yet suggesting careful inquiry.†

The bones examined after death show the consequences of an inflammation affecting, in the skull the whole thickness, in the long bones chiefly the compact structure, of their walls, and not only the walls of their shafts but, in a very characteristic manner, those of their articular surfaces.

The changes of structure produced in the earliest periods of the disease have not yet been observed, but it may certainly be believed that they are inflammatory, for the softening is associated with enlargement and with excessive production of imperfectly developed structures, and with increased blood-supply. Whether inflammation in any degree continues to the last, or whether, after many years of progress, any reparative changes ensue, after the manner of a so-called consecutive hardening, is uncertain.

The inflammatory nature of the disease is evident also in the changes of minute structure in the affected bones.‡ On these Mr. Butlin writes,

> "With regard to the nature of the process by which these changes were accomplished, there are probably only three things which could produce so great an increase in the size of a bone, namely, new growth (tumour), hypertrophy, and chronic inflammation.
>
> "The first of these may be at once set aside as out of the question.
>
> "Nor is the second much more probable than the first, for the process is evidently no mere hypertrophy. The whole microscopical architecture of the bone has been altered; the structure appears to have been almost entirely re-

* There has not only been no history of syphilis in any of the cases, but no known syphilitic changes have been observed in any patient.

† See, also, Sandifort, quoted at p. 61; Museum of St. Bartholomew's, ser. i, 111 and 112, sections of a femur, large, curved, porous, with a tumour growing around its shaft; and 49, a hyperostotic skull from a man who died with cancerous disease of the eyeball, heart, and other organs; and Museum of Guy's Hospital, specimens of symmetrical osteoid cancer of the ilia, with cancer of the spine and cranium, associated with hypertrophy of the cranium. Dr. Goodhart was so good as to give me a report of this case.

‡ And this is also the opinion of Wrany, l. c.

moved and laid down afresh on a different plan and in a larger mould.

"Of the three causes chronic inflammation alone remains, and upon examination one or two facts will be found to bear strongly upon the theory of this being essentially an inflammatory disease. Not only the absorption of the old structure which has taken place, but also the manner of this absorption, point to its inflammatory nature. Traces of this are not, of course, always discernible, as the process is almost everywhere far advanced. But still careful observation not uncommonly discovers that the sides of the widened canals, instead of being smooth and even (Plate III, fig. 10), are eaten out in a series of curves or concavities with the production of what are called Howship's lacunæ, so characteristic of inflammation. The tissue contained in the canals, too, almost precisely resembles the tissue found in the spaces of inflamed bones, only differing from it in being generally more fibrillar and less rich in cells, a fact easily to be accounted for by the very long duration of the disease and the general tendency towards organisation which was displayed throughout. The apparent cessation of the process of absorption and the gradual process of repair may be regarded as still further leading towards the same conclusion.

"Further than this the microscopical observations do not extend."

The chemical analysis by Dr. Russell may be regarded as confirming this conclusion. It shows, at least, that there is no such change of composition in the bone as would be expected in any merely degenerative softening.

Holding, then, the disease to be an inflammation of bones, I would suggest that, for brief reference, and for the present, it may be called, after its most striking character, Osteitis deformans. A better name may be given when more is known of it.

It remains that I should point out the distinctions between this disease and the several forms of hyperostosis, osteoporosis, and other diseases among which it has been confused.*

1. Among cases of hyperostosis are included those of simple overgrowth or hypertrophy of bones in adaptation to increase or change of office. The distinction of these from any form of disease is plain enough; they show a mere increase of natural structure.†

2. Scarcely different from these and as easily distinguished are the hyperostoses, best seen in the skull, in which the bones have more than normal thickness, hardness, and weight, and marks of greater vascularity, yet preserve a just relation of their several parts and a scarcely changed structure. They probably illustrate the effects of simple inflammation of bone recovered from.‡

3. A group of hyperostoses consists of those cases in which bones are enlarged in consequence of an increased supply of blood or lymph. Such a case is that recorded by Dr. Day§ in which the bones of a boy's limb with obstructed lymphatics are much longer than those of the sound limb;|| and such are all those in which bones near inflamed joints, or with partial necrosis, or in limbs long hyperæmic, from whatever cause, grow in length and circumference till they considerably surpass the bones of the healthy limb.* These are easily distinguished. They have not signs of disease proper to themselves; they occur in the young alone; they may present a healthy texture, or one only slightly

* Many of the statements here made are derived from the examinations of the collections of diseased bones in the College of Surgeons and St. Bartholomew's Hospital, which I made while writing the catalogues of their pathological museums.

† Mus. Coll. Surg., 379, 380, 2838, 2839, 2842, 2843, &c.

‡ Mus. Coll. Surg., 2840, 2841.

§ 'Transactions of the Clinical Society,' vol. ii, p. 104, 1869.

|| Broca, 'Des Anévrysmes,' 8vo, p. 76, 1856, gives a case of femoral arterio-venous aneurism attended with considerable elongation of the limb.

* I believe these were first described by Mr. Stanley, 'On Diseases of Bones,' p. 20, *et seq.*, and myself, 'Lectures on Surgical Pathology,' p. 64, ed. 3, and in the catalogues already referred to. Langenbeck has published a very interesting paper on them in the 'Berliner Klin. Wochenschrift,' 1869, No. 26. Cases are also cited from Weinlechner, Schott, and Bergmann, in Virchow and Hirsch's 'Jahresbericht für 1869.'

changed as by partaking of the adjacent inflammatory process; and with the exception of the tibia they do not become deformed. The tibia, when it lengthens more than the fibula, is almost compelled to curvature by the fixed unyielding attachment of its ends;† and the curve is usually similar in shape and direction to the curve of the tibia in the osteitis deformans. But there is no other likeness between the two conditions.

4. A very large number of cases of hyperostosis are consequences of inflammations of bone; some of simple inflammation, others of scrofulous, syphilitic, or gouty inflammation. It is not necessary here to distinguish these from each other,‡ but there are sufficient signs for the distinction of all from the osteitis deformans.

It is clear that the summary which I have given of the clinical characters of this osteitis would not tally with that of any case of simple osteitis, such as might ensue in a healthy person after injury, or in the neighbourhood of a sequestrum; and the clinical difference is as complete between it and any case that could justly be regarded as strumous or syphilitic or gouty osteitis.

The anatomical differences are as well marked: chiefly in the facts that in these inflammations the bones do not become curved* (unless in the case of the tibia already explained); that they commonly display much more considerable external periosteal outgrowths or deposits, as if from a greater participation of the periosteum in the inflammatory process; that the rarefied or, it may be, porous structure of the swollen shafts of bones usually shows appearances of separation and expansion of the component layers; that the medullary canals are commonly invaded by the thickening walls, or are as much changed as the walls themselves; that the whole length of a bone-shaft is very rarely affected; and that the thin articular layers of bones are, I believe, never thickened as they are in the osteitis deformans.†

It may be added that it is very improbable that any form or degree of scrofula or syphilis or gout should exist in bones or any other textures for ten or more years without affecting other parts and without impairing the general health. The retention of good general health during many years of localised disease is, indeed, one of the most striking characters of the osteitis deformans. The only parallel known to me is in the rheumatoid or chronic rheumatic arthritis, and the likeness between the two in this respect may suggest that they are nearly related; yet they are not found concurrent. In the case that I have related the amount of chronic rheumatic arthritis was trivial, and (which is more important) in all the records and specimens of the arthritis which I have seen I have not found an instance in which there were any of the morbid changes characteristic of the osteitis.‡

5. There are, I think, only two other diseases, namely, rachitis and osteomalacia, from which it can be necessary to discriminate the osteitis deformans, and the differences between them are very wide. They have scarcely a feature in common except that in all of them the bones bearing weight

† Such curved tibiæ are in the museum of St. Bartholomew's, Nos. A. 3, A. 46.

‡ An attempt to do so is made in the pathological catalogue of the College of Surgeons.

* The absence of curving in bones around sequestra is remarkable, for they are long and often acutely inflamed, and those of the lower limbs are commonly used and bear weight.

† Among the specimens in which these changes may be studied are, in the College Museum, Nos. 3085, 3089, 598, 3090, 3091; in the museum at St. Bartholomew's, A. 1, and ser. i, 56, 132, 138, 196—198.

‡ There is not even any mention of them in Mr. R. Adams's elaborate 'Treatise on Rheumatic Gout,' 1873, 8vo and folio.

become curved or misshapen, and the spine is usually deformed, and the skull may become very thick and porous. But in rachitis the bones are too short, not too long; too small, not too large; and their curvatures are quite unlike those of the osteitis. And in the osteomalacia the walls of the bones become exceedingly thin, wasting with an acute atrophy; and when they yield it is not with regular curving but with angular bending or breaking. By these and many other differences, as well clinical as anatomical, the diagnosis of the osteitis from rachitis and osteomalacia is sufficiently clear. With rachitis it may be judged to have no affinity whatever; with osteomalacia only so much as may exist between a chronic inflammation and an acute atrophy of any part. Yet by one character which all these three diseases have or may have in common, namely, the osteoporosis of the skull, they are constantly confounded in museums, if not in practice, with each other, and with diseases different from them all.

The study of the osteitis deformans led me to learn what I could of the various recorded descriptions of large, thick, and porous skulls often found in museums. Nearly every large museum contains one or more specimens of such skulls whole or in fragments. They are all big, thick, porous, or spongy, with obliterated sutures and wide apertures and grooves for blood-vessels. Very few of these specimens have any life-histories; they are all, in many respects, alike and usually are all named alike. Many of them it may be impossible to name or classify without much better knowledge of them than may now be had, but I believe that among them are the results of several different diseases; and it may save some trouble to future students if I refer to some of the specimens and records which have led me to this belief.

1. Some are examples of the osteitis deformans which I have described.*

2. Some are derived from cases of osteomalacia. Mr. Durham† has written on these, and Mr. Solly's‡ well-known paper gives a good instance of them. In general, I think that these may be distinguished, at least in the recent state, by their softness and lightness; the abundance of soft medulla contained in them, and the comparative brittleness of the bones when dry.

3. Some are from rachitis; they are, unless after recovery and repair, very light, almost friable, and on their surface not porous, but like fine cloth or felt.§ Like these are the skulls of some lions and monkeys which have died young, in confinement, of what is considered rickets. A collection of these skulls and other similarly diseased bones in the college museum|| deserves careful study, especially because of their likeness to the cases included in the next group.¶

4. These are the results of a disease of early life, sometimes even of childhood, in which all the bones of the face as well as those of the cranium are affected, and, it is said, the bones of the limbs. All the affected bones, facial as well as cranial (and herein is a clear ground of diagnosis), become hugely thickened, porous, or reticulate. The whole skull is very large, clumsy, and featureless. Commonly the cranial cavity is diminished.

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* To those already referred to these, I think, may be added: Sandifort, 'Museum Anat. Acad.;' Lugd.-Bat., fol., 1835, vol. i, p. 142, vol. ii, tab. xiii, Skull of a man forty-three years old, with a "fungus" over the left orbit (? a cancerous growth). Other similar skulls are here referred to. Similar specimens are, probably, Nos. 2840 and 2858A in the College Museum; and, more uncertainly, 2841 and 2858, which, perhaps, belong rather to the fifth group.

† 'Guy's Hospital Reports,' ser. iii, vol. x, 1864.

‡ 'Med. Chir. Trans.,' vol. xxvii, p. 435, Mus. Coll. Surg., 395.

§ See Mus. Coll. Surg., 390—394, 2844, and 2857. I believe that Huschke, 'Ueber Craniosclerosis,' 1858, quoted by Virchow, contains facts on the rachitic osteoporoses, but I have not been able to refer to it.

|| Nos. 386—388, 2854—2856, 2855A, &c.

¶ Although bones such as these are not described by Paul Gervais, yet his paper quoted below should be studied on all that relates to hyperostosis in animals.

The orbital and nasal cavities are contracted, the antra are often filled, by the ingrowth of their several walls; the apertures for nerves are narrowed or obliterated.*

Of these cases, which are among those named by Virchow† Leontiasis ossea, the best are related by Ilg‡ and Jadelot.§ Their descriptions are very scanty, yet they give sufficient facts to distinguish the disease by their account of the cerebral symptoms associated with it. In Ilg's case, for example, the patient who died at twenty-seven, after seventeen years' disease, had amaurosis, epilepsy, severe general headache, delirium, convulsive attacks, and at last total deafness, witlessness, difficulty of swallowing, and loss of smell.

5. Some cases, perhaps not different from these, though they have occurred in later life, are those by Schützenberger,|| Otto,¶ and Wraný.**

6. And, lastly, there are cases not so much of thickening of the cranial and facial bones as of enormous bossed and nodular hard bony outgrowths overspreading them or projecting from them. The leading case among these is that published in the 'Transactions' of the Pathological Society by Dr. Murchison,* with a report on the specimens by Mr. De Morgan and Mr. Hulke.† The disease in which the facial more than the cranial bones are affected is clearly distinct from any of the foregoing, or if it be in any way connected with them, especially with those of the fifth group, may be regarded as transitional from them to the exostoses, especially the massive tuberous and bossed ivory exostoses, which grow on or among the bones of the face and skull. The same approach to the character of hard exostoses is shown in the disease of the fibula in Dr. Murchison's case, a section of which, from the museum of the Middlesex Hospital, is now before the Society.

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* Among the casts in the museum at St. Bartholomew's, No. 10, is that of a skull affected with this disease, and in ser. i, 36 are fragments of a bone, which, I think, may be referred to it.

† 'Die krankhaften Geschwülste,' B. 11, 1864-5. I need not say that this contains a very complete account of all forms of overgrowth of bone.

‡ 'Einige Anatomische Beobachtungen,' 4to, Prag, 1821.

§ Quoted by Ilg from Meckel. The best of many accounts of this specimen is given by Paul Gervais, "De l'hyperostose chez l'homme et chez les animaux," in the 'Journal de Zoologie,' t. iv, 1875. He has carefully re-examined the skull and face and described them.

|| 'Gazette Médicale de Strasbourg,' and in Canstatt's 'Jahresbericht für 1856,' B. iii, 34, with references to cases by Breschet and Nélaton.

¶ Otto, 'Neue seltene Beobachtungen,' 4to, 1824, p. 2. Both head and face are affected; the bones are described as, after softening, very hard, dense, and almost ivory-like. Six hyperostotic skulls are mentioned in his 'Neues Verzeichniss der Anat. Sammlung zu Breslau,' 1841.

** Wraný, "Hyperostosis maxillarum," in 'Prager Vierteljahrschrift,' 1867, B. 1, similar affections of the facial and cranial bones, with cerebral symptoms. Doubtful cases by Ribelt are quoted by Ilg, l. c.; Malpighi, 'Opera Posthuma,' 4to, Amstel., 1700, p. 68; Kilian, 'Anat. Unters. über den neunten Hirnnervenpaar,' Pesth, 4to, 1822, p. 133; Quekett, reported by Hewett, 'Medical Times and Gazette,' Sept. 8th, 1855, p. 229.

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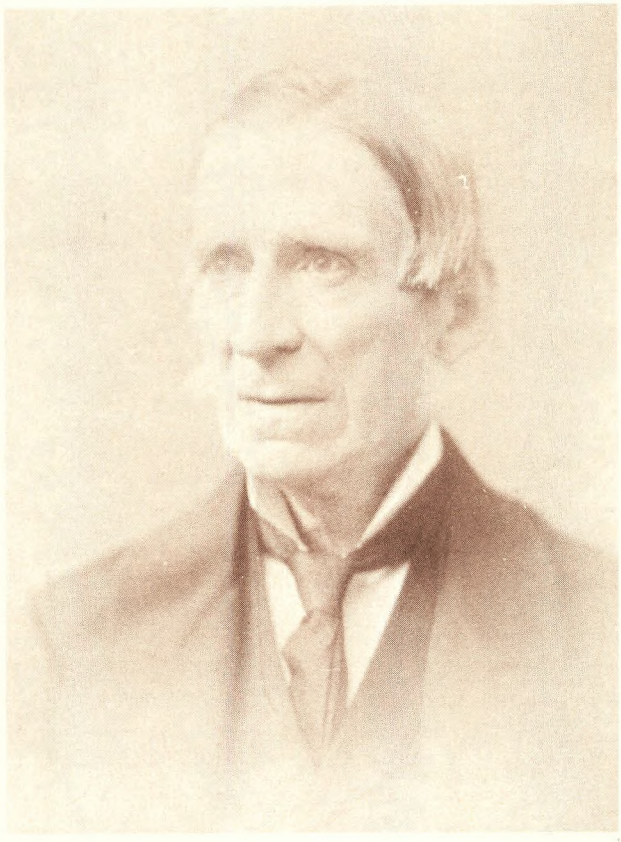
* Vol. xvii, 1866, p. 243.

† Similar cases are illustrated by Forcade, quoted in Virchow's 'Die krankhaften Geschwülste,' B. 2, p. 22; Weber, from a specimen in the Dupuytren Museum, in v. Pitha and Billroth's 'Handbuch,' B. 3, Abth. 1, Lief ii, p. 257; Howship, 'Practical Observations in Surgery and Morbid Anatomy,' 1816, p. 26; Adams in 'Trans. of the Pathological Society,' vol. xxii, p. 204, 1871; Lysthay, in Canstatt's Jahresbericht für 1858;' Mus. Coll. Surg. Eng., 3093. Virchow has a full account of nearly all these cases, and of the analogies of the disease with elephantiasis of soft parts.



SIR JAMES PAGET

Sir James Paget (1814-1899), a graduate of "St. Bart's" of London and with which he was associated throughout his career, was one of the pioneers in a discipline which formed the careers of a large portion of the significant investigators of the 19th and the early 20th centuries—surgical pathology. However, he was of a sufficient surgical stature to have become Sergeant Surgeon to Queen Victoria. Among his most important contributions was his definition of Paget's disease, and there were several other equally as singular. This paper was reprinted 30 years ago in an excellent volume *Medical Classice* (Williams and Wilkins, 1936); but although always referred to, it has not been recalled in orthopaedic literature. The etiology of this disease is as obscure as it was when Paget described it. Some day, in this editor's opinion, it will be related to a systemic and probably pathophysiologic aberation. It merits renewed study.

CLASSIC 27

Die ischaemischen Muskellähmungen und Kontrackturen

(Ischaemic Muscle Paralyses and Contractures)

RICHARD VON VOLKMANN* (1830–1889)

For many years I have noted on occasion, following the use of bandages too tightly applied, the occurrence of paralysis and contraction of the limb, not, as has been previously assumed, due to paralysis of the nerve by pressure, but as a quick and massive disintegration of the contractile substance and the effect of the ensuing reaction and degeneration. The paralysis and contracture are to be understood as purely myogenic.

A series of new experiences has merely confirmed the correctness of this assertion, and also produced certain views about the character of the process here in question. Accordingly, I might summarize my views in the following sentences:

1. The paralyses and contractures appearing after too tight bandaging of the forearm and hand, less frequently in the lower extremity, are to be considered ischemic. They are caused by prolonged blocking of arterial blood. The almost simultaneous occurrence of massive venous stasis manifests itself at the beginning of the paralysis only to accelerate its progress.

2. The paralysis is based upon the fact that the muscle bundles, too long deprived of their acids, become necrotic. The contractile substance coagulates, disintegrates into clumps and will be resolved later. The ensuing contracture is thereby to be understood above all as simply rigor mortis and shows the paralyzed and contracted limb—if as usual the entire musculature of a limb or part of a limb is affected—always in the same position which we find in the limbs of rigor mortis.

3. Characteristically, the paralysis and contracture appear simultaneously or follow immediately after one or the other, while in paralysis of nerve origin in the extremity the contracture develops gradually, and often much later, months and years pass before a deformity develops that cannot be overcome by immediate passive hand-power.

4. On the contrary, ischemic contracture shows its nature from the first moment by the great resistance it opposes to straightening the limb. The affected muscles have already completely and immediately lost their elasticity as in rigor mortis and are completely stiff.

5. The reactive and regenerating processes, always very imperfect in man, fol-

* Translated by Edgar M. Bick.

lowing the disintegration of the contractile substance, make the diseased muscles even more unyielding and further increase the contracture by cicatrization.

6. Ischemic paralysis and contraction of similar character also occur after application of any tight bandage, too long continuation of an Esmarch constriction of the limbs, and also after lacerations and contusions of large vessels, and perhaps also after long periods of severe cold. It is possible that a part of so-called rheumatic contraction is of an ischemic nature.

7. That animal muscle cannot endure complete interruption of its arterial supply for 6 hours without causing a great number of fibers to be destroyed, and that after 6 hours of complete interruption a strong reactive process has already developed has been shown clearly by Kraske in his fine work and is to be considered as the so-called autotransfusion. That until now, as far as I know, no unfavorable experiences have occurred by the use of related procedures, although elastic bandages are left on for hours, not much can be said, since the greater part of this lesion is yet to be investigated. Complete ischemia will never occur after too tightly applied bandages. The greater or lesser subsequent disturbance will depend on how severe the ischemia was and whether a greater or lesser number of fibers were affected. If the ischemia was of considerable extent, alarming symptoms would appear quickly so that the bandage would be removed quickly, although half a day or less could have been enough for a hand and fingers to suffer a dismal permanent crippling. Were the contraction less, and in spite of many repeated complaints about pain, and in spite of edema and cyanosis of finger and toes, the bandage were left on for a week, the result would be a massive loss of muscle and an extensive contracture. Such massive contractures were especially observed after fracture of the radius. The residual mild deformity of the fingers yields but only after a month long continual energetic management.

8. The prognosis of ischemic paralysis and contracture will depend on the number of dead and necrotic fibers. The worse cases in the hand are regarded as absolutely unrecoverable. The prognosis is better in the lower extremities because here the chief symptom, muscle shortening, can be overcome by tenotomy. But even the mild cases, as already indicated, are only improved by energetic and persistent management.

9. Other than mechanical remedies are entirely useless. In recent ischemic contractions one sees that even under chloroform narcosis the greatest strength is required to stretch the shortened and rigid muscles. In fairly old cases this is unsuccessful; one would sooner break the bones and cut the tendons, before the muscles yielded.



RICHARD VON VOLKMANN

Richard von Volkmann (1830-1889) of Leipzig was a leading surgeon whose interests in several areas greatly influenced the development of surgery in Germany during the middle of the 19th century. Among his original contributions was the recognition of ischemic paralysis and its cause. His original paper on the subject is presented here in translation—its first in English, I believe. Although he appears to have noticed it most frequently in fractures of the radius, in more recent decades it has been feared mostly in fractures about the elbow, especially after closed reduction.

CLASSIC 28

Neuritis of the Brachial Plexus Mechanical in Origin

The Scalenus Syndrome

HOWARD C. NAFFZIGER, M.D., F.A.C.S., (1884–1961)

AND

WILLIAM T. GRANT, M.D.

The scalenus syndrome is assuming progressively greater importance in the diagnosis of pain in the upper extremity. The present study is a review of the cases of 18 patients operated on in this clinic during the past 9 years, for complaints suggestive of cervical rib. On x-ray examination, however, these patients had either no evidence at all of cervical rib, or no more than a small outgrowth which of itself was too insignificant to account for the symptoms, or even to require removal at operation. For this group we have applied the term "scalenus syndrome."

In 1903, Bramwell attributed symptoms in such patients to pressure caused by a normal first dorsal rib. Murphy, in 1906, first drew attention to the anterior scalenus muscle as a factor in the production of symptoms arising from cervical rib. He showed that the cervical rib, in carrying the brachial plexus and subclavian artery forward, pressed these structures against the anterior scalenus muscle, and he advanced the idea that this muscle was essential to the production of symptoms.

In 1913, Morley described a case and added supraclavicular tenderness to the list of signs. Two years later, Outland and Clendening reported a similar case but made no significant comments. In 1919, Stopford and Telford reviewed 10 cases and observed that the loss of protopathic sensation was greater than that of epicritic sensation, as had been noted by Charcot in 1892. In treatment, Stopford and Telford removed part of the first rib and divided the anterior scalenus muscle incompletely, with entirely satisfactory results. In the following year Wheeler reported 2 cases treated successfully by resection of the first rib. In 1921, Bramwell and Dykes published a study of 23 patients with the clinical picture of cervical rib. At least 6, however, had no such supernumerary rib. Tenderness usually was present over the seventh cervical transverse process.

Brickner and Milch reviewed the literature in 1925, and added 1 case. They found references to the condition by Hvoslef, Szawicki, and Clerc. Hvoslef thought that

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there was an abnormal connection between the first and second ribs in his patient. Szawicki had 1 case. Clerc observed an abnormal scalenus medius muscle in his patient. The following year, Henry and Handousa recorded the case of a young patient who suffered "gangrene of the fingers" of the left hand while sleeping on the left side. The pulse was absent in the arm, but returned 30 seconds after the arm was elevated. No cervical rib was present.

In 1927, Adson and Coffey pointed out that, since the scalenus anticus muscle played an essential rôle in the compression of the brachial plexus and subclavian artery against the cervical rib, simple section of this muscle should effect a cure. To prove this, they reported on a series of patients who had been so treated with results as satisfactory as those formerly obtained by the more extensive operation of removing the rib. In a second article, Brickner added 6 cases and stressed the fact that, in the operative treatment, the anterior scalenus muscle should be sectioned in order to remove all pressure from the brachial plexus. Stiles, in 1929, advised section of the lower end of the scalenus medius muscle and the anterior portion of the first rib. Puusepp, reporting a case in 1931, considered the point of compression of the brachial plexus to be in the "costo-interscalene trigone," formed by the first rib, and scalenus anterior and scalenus medius muscles. His patient had an ipsolateral Horner's syndrome. For treatment, he advised section of the anterior scalenus muscle. In 1935, Ochsner reported 6 cases of scalenus syndrome of the type in which we have been especially interested. The following year, Wartenberg covered most of the German literature bearing on the subject. He included the scalenus syndrome in the large group of factors responsible for "brachialgia statica paraesthetica" and quoted Gaupp who, in 1894, said that there might be some angulation of the brachial plexus between the clavicle and the first rib. Braus suggested, in 1921, the possibility of compression between these two structures. In 1936 also, Flothow recorded 2 cases in which cervical ribs were present and 2 in which they were not, although all the patients had the same symptoms. In the 2 without cervical rib, section of the anterior scalenus muscle resulted in complete relief. In 1937, Craig and Knepper reviewed 6 cases of the scalenus syndrome and, in the same year, Henschen and Heusser reported 2 cases and discussed the operative treatment.

In the literature to date are the reports of 51 patients who had symptoms of cervical rib, but in whom this anomaly was not found.

Many persons with cervical ribs are free from symptoms until some time in adult life, and many carry these anomalies throughout life without symptoms. These accessory ribs vary greatly in size and in length. When they spring from the seventh cervical vertebra and are of sufficient length—5 centimeters or more—they pass forward beneath the lower cord of the brachial plexus and the subclavian artery. When ribs of this size are present, it has been our experience that simple section of the scalenus anticus will not suffice to relieve all of these patients of their symptoms, but that resection of the rib is also necessary. It has become apparent that, in the patients with symptoms from large cervical ribs and in those included as presenting the scalenus syndrome, similar factors may be concerned in the appearance of symptoms. All of them contribute to the mechanism that eventually causes undue pressure on the brachial plexus. Among them are points of embryological, anatomical, developmental, and occupational interest.

In the embryo, the arm-bud appears with its axis of growth at the level of the seventh cervical segment, but several segments are included. In time, the longitudinal growth

exceeds the transverse growth of the bud, so that the nerves which pass into it tend to converge from above and below. It has long been known that some variation in the position of the limb-buds relative to the body segments occurs. A prefixed plexus is one with a more cephalic innervation, while a postfixed plexus has a larger contribution from lower roots such as the second thoracic. The variation in the position of the developing limb-buds thus determines the variation in the nerves which supply them, the prefixed plexus having a larger contribution from the fourth cervical segment. The lowest trunk of the brachial plexus is composed of the eighth cervical and first and second thoracic roots. With a postfixed plexus, these large contributions to the brachial plexus pass more obliquely upward to cross the first rib, or the cervical rib if such is present, before they turn downward to pass into the arm. It is much easier, because of their course, for them to be subjected to angulation, tension, and stretching. In the embryo, the elements of the nervous system are larger than the mesoblastic masses which later develop into ribs, and the neural elements affect the growth and form of these. The grooves which appear in bones and correspond with the course of nerves bear evidence of such a sequence of development. These are seen on the upper surface of the first rib and in the upper arm in the groove for the musculospiral nerve.

Anatomically, the lower roots of the brachial plexus and the subclavian artery arch upward and over the upper portion of the rib cage where they may be angulated abruptly. In addition to this angulation, these structures pass slightly forward, so that the scalenus anticus restrains them and holds them in a more dorsal position than they otherwise would assume. The anatomical relationships vary not only in different persons, but in the same person, depending upon posture and other factors, among which are the relationships of the position of the shoulder girdle to that of the thoracic cage.

Developmentally, in infants and children the relative position of the shoulder is high, but later, at puberty, a gradual descent occurs to the adult position. In the female the descent is greater, and the ultimate position of the shoulder is more sloping. This suggests a relationship between position and the greater incidence of the symptoms of cervical rib in women, and offers an explanation for the rarity of symptoms before adolescence.

The continued carrying of weights on the shoulder, as in hod carriers and soldiers, may be the immediate and exciting cause of symptoms. Loss of muscular tone and the drooping of the shoulders as seen in the aged, are other possibilities. The relative positions of the shoulder girdle and the rib cage are important, as indicated by the fact that deep inspiration and raising of the rib cage may cause an alteration in the pulse on the affected side, together with a change in blood pressure. Such an inequality between the two sides disappears when the arms are elevated. Many patients who have symptoms suggestive of tension on the brachial plexus have found that resting the elbow on the arm of a chair and leaning toward it so that the arm is supported, or resting the arm on a nearby table, or supporting it in a sling, or lifting the extremity by placing the other hand under the elbow, gives relief.

In this study, the records of 18 patients were reviewed. Twelve had no evidence of cervical rib; in 6 very small ribs were present, but were not seen at operation.

CASE REPORTS

CASE 1. Mrs. M. C., 40 years of age, entered the hospital on June 4, 1929, complaining of aching pain in the right shoulder and arm, of 5 years' duration. This pain spread over the outer surface of the upper part of the arm and the inner surface of the forearm to the right fourth

and fifth fingers. One year before her admission to the hospital, the pain gave place to a feeling of numbness and occasionally of prickling, in the same area. The pain had always been worse when the patient lay on the right side, or on exposure to cold which caused the right hand to cramp in a claw position. For 2 years she had noticed a gradual wasting of the thenar eminence, more rapidly progressive during the year prior to admission. With this there had been great weakness of the thumb and first two fingers, without sensory disturbance. More recently, she had observed weakness and wasting of the right forearm.

Examination corroborated the patient's observations. In addition, there was a small area of diminished sensation to all forms of stimulation over the thenar eminence medially. The sensory loss was greatest in the area supplied by the right ulnar nerve. There was pronounced weakness of the muscles supplied by this nerve, less evident weakness of those supplied by the median nerve, and no apparent weakness in the muscles supplied by the radial nerve. The right arm was colder than the left. The blood pressure on the right was 105/80 and on the left, 120/80. The head was held deviated to the left. In the right supraclavicular fossa, firm pressure over the insertion of the scalenus anticus muscle caused considerable local pain and reproduced the tingling in the arm. Forcible turning of the head to the same side, hyperextension of the neck, or depression of the right shoulder caused an exacerbation of her symptoms. It did not, however, produce a fall in the right radial blood pressure.

On June 5, 1929, the right scalenus anticus muscle was exposed. It was under tension and exerted great pressure on the underlying subclavian artery which was forced back against the right brachial plexus. On dividing the muscle close to its insertion on the first rib, the subclavian artery bulged forward and the brachial plexus behind it was no longer tense. Three days after operation the right arm was much stronger and, objectively, felt as warm as the other. The blood pressure was then 110/80 in the right arm and 112/80 in the left. The pain was entirely relieved and the patient was discharged from the hospital on the fifth day. Two months later, she had no complaints and both the right forearm and the right thenar eminence had begun to increase in size.

Many of the patients had similar histories, but a few presented other interesting symptoms and signs.

CASE 2. Mrs. L. P., 42 years of age, had suffered for a year and a half from a feeling of pressure on the outer side of the right shoulder, with numbness in the right fourth and fifth fingers. There was flushing of the skin of both arms as well as a peculiar tenseness of the skin on the right hand. X-ray examination of the cervical spine showed enlargement of the transverse processes of the seventh cervical vertebra, more evident on the right side. By measuring on the film, the transverse process of the seventh cervical vertebra was shown to be 1.1 centimeters longer than that of the first thoracic vertebra. At operation, the chief abnormality found was undue tension on the right subclavian artery. All complaints were relieved by myotomy of the right anterior scalenus muscle.

CASE 3. Miss I. B., 21 years of age, had noticed a severe dragging pain over the right scapula for 7 years which so interfered with movement of the right arm that she could not carry even a small bag without increasing the pain. Numbness and tingling were present over the ulnar side of the right hand and arm, with some weakness in the right hand. For relief, she held her head turned to the left and tilted to the right. With the patient at rest, the blood pressure in the two arms was equal, but with tension on the right scalenus anticus muscle, the right radial pulse disappeared and the blood pressure in the right arm fell to zero. In x-ray films of the cervical spine, the transverse process of the seventh cervical vertebra was only 1 millimeter shorter than that of the first thoracic vertebra, and the transverse process on the right was much larger than that on the left. At operation there was extreme pressure on both the right subclavian artery and the right brachial plexus. Eight days after myotomy of the right anterior scalenus muscle the patient was free from symptoms.

CASE 4. Mrs. T. E., 31 years of age, had had sharp pain in the right hand for 6 years. The pain was worse at night. Three months after the onset pain was felt in the left hand as well and the patient soon noticed a constant tingling over the ulnar distribution on both sides. On 7 occasions she had experienced attacks of numbness over the entire right side of the face, arm, and hand, lasting for 1 hour each time and precipitated once by reaching down to pick up her baby. By auscultation above the clavicle on either side, a bruit could be heard when the anterior scalenus muscle was tensed. On exposure of the right scalenus anticus muscle it was found to have an attachment to the first rib over

a distance of 5 centimeters. Myotomy was done. Within a few hours the patient was free from pain even when the right shoulder was strongly depressed.

CASE 5. R. F., a busy surgeon, 49 years of age, suspected that he had syringomyelia because he had suffered from aching over both trapezii for 12 years. This spread to the right side of the neck and the upper part of the right arm 8 months before admission. Numbness and tingling corresponding to the distribution of the median and ulnar nerves, had been present in the right forearm and hand for 6 months when he was first seen. Even the wearing of rubber gloves made the pain worse. He was also subject to hemicrania on the right, with visual phenomena pointing to the right hemisphere. After myotomy of the right scalenus anticus muscle, there was gradual but steady improvement, so that in 3 weeks he felt greatly improved. In 4 months he was almost back to normal and within a year, he was completely cured.

CASE 6. Mrs. G. S., 54 years of age, had felt a dull aching in both shoulders for 6 years, and a severe crushing pain in the right finger tips for 6 months. Finally she could move about only by carrying the right arm supported in a sling. The right pupil was larger than the left, but there was no other sign of Horner's syndrome. The blood pressure was the same in both arms. The tips of the right second, third, and fourth fingers were tender to firm pressure, as were the bases of all the metacarpals. The joints were swollen and tender; the bone showed marked osteoporosis and a diagnosis of atrophic arthritis had been made. On examination, the characteristic radiation of pain with some sensory change over the ulnar area and tenderness of the scalenus anticus muscle led to a myotomy of this muscle. Five days later the pain had entirely disappeared and one and one-half years following operation the only symptom that could be found in this patient was an occasional numbness of the tip of the right fifth finger.

CASE 7. Mrs. L. L., 52 years of age, had had severe, sharp pain over the precordium for a year and a half, and a diagnosis of angina pectoris had been made. Severe organic heart disease had followed a fever in early life. The pain was brought on by exercise only if the left arm participated, and it prevented her from raising the left hand to her head. There was also numbness in the left fifth finger. Although the pupils were equal, she had a narrower lid-slit on the left. The left radial pulse was weaker than the right; the blood pressure was 117/80 on the right and 110/70 on the left. She had been totally disabled by the severity of the pain for a year and a half, but 2 days after myotomy of the left scalenus anticus muscle, the pain was very much less. After 2 weeks it disappeared entirely and shortly thereafter she was able to resume her work as a physical therapist.

An analysis of the 18 cases studied disclosed the following findings: Among the 12 patients without cervical ribs the condition was twice as common in women as in men. The age of onset varied from 14 to 60 years, with an average age of 32 years, although the majority of patients were between the ages of 20 and 30. The duration of symptoms had been from 5 months to 15 years, with an average of 5 years. One patient was affected bilaterally. Of the others, 8 had symptoms on the right side and 3 on the left. A history of injury was obtained in 5 of the 12 cases.

Among the patients with rudimentary cervical ribs there were 5 females and 1 male. They were in a later age group, the average age of the onset of symptoms being 45 years. The duration of symptoms had been slightly longer than among those in the group mentioned above. The condition was bilateral in 1 patient, on the right side in 2, and on the left in 3. None gave a history of trauma. One cannot fail to be impressed by the wide variety of symptoms presented by these patients. One of the most common complaints is that of a heavy dragging sensation in one or both shoulders, or pain over the deltoid area, which at times extends down the arm often centering in and about the elbow. In more severe states, the pain extends down the forearm into the hand on the ulnar side; occasionally it may appear on the radial side. Certain forms of exercise of the extremity exaggerate the pain, and tenderness over the lower third of the scalenus anticus muscle immediately above the clavicle is unfailingly greater than normal. Other symptoms and signs are more variable. At times the pain is indicated as radiating up in

the region of the trapezial fold or up into the cervical region or head. The patient may indicate discomfort over the region of the seventh cervical vertebra, which is sometimes relieved by extending the head and neck. In some, use of the extremity is prohibited by the production of pain, and the arm is carried in a sling. Others make the statement that certain acts, such as playing the piano or sweeping, are particularly likely to cause an increase in symptoms. A subjective feeling of numbness or sensory alteration over the ulnar area or even over the radial part of the hand is much more common than objective impairment of sensation. The latter, however, though mild, is not infrequent and is usually over the area of the ulnar nerve. Rarely has the condition gone on to more than a slight atrophy of the intrinsic muscles of the hand. In the scalenus syndrome, as in the majority of cases of cervical rib, marked circulatory alterations in the extremity are not frequent. In 1 patient without a cervical rib, however, the pressure on the subclavian artery was sufficient to occlude it. Gangrene of the terminal portion of the extremity resulted, and amputation was required. Milder evidences are not uncommon—for example, a blood pressure lower by 10 or 15 points on the affected side, an alteration in oscillometric reading, or perhaps some slight vasomotor change. In the English literature, Stopford called attention to the position of the sympathetic fibers which lie on the undersurface of the inner cord of the brachial plexus so that they are readily subjected to pressure. It is his belief that the circulatory changes in the extremity are brought about through the agency of mechanical pressure upon these sympathetic fibers. In our experience, however, it has been unusual to find marked circulatory alterations, though a larger series of these cases of scalenus syndrome might well reveal other striking instances of them.

Motor symptoms were usually late in appearing and, in many patients, an apparent loss of power was actually caused by the pain incident to strenuous effort. True weakness occurred in the small muscles of the hand in 7 cases, with thenar wasting in 2. Weakness of the flexors of the wrist was found in 3 patients.

Without exception, the pain was brought on or increased by tensing the anterior scalenus muscle on the affected side. This was most commonly discovered on carrying objects with the arm extended, but could usually be elicited by passive depression of the shoulder, turning the head forcibly toward the affected side, or, in many cases, by any muscular effort of the arm. Conversely, in every instance, elevating the shoulder by supporting the elbow alleviated the pain immediately.

Examination of the neck consistently revealed tenderness over the insertion of the scalenus anticus muscle on the first rib. A drooping shoulder was seen in only 2 patients. In 4, the head was held tilted toward the affected side or slightly turned to the opposite side, in such a position as to relax the scalenus anticus. On auscultation above the clavicle, an arterial bruit was heard in 2 patients, while in 8, the radial pulse was diminished in volume by tensing the scalenus anticus muscle on the affected side. At rest, the blood pressure on the affected side was lower in 5 instances and higher in 3.

Evidence of sympathetic disturbance was present in 9 of the 18 patients. It consisted in flushing of the skin over the arm or hand, swelling of the hand, tenseness of the skin, cyanosis, brittle nails, rarefaction of bones, enophthalmos, migraine, and attacks of flushing over the blush area on the affected side. In 4 others the hand or arm was colder than its fellow, but this was assumed to be a direct effect of interference with the blood flow in the subclavian artery.

Among the patients seen have been many in whom the clinical picture seemed sufficiently typical to warrant a diagnosis of the scalenus syndrome, and yet the symptoms

were comparatively mild, causing hesitation in advising operation. In a considerable number of these, improvement in the posture, exercises to strengthen the trapezius and the muscles elevating the shoulder girdle, have been followed by improvement and often by complete relief. It is our feeling that there must be a considerable number of persons in this less severe group, in whom properly directed exercises will be sufficient to effect a cure.

It is assumed that the scalenus syndrome occurs in persons who have an inherent variation in their development. Three of our patients had other abnormalities. One of them, with a bilateral scalenus syndrome, had more severe symptoms on the right side. She had, as well, a horseshoe kidney on that side, which required operation, and also a nodule in the right side of the thyroid. Another patient with the scalenus syndrome on the right, had right hemicrania with symptoms referable to the left side of the body. The third, had a flexed right fifth finger that was familial. Her scalenus syndrome was on the same side.

A history of trauma was obtained in 5 of the patients, none of whom had a cervical rib. It usually occurred shortly before the onset of symptoms and consisted in a blow from above on the affected shoulder so that it was forcibly depressed.

At operation there was, in every case, a definite tension on the subclavian artery and brachial plexus which were angulated against the scalenus anticus. This muscle was always firm, tense, and often appeared to be hypertrophied. On dividing it, the underlying structures were displaced forward and the brachial plexus was then seen to be lax. Sometimes the outer edge of the muscle sheath was thickened, its free outer edge constituting the point of greatest pressure on the subclavian artery. In none of the patients reviewed here was a cervical rib seen at operation, although, when present, it could usually be felt on deep palpation.

Relief from pain usually dated from the day of operation, and sometimes began immediately on recovery from the anesthetic. In some patients it was complete within a week after operation; in others it came about gradually over a period of from 1 month to a year. The hypesthesia cleared rapidly, often in a few hours. Among the motor signs, the generalized weakness of the extremity disappeared in a few days, indicating that it was secondary to the pain. Atrophied muscles began to increase in size in about 2 months. Recovery, though steady, was sometimes prolonged, necessitating a convalescence of as long as 8 months, but resulting in a return to work such as had been impossible before operation.

In half of the patients without cervical ribs, x-ray films of the cervical spine showed an enlargement of the transverse process of the seventh cervical vertebra so that it exceeded in length that of the first thoracic vertebra. This was possibly the result of overdevelopment of the costal element in the lateral mass of the seventh cervical vertebra. The transverse process of the seventh cervical vertebra was considered to be abnormally large if its tip extended beyond the limits of the first thoracic transverse process.

The present study of 18 cases emphasizes certain aspects of the scalenus syndrome. The bizarre symptoms and insidious onset render early diagnosis difficult, as does the fact that objective signs may appear relatively late. The early symptoms are usually vague pains about the shoulder. Their one common characteristic is that they bear a definite relation to exercise and to posture. Trauma to the shoulder may have preceded the onset of symptoms. The patient with precordial pain, first diagnosed as having angina pectoris, illustrates how one may be misled in the interpretation of a single symptom.

Realizing the congenital structural peculiarities and the other factors more immediately responsible for the onset of the syndrome, we believe that the production of

symptoms, depends upon an abnormal relationship of the shoulder girdle to the thoracic cage and its attached structures. This conception is the guide to treatment whether by exercises and correction of posture or by operation.

SUMMARY

The diagnosis of the scalenus syndrome is made in patients who have symptoms and signs suggestive of cervical rib, but in whom roentgenograms show either no cervical rib or at most a small outgrowth that could not itself be responsible for the disability.

The condition has been observed for some time and reported under various headings, most of which point to an abnormality of the first rib as the primary cause. In many respects the mechanism involved resembles that in patients with well developed cervical ribs.

The etiology consists largely in anatomical and developmental factors that result in an abnormal position of the shoulder girdle in relation to the thoracic cage. Embryologically, a postfixed brachial plexus is more readily subjected to tension and angulation in its course over the first rib and behind the anterior scalenus muscle. Injury, excessive occupational strain, or poor musculature may cause the shoulder to droop and precipitate the signs and symptoms.

The chief complaint of pain may be varied in character and distribution over the upper half of the body. The signs all point to a peripheral neuritis of the brachial plexus with striking relation to posture.

Myotomy of the scalenus muscle is required when postural exercises fail to relieve the symptoms. Operative results are excellent, though sometimes complete recovery takes several months.

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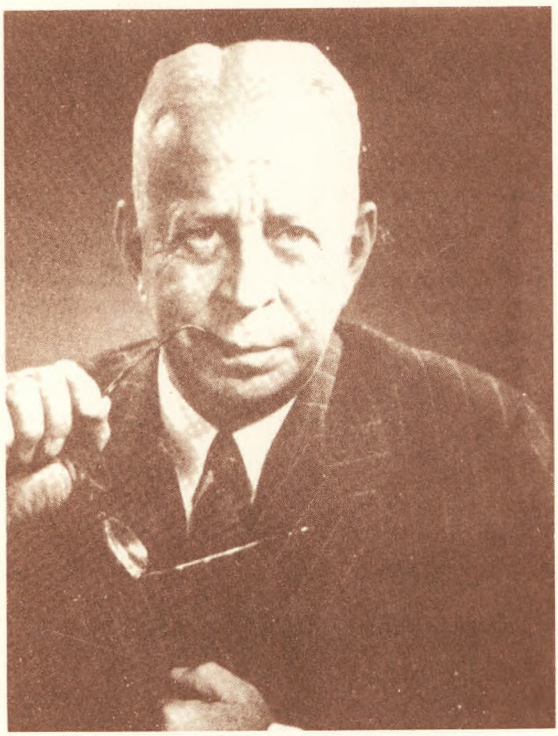

HOWARD C. NAFFZIGER

Howard C. Naffziger (1884-1961), working at the University of California, published this paper in 1938. Although the anatomic relationship between the scaleni and the brachial plexus in the presence of cervical ribs was well known, since Murphy's discussion in 1906, Naffziger's paper introduced into the general surgical literature the concept of the scaleni alone producing brachialgia in the absence of cervical rib. Although the operation of section of the scaleni is not performed as frequently as it was following Naffziger's report, the scalenus syndrome redirected the studies of brachialgia from any etiology ever since its publication.

CLASSIC 29

Die Gelenkerkrankungen bei Blutern mit besonderer Berücksichtigungder Diagnose

(Diseases of the Joints in Bleeders, Especially with Regard to the Diagnosis)

FRANZ KÖNIG* (1832–1910)

Among the symptoms of hemophilia, the disease that in many regards is puzzling, probably no symptom is of such importance to surgeons as that which causes bleedings in the synovial sac. While many chapters about hemophilia, as for instance that of its etiology as well as that of family illness and heredity, are completely obscure, the clinical story of the joints which we call bleeders' joints is clear today. True, it has taken quite some time until the joint diseases of bleeders, caused by repeated bleedings in the synovial sac, were recognized as bleeder's joints. Former authors who during this century took an interest in this question, had different opinions about the nature of diseases of the joints; many considered them to be gouty joints; others with more experience distinguished between different forms. Elsässer too recognizes gout in the joints, but he also tells of a patient who (after another form of the disease had affected another joint) developed a "tumor albus" in the knee joint. This tumor was healed through treatment (rest and plaster against blisters). We will find that Elsässer diagnosed correctly various stadia of the disease according to its form. Toward the end of the 1840's Wachsmuth did not distinguish bleeders' joints from rheumatic joints. He considered the disease in the joints to be a pseudorheumatismus, rheumatismus spurius. Lange (1851) considers the disease in almost the same manner. However, he includes Elsässer's "tumor albus": tumor albus rheumaticus accompanied by various degrees of inflammation. Finally, even Grandidier, the physician who with great interest has treated hemophilia, even in his treatise published in the 1870's has maintained the supposition of gout and rheumatism as the cause of diseases of the joints in bleeders.

First in the 1860's some individual surgeons were inclined to accept the idea that joint diseases in bleeders are caused, at least in part, by a bleeding in the joint. Richard Volkmann in his pioneering book (published in 1868) about diseases of bones and joints, states that in cases of scurvy and hemophilia, hemarthrosis occurs, evidently spontaneously or due to insignificant causes. Also in this thesis Reinert, with an exceptionally interesting case, in a very determined manner tries to prove that at least the majority of all bleeders' joints can be traced

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back to intra-articular bleeding (Göttingen, 1869). In the most decisive manner Lossen has rejected the hypothesis of the uric acid diathesis or the rheumatismus of bleeders. He explains bleeders' joints as disturbances caused by bleeding in the synovial sac.

It is necessary to consider the history of this disease in order to understand why fairly little is known about it, even by orthopedic surgeons. The rarity of its occurrence is not sufficient to explain this.

As long as the opinion was held that hemophiliacs could get various rheumatic, arthritic or tumor albus-resembling diseases in their joints, it was not worth while to explore these various apparently known forms of disease. But when it became known that the diseases in joints of bleeders showed characteristic forms, that their study gives interesting pathologic-anatomic results, that their clinical study in certain cases may place the physician in the position—on the basis of the course and the form of the illness—to diagnose the bleeder and bleeders' joint, and that from all this important knowledge can be gained for the treatment, that was another matter. As soon as these facts which explain the nature of bleeders' joints have been accepted by the physicians and the causes of bleeders' joints will be known, we are of the opinion that they do not occur with such rarity as it is supposed, especially as their clinical appearance and their course often prompt the ignorant to mistake them for tumor albus or for tuberculosis of the joints. Precisely as will be seen, the possibility of this confusion may be fatal to the hemophiliac. Of the 8 bleeders who during a decade were treated in the Clinic in Göttingen, 2 passed away due to the effects of the wrong diagnosis and the treatment based on the diagnosis.

The main purpose in presenting this information is a practical one. It stems from the desire to guard specialists against such mistakes as the writer of this article has seen. A person who helplessly has seen the bleeding wound after an operation on a hemophiliac; a person who once has witnessed that such a man, under his hands died from the wound of the operation, for whom he had cared to his best ability, such a person will gratefully recognize the attempt that will be made here—to make available at least a part of the diagnosis of bleeders' joints.

The strange appearances shown by bleeders' joints, not only those at the first sign of a bleeding but the many changing pictures that they show, sometimes in a very chronic course, are due to the fact that in the joint or joints bleedings occur repeatedly when the joints are in use. For instance, the bleedings are increased due to the irritation of movement as will be seen below, whereby a peculiar picture of inflammation of the joint is created. Finally, this may lead to sectional destruction of the joints, to heavy contractures, ankylosis and various deformities. On account of all this there is a certain justification to the idea of dividing the bleeder disease of the joints into 3 stadia. The first stadium is the first bleeding; its picture is a true hemarthrosis. Naturally, in certain cases the disease may end in this stadium, and the hemarthrosis be cured. Should that not be the case, then the blood that is present produces irritation; new blood is added; and a strange kind of inflammation is created which takes the form of panarthritis. As well in the pathologic-anatomic picture as in clinical appearance it has great similiarity to the kind of tuberculosis in the joint which I have called hydrops tuberculosis fibrinous. This stadium may be called the inflammatory stage; surely, it is this stage that has caused former authors to take it for a kind of tumor albus of bleeders' joint. The third stadium would be the one where regressive metamorphoses play the main role, the stage of wasting away of the joint, the growth of the displacement of the joint surfaces, the stadium of contracture, the ankylosis, the deformity of the joints.

We must differentiate between: 1. The stage of the first bleeding, the hemarthrosis

of the bleeder; 2. the inflammatory stage, panarthritis in the bleeders' joint; 3. the regressive stage which causes permanent deformity of the bleeders' joint, the contracture of the joint.

Let us look first at the clinical appearance of bleeders' joint. It is not necessary to explain that a spontaneous blood effusion is quite different from a traumatically caused blood effusion. Inasmuch as the bleeder usually has no trauma, other causes must be present in order to make the diagnosis that the effusion in the joint is a bleeding effusion. In this regard it must be taken into consideration that the effusion in a bleeder usually occurs rapidly, which is analogous to the traumatic effusion. In some cases subcutaneous ecchymosis around the joint and a few days later the green-colored skin not far from the joint lead to the diagnosis. Naturally, the knowledge that the patient is a hemophiliac considerably facilitates the diagnosis, or that he belongs to a hemophiliac family. I was in a very favorable position to observe the clinical picture of a patient last year.

D. H., 17 years old. Some months ago this pale young man suddenly, without any traumatic occurrence, got a painless tumor in the knee. The knee was not strained much, moved freely, with the patella dancing. The patient had been using the leg because he had no pain and could move it freely. Already when discussing the case I had emphasized that due to the patient's pallor, the sudden appearance of the fluid effusion, lack of pain in the joint and the freedom of movement, one had to consider a bleeders' joint. When the patient who was present at the discussion heard this, he stated that the physician had told him to say that he belonged to a family of hemophiliacs. Small wounds caused bleeding; once one of his brothers had had profuse bleeding after a tooth extraction.

Puncturing with a trocar resulted in about 100 grams of fluid blood. After compression a knee protector was applied, and the patient left as cured.

As a rule the surgeon does not see this first bleeding in the joint; instead, he finds the symptoms that are found in the second stage of the illness. Repeatedly, we have referred to the fact that the exterior picture of bleeders' joints at this moment may look very much the same as a joint with tuberculose hydrops fibrinosus. When discussing the pathologic anatomy it will lead immediately to the source of the similarity. Here we wish only to refer to the fact that in both cases it relates to the effusion of a fluid which contains fibrous elements. These are present partly in the liquid, partly on the surface of the joint, where they arrange themselves systematically. On account of this, in both joints a fluctuating effusion is created, besides alternating thickness of the synovial fold.

Due to these conditions it may be doubtful whether it will be possible in such a case to make the diagnosis. We are also of the opinion that under some conditions it will be impossible. If we know nothing of the anamnesis, of the manner in which the disease in the joint occurred, above all if we do not know whether or not the patient is a hemophiliac, if he has only one diseased joint, then even an expert will not be able to diagnose the disease. However, often details exist which will guide surgeons with knowledge of bleeders' joints to make the right diagnosis.

Here we shall try to discuss these details, which may help in making the diagnosis. First, it must be emphasized that as a rule the bleeders' joint disease usually occurs in young men. The number of men with bleeders' joints is probably more or less the same as the general number of male hemophiliacs. As a rule the patients are recognized by their pallor. It may be added that patients, besides the newly inflamed joint, also have one or more diseased, deformed joints; it may even happen that during the examination of the patient new effusions take place, whereby the diagnosis that it refers to various stages of bleeders' joints is all the more probable. The diagnosis becomes almost sure if the patient states that the joint gave no pain but

functioned normally, and that the deterioration came gradually.

I came to know all these arguments that point to bleeders' joints, unfortunately through mistakes on my part. I believe that it will be instructive if I describe some cases.

In 1880 I received an 18-year-old boy for treatment whose father had died in pulmonary phthisis. He himself supposedly had been healthy until 18 months ago when his left knee became affected. Soon it was better, then it was worse; finally, it was swollen but remained moderately flexible and stiff in a knock-kneed position. At the same time the left foot joint was affected and gradually had developed into a "pointed foot." Three months after the left knee, the right knee too was affected. At the admission of the patient the right knee presented the picture of a hydrops tuberculosus. The joint showed a clear fluctuation due to the considerably knotty, creaking swelling of the synovial. During the treatment one of his elbows temporarily became swollen.

The pale boy was not found to suffer from any other disease.

After many attempts to stretch the left, contracted knee joint and to cure the inflamed swelling of the left knee, in the belief that it referred to tuberculosis, I made an incision. This proved that it was a characteristic bleeders' joint. Then I only drained the joint. On the third day in spite of all attempts to stop the continuous bleeding, the patient died.

Both his parents were dead, and the question as to whether or not the family contained other hemophiliacs could not be answered. At or soon after the birth of the boy his mother had died (bleeding to death?).

This was at a time (1880) when I had not yet seen many bleeders' joints. In the same year I had a second case which, in spite of the symptoms pointing to a bleeders' joint, I did not diagnose, alas also to the disadvantage of the patient.

For 3 months a very pale 8-year-old boy whose parents are dead, has a bad knee joint. It is considerably swollen, spindlelike, and in the upper recessus a dark fluctuation can be felt. For some time his left elbow has been swollen. Both joints are painful and do not move easily. After various treatments, in the supposition that it is tuberculosis of the joints, a capsular resection was tried on the knee. The first incision showed clearly a bleeders' joint; hence, the operation was stopped, and the joint only drained. In spite of all attempts to cure the patient, after 10 days he passed away due to continuous bleedings.

The experience of this case prevented me from making the wrong diagnosis for a brother of the deceased. The brother was admitted a few days later, also with disease of the joints which seemed to be a contracture with tuberculosis. His right knee was slightly bent in a genu valgum position with the medial condylus projecting considerably. Synovial swelling was small. Attempts had been made to correct the position and to hold it in a cast. Suddenly the 11-year-old pale boy had effusions in both elbows. In the meantime his brother had been operated on, and in his hometown it had been found out that they belonged to a hemophiliac family.

On the other hand, a 23-year-old man was diagnosed as a hemophiliac, in spite of the fact that at the same time he suffered from tuberculosis (facial lupus and tuberculous epididymitis). At the age of 10 he had a swelling of the left knee. At the age of 14 his right knee was affected, and while the disease in the left had receded, swellings occurred repeatedly in the right joint which finally caused contracture and deformity. Temporarily, the left ankle joint had also been full of effusion.

This patient too belonged to a hemophiliac family.

In the winter 1890-91, due to his lupus and a scrotal tuberculosis, he was treated with Koch's injections. While the reaction of the lupus and the scrotal tuberculosis was

intensive, none of the joints showed a reaction to the injections. Thus in this case the tuberculin injection confirmed the supposition that the diseased joints were not tuberculous.

After what has been stated above, in many cases of diseased joints we are in the position to diagnose bleeders' joint. We have said that this diagnosis is relatively easy when the sick joint is that of a known hemophiliac, and that in such a case it may suffice to observe the rapid development of an effusion in the joint. If it is not known that the patient is a hemophiliac, then frequently the diagnosis will not be made. It is possible to make the diagnosis in a pale young man by observing the rapid development of effusion in the joint and at the same time to observe other characteristic changes in the joint, such as ecchymosis.

We have assumed that we shall make the diagnosis for a recently diseased joint as it appears after the first bleeding (hemarthros) or after repeated bleedings (panarthritis): on the other hand, at present we have disregarded the question whether it is possible to recognize the form (3rd stage) as such. In order to give an answer to this question and in general to improve the knowledge of bleeders' joint, we will give a résumé of bleeders' joint from the pathologic-anatomic point of view.

We do this on the basis of 2 preparations tried out by us, as in the literature about hemophiliacs little can be found about it, and the pathologic-anatomic collections contain practically no preparations under the heading hemophiliacs. Unfortunately, many preparations originated after the time that the 2 patients passed away due to operations. However, I had the opportunity at the incision in a joint on another man, who did not pass away, to see the same pictures. All 3 cases refer to knee joints. One of them has already been described by Dr. Boxkelmann in this thesis published in 1881.

Starting with the early stages where, a few weeks after a bleeding in the joint, we find fluid blood in the knee-pan, we also find clots partly discolored, some of them swimming separately in the fluid, others sticking to the capsule. The capsule itself is thick, succulent, imbibed with blood-coloring and correspondingly discolored. Fibrous deposits start to form in odd places not only on the capsule but also in typical places of the cartilage surface, for instance on the frontal part of the thigh from one side to the other. Sporadic brown tufts are being formed. Already at this time the cartilage starts to change, to become fibrous, and the strangely sharp-edged defects described below, start to develop.

The anatomic examination of the joints in the 2nd stage, which is similar to the picture of tuberculous hydrops fibrinosus, shows the changes mentioned above but more developed. If no new bleeding has taken place, the contents of the joint are not purely blood but bloody serous or purely serous with a slightly brown color. At incision in these joints the great number of brownish synovial tufts was particularly noticeable. In the joint of the patient who passed away after operation, the same somewhat thickened synovialis was found, as if covered with moss. In water the strange brown, soft tufts, standing close together, gave the impression of a Medusa head. In a similar manner as these tufts the entire synovialis is changed, especially its color conditions, which become red-brown, brown or gray.

Besides these characteristic changes, striking changes are also shown on the upper surface of the cartilage. All over it has lost its white color and its shine; it is discolored a dirty red-brown or gray-brown. In odd places the cartilage has a fibrous mass which shows a tendency to form connective tissue. This fibrous mass is important as a forerunner to synechia in the joint. However, the truly characteristic changes consist in strangely sharp-edged defects, advancing as on a landmap, small and big, deep in the joint and on the surface, with gnawing defects to the cartilage, in various spots of the

joint but mostly at the same places where the fibrous deposits are found. I have not been able to find out whether they originate due to the exuberance of the tufts in the fibrous cartilage or are due to the fibrous deposits(?). However, we have found no actual changes on the edge of the cartilage surface as is the case in arthritic deformity; but apart from these deep defects, the cartilage also shows unevenness in its surface as it dwindles unevenly. Histologically, little can be added to this microscopic note. On the surface the tufts show granular blood pigment, and also in the depth near the numerous vessels an abundance of blood pigment is found. The surface layers of the synovialis show similar conditions. Many rests of blood pigment were found in the joint cartilage, decayed to connecting tissue.

A bleeders' joint does not remain in this stage if no new bleedings occur. According to the picture just described, as a rule a very evident regressive metamorphosis takes place in the tissue. The scar, the shrinking formation of connecting tissue sets in. This, together with the mechanical influences which during this time have had an effect on the joint, make it what it will become, i.e., usually a stiff, more or less deformed part of the limb. The joint is laid waste while its surfaces, bared of cartilage, partly covered by connecting tissue, grow together partly or totally. The same thing can happen to the capsule. Everywhere the changed blood pigment reminds one of the development of the contracture; it can even happen that one part of the capsule is laced up and receives the shrinking brown tufts and the brownish serous fluid in this laced-up part. In this stadium too the thickening of the joints is only apparent. In the knee which is used for walking and thereby is pressed into a light bending and abducent position, the swollen condylus develops on the inner side, and similarly delusive pictures of swollen joints present also other deformities.

From all this it is evident that all these positions have great similarity with those that with time develop in tuberculosis. On the other hand, no stages of hemophilia show a tendency to abscess and fistula formation. Many often heal in a short time, and the diagnostician will always be startled when a young person shows several apparently tubercular joints which heal rapidly.

Often the first bleeding in the joint of a hemophiliac disappears, as I myself have observed, without leaving traces. However, we are convinced that it cannot be expected that a joint in the second stadium as described above, will heal and become completely flexible. A more or less defective function must always be anticipated, especially since violent movements made for whatever purpose make the result very doubtful. For the prognosis one must also take into consideration that in cases where a hemophiliac is likely to have bleeding joints, often the bleeding does not confine itself to the joints.

Above all, a new hemarthrosis in a hemophiliac must be treated so that the patient does not use the joint in question. When it refers to a leg, he must not walk, and when it refers to an upper limb he must not work with his hands. As a rule, he does it anyhow because the symptoms of this first bleeding are so vague that often the sick person does not notice this first effusion and does not go to a physician. A moderate compression is sufficient for the resorption. Many times we have seen a cure in this way. However, the older the effusions are and the more the joints resemble the 2nd stage, the less likely a cure is. This is the reason why the question of surgical treatment must be discussed, as in this stage the patients often complain of their pain, without even mentioning the fact that the physician has not made the diagnosis of hemophilia. Therefore, the following question must be asked immediately: is surgical treatment at all permitted for the cure of a recognized bleeders' joint? We believe we can answer this question affirmatively insofar as it refers to the puncture of the joint. Totally, I have made 3 punctures of knees; twice I have

washed with carbol. It caused no damage to the bleeding in any of these cases; two patients were discharged, one cured, the other much improved. However, we would advise to limit the surgical treatment. Where we operated on joints in the mistaken supposition that it referred to tuberculosis, 2 patients bled to death and only 1, after repeated bleedings, was cured but the joint remained stiff.

On the other hand, often it will be possible to remove contractures by means of extension, the use of force and a cast or machines. The question as to what to do for bleeders' joint is completely secondary to the question what *not* to do.

The purpose in presenting this clinical thesis is to advance the knowledge of the not-too-rare disease and thereby to save the surgeon from the worry of having a patient bleeding to death, and above all to save the hemophiliac with bleeders' joint from such a death.



FRANZ KÖNIG

Hemophilia was known to the ancients of many cultures. However, it was seldom and in the known literature rarely related to the swollen joints which are a not uncommon manifestation of the disease. Not until this publication by one of Germany's leading surgeons of the latter 19th century, Franz König of Göttingen (1832-1910), was the relationship between hemophilia and hemophilic hemarthrosis clinically and definitively established. The reasons for this 3,000 year oversight are clearly indicated in his paper. I believe this to be its first translation into English. The translation on this occasion is professional.

CLASSIC 30 Interinnomino-abdominal (Hind-Quarter) Amputation

By G. Gordon-Taylor (1878–1960)
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AND
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Interinnomino-abdominal amputation is fortunately an infrequent operation of surgery, and must remain for all time one of the most colossal mutilations practised on the human frame. Though this mighty ablation was first performed by Billroth[1] in 1891, to Girard[2] belongs the credit of having achieved, in 1895, the first success.

The term 'interinnomino-abdominal amputation' would seem to be the best and most appropriate appellation for this operation, for 'interpelvi-abdominal amputation', the title used by Hogarth Pringle,[3] is rather suggestive of some feat of expert swordsmanship, and would appear to betoken an even more stupendous undertaking than that which is on occasion essayed by surgeons. It is true that in one of our cases a testicle required removal as well, that in another one line of bone section involved the ischial and pubic portions of the opposite innominate bone, and that in one successful case part of the sacrum required removal with the mass; nevertheless, this hyperbolic and ambitious nomenclature hardly seems justified, even although the usual limits of the amputation are transcended by these additional sacrifices of bone or gonad. 'Interilio-abdominal removal' might be applicable to certain more limited growths, but in the cases that have been encountered by the writers nothing but the sacrifice of the whole innominate bone seemed practicable, if the operation were to be effective in its object and purpose. 'Hemipelvectomy' evokes a shudder, and a sigh of regret that some knowledge of Latin and Greek is no longer considered necessary for those who claim to have received more than a kindergarten education.

The literature of the subject has been tabulated by Hogarth Pringle[3] in this Journal in 1916, and by Judin[4] in 1926; the latter author, though writing in English, had been working in Russia, and, perhaps on account of the inaccessibility of references, his table contains a number of inaccuracies. Many of the cases reported in Russian papers and journals are unobtainable in London, and others were personal communications to Judin, so that an accurate scrutiny of these cannot be made. The perusal of the relevant surgical literature indicates, however, that the operation has now been performed at least 79 times by 48 different sur-

geons, but of the reported cases only those of Hogarth Pringle and the present series emanate from British clinics.

The opportunity presented to one of us (G. G.-T.) of performing this amputation as a *single-stage operation* on no fewer than five occasions would seem to be unique. It is true that Hogarth Pringle in his memorable paper already mentioned reported five cases, but in three of these the operation was performed in two stages, the time intervening between the two séances varying between three months and fifteen months, and in two of the cases the second operation was merely the ablation of a disintegrated os coxæ.

Fortune has kindly ordained that the two authors of this communication have been associated together in the performance of the last four of the five operations that constitute the basis of this paper, and it is perhaps significant that of these four cases only one succumbed. Moreover, the last three cases of the series were operated upon within a few months of each other, and an unparalleled opportunity has thus been afforded us of not only familiarizing ourselves more thoroughly with the technique of the manœuvre, but also of reviewing the anxieties of the undertaking, its technical difficulties and pitfalls, and the post-operative complications. We are furthermore enabled to form some opinion as to the degree of final disablement produced by the ablation and to adjudge the amount of interference with the patient's subsequent *modus vivendi.*

Hogarth Pringle's most admirable paper has been of the utmost assistance to us in the operative treatment of the cases dealt with in this communication, and that author is indeed to be congratulated on his low mortality, when it is remembered that at the time his operations were performed blood transfusion was not readily available, at any rate in Great Britain, and the shock of the operation had to be combated with nothing more serviceable than saline infusion.

The conviction has grown upon us that some description of the operation as we have experienced it might be of value to those who may from time to time find themselves constrained to advise and to perform this amputation, and the sketches illustrating certain of the stages of the undertaking and the anatomical structures displayed in the course of its perfomance may be an aid to such surgeons as have less experience of this amputation than ourselves.

It is probable that in the future this operation will be less and less frequently performed. Radiation therapy at the moment seems to be displacing the more crude and more maiming methods of ablating cancer, but even with the growing perfection of methods of radiation, the treatment of certain forms of sarcoma may perhaps still occasionally demand this operation, and so long as procrastination remains a characteristic human trait where disease is concerned, and while benign or quasi-benign tumours are allowed to attain colossal and crippling proportions, only this type of procedure will rid the patient of his encumbrance, his pain, and his menace of malignancy.

CASE REPORTS

Case 1.—Sarcoma of upper end of femur with involvement of innominate bone. Interinnomino-abdominal amputation. Death.

HISTORY.—A. H., male, aged 25. The patient's father had died of a sarcoma of the leg twenty-three years previously. The patient had complained of pain in the right hip for four years, but there had been no swelling during that period. He sustained a fall on May 16, 1922, after which he became lame. Radiography now revealed the true nature of the malady, and the report from another institution, dated May 17, 1922, was as follows: "Large periosteal sarcoma of the upper end of the right femur, extending from the region of the great trochanter on to the inferior surface of the neck of the bone and for six or seven inches down the shaft. There are also opacities in the acetabulum and ilium above, which may be secondary deposits. There is considerable outward bowing of the shaft of the

femur." An X-ray report dated May 22, 1922—a week later—revealed a transverse fracture of the shaft at the lower end of the growth, which had increased in size in that short space of time. The patient was transferred to my care (G. G.-T.) at Middlesex Hospital as an inoperable case in the middle of June, 1922, and by this time there was radiological evidence of the involvement of the acetabulum by the neoplasm.

On Examination.—The general condition of the patient was poor: he was anæmic; his pulse was 100, and at times irregular; and he suffered untold pain in the region of the right hip and thigh. In the upper and middle thirds of the latter there was a large diffuse swelling; there was marked outward bowing. The right leg and foot were greatly swollen and there was considerable ædema. In the right groin was a hard, fixed mass, extending on to the abdominal wall. The circumference at the upper end of the thigh measured 56 cm. on the right side and only 41 cm. on the left. A diagrammatic sketch of the swelling is appended (*Fig.* 453); the X-rays have unfortunately been destroyed.

It was resolved, if the peritoneum were free of involvement by the new growth, to attempt to eradicate the mass by an interinnomino-abdominal amputation.

Operation (July 7, 1922).—Spinal anæsthesia and general anæsthesia were administered by Mr. A. E. W. Idris. The steps of the operation were those outlined by Hogarth Pringle, but in this case the extent of the growth necessitated the removal of the right testicle as well. Very considerable hæmorrhage was encountered in the extraperitoneal tissues in the neighbourhood of the cut symphysis and the bladder, and despite the fact that the common iliac vessels had been already secured, much blood was lost. Unfortunately all the arrangements for blood transfusion miscarried; the arrangements for transfusion were not organized as they are now, nor were the services of the Blood-Transfusion Society available then. In our emergency we could only avail ourselves of the services of a diminutive "girl-guide", who donated with great spirit, but with little effect! The patient died of shock about six hours after the completion of the operation.

Histological Report (No. 4197/22, dated 26/7/22).—

Macroscopically the tumour had destroyed probably the whole thickness of femur for a distance of about three inches immediately below the trochanter. It had invaded the glands along the external iliac vessels; all except the most recently formed portions contained bone.

Microscopically the section showed the structure of a round-celled sarcoma. The cells showed a tendency to line the small alveoli formed by trabeculæ of fibrous tissue.

Autopsy.— There was one note of encouragement from the autopsy: despite the magnitude of the primary growth there was a complete absence of any metastases throughout the body.

Case 2.—Osteoclastoma of innominate bone. Interinnomino-abdominal amputation. Recovery.

History.—W. J., male, aged 17, while playing football sustained a blow in Scarpa's triangle on the left side; the injury was sufficiently severe to lame him and he was unable to continue the game. His incapacity persisted and he consulted his doctor; a radiogram at this period revealed no bony change. For several weeks thereafter the patient was lost sight of by his medical attendant, having betaken himself to some unqualified persons who enjoyed the confidence and patronage of the chief football club of the town in which he dwelt. By these he was massaged and manipulated, but a swelling having now appeared in the adductor region of the left thigh in the vicinity of the cruro-scrotal fold, the patient returned to the doctor whom he had neglected and was promptly sent up to Middlesex Hospital.

On Examination.—A well-marked tumour could now be felt in the upper part of the thigh and in the perineum, where it could be identified on rectal examination and on deep palpation in the urogenital triangle and left ischio-rectal fossa; it was fixed to the pubic bone, was tender on pressure, and was much more considerable on the deep surface of the innominate bone than on its superficial aspect. All movements of the left hip were slightly limited and there was definite wasting of the quadriceps extensor muscle of the affected side.

Radiological Report (Middlesex Hospital).—The left ischio-pubic junction has almost completely disappeared. There is irregular new bone formation in this region. The remainder of ischium is increased in density and there is a tumour with bone formation encircling it. Appearances point to osteosarcoma (*Fig.* 454).

The clinical characters of the tumour, the rapidity of growth, the radiological report, and particularly the marked contrast between the first and second radiograms taken at a short interval of time, together with the history of injury, prompted the diagnosis of a sarcoma of the innominate bone, which was shared by several of my colleagues. The case was considered to be one more likely to be permanently benefited by amputation than by radium therapy; it was

thought that the relative inaccessibility of the tumour might tend to imperfect radiation.

OPERATION (February 4, 1929).—Interinnomino-abdominal amputation performed by G. Gordon-Taylor. Spinal anæsthesia was induced by Dr. H. P. Crampton, with heavy stovaine; this was supplemented by light open ether. Messrs. Eric Riches, P. Wiles, and H. K. Evans rendered loyal and valuable assistance.

The incision and the steps of the operation were mainly those outlined by Hogarth Pringle. It was deemed important to satisfy oneself at the earliest moment as to the relations of the tumour to the peritoneum, and to convince oneself of the possibility of ablating the neoplasm. The flat muscles of the abdominal wall were therefore cut through at their attachment to the iliac crest at the very commencement of the undertaking. The symphysis required division by sawing. In this case the common iliac vessels were not ligated; the external iliac artery and vein were tied distal to the origin of the deep epigastric vessels. The nerves were injected with novocain and were treated with 80 per cent alcohol after section. The iliac portion of the innominate bone was sawn through lateral to its sacral articulation. Subsequently this articular portion of the innominate bone was found to project unduly, and was easily and expeditiously removed. Immediately before operation 800 c.c. of blood were obtained from the patient's brother, citrated, and kept warm. This was given slowly, commencing immediately the main vessels were divided. A further transfusion of 400 c.c. from another donor was given some hours after the operation.

SUBSEQUENT PROGRESS.—The wound healed by first intention, and convalescence was uninterrupted. The bladder required catheterizing after the operation for eighteen hours and then resumed normal function. There was no trouble with the bowels. The patient was discharged on the forty-ninth day after operation. A special webbing support taking the weight from the right shoulder was designed in consultation with Messrs. Ernst, and this is worn day and night. Five and a half years after the operation there is no sign of stretching of the abdominal parietes. As a young and active boy he had no difficulty in adapting himself to new conditions, and was soon able to sit comfortably and to get about with the aid of crutches. He has refused offers of any endeavour to fit a prosthesis. He is now able to take an active part in the work of a busy butcher's shop in his native town; he drives a car, and is at present courting a sweetheart! (*Figs.* 455-458.)

Case 3.—Enormous chondroma of innominate bone, overlapping upper end of femur and extended to costal arch. Interinnomino-abdominal amputation. Recovery.

HISTORY.—H. S., male, aged 59, golf-course labourer. The patient had known of the presence of a "lump in the left groin" since infancy. This had gradually increased in size throughout his life, but during the two years preceding his admission the growth of the tumour had been rapid, and it had attained the enormous dimensions shown in the accompanying photographs (*Fig.* 459). The huge size of the mass had interferred with his walking for the past six months, and nine weeks previously he was compelled to give up his work on the golf-course. He could walk less than a hundred yards and had to stop by reason of the pain which he experienced. The pain was of a rheumatic character and radiated down the lateral aspect of the left thigh to the foot; although not always present, this pain was sometimes most severe, and before admission to the Middlesex Hospital its intensity had necessitated the daily and nightly employment of veramon, nepenthe, etc., in increasing doses for its relief. He was virtually 'house-tied' by reason of his encumbrance and his sufferings.

The patient had been operated upon for a carcinoma of the lower lip in 1931; the growth had been excised and there was *no* evidence of any recurrence.

The enormous tumour of the left innominate bone, for which he claimed admission to hospital, reached to the left costal margin, pushing upwards and outwards the costal outlet; it extended downwards to the great trochanter, anteriorly almost to the umbilicus, and posteriorly it filled up the renal parallelogram. The mass was coarsely nodular, tightly stretching the skin; but the latter was not attached to it. The consistence of the tumour varied; in some parts it was cystic, in others very hard. There was well-marked calcification of the blood-vessels of the limbs, as demonstrated by radiography.

The anatomical connections precluded thorough removal of the tumour by any operative measure less severe than a hindquarter amputation; indeed, the manner in which the mass overlapped the great trochanter is well shown in *Fig.* 462.

The rapid growth of the tumour in the recent months which preceded his admission, and the pain experienced, cogently suggested a malignant transformation of an old-standing chondroma; moreover, it was felt that in the event of the tumour not being already malignant in na-

ture, a more local, but imperfect, operation might expose the patient to the supervention of the sarcoma on the relics of a partially ablated chondroma—a calamitous experience which has indeed befallen one of us (G. G.-T.). It was therefore decided that an interinnomino-abdominal amputation held out the best hopes of a permanently successful issue, and, despite the calcified condition of his arteries, arrangements were instituted for its performance.

OPERATION (Nov. 5, 1933, G. G.-T.).—Messrs. Wiles, Banham, and Gowar gave most valuable and loyal assistance, and Mr. E. G. Muir made himself responsible for such methods of intravenous therapy as appeared to be indicated during the operation. In point of fact, no less than 1200 c.c. of blood were transfused during the operation, and in addition 200 c.c. of saline were infused. Anæsthesia was partly by means of intrathecal injection of 2 c.c. of 5 per cent stovaine, and partly by means of gas and ether induction with a Clover inhaler, followed by open ether. Mr. Idris most skilfully anæsthetized and courageously refused to exhibit any worry or alarm, even when in the middle of the operation the condition of the patient was desperate in the extreme.

The position and magnitude of the tumour had occasioned us some anxiety as to the possibility of having sufficient skin-flaps to cover in the large raw area; consequently an internal flap from the adductor region of the thigh was employed according to the method of Savariaud (*see Fig.* 471, E) and the superficial femoral vessels were ligated low down so as to endeavour to secure the vitality of this flap. Apart from this region of the dissection, where the anatomy was undisturbed, the rest of the amputation was performed blindly, since the colossal tumour had obscured all landmarks, and there was no possibility of demonstrating the branches coming off the internal iliac artery and controlling these before they were cut. The patient had to be moved on to his side and back again into the supine position on more than one occasion, with the result that an alarming fall of blood-pressure ensued which almost proved fatal. Fortunately there was ample blood in readiness for any instant transfusion, and its expeditious and timely employment undoubtedly staved off a disaster that was imminent. Later in the evening of Nov. 5 the patient was given another 500 c.c. of blood and an additional pint of saline infusion.

SUBSEQUENT PROGRESS.—The post-operative convalescence was by no means so uneventful as in *Case* 2, for the internal flap sloughed, and the wound everywhere healed badly. A post-operative thrombo-phlebitis of the popliteal vein of the other limb also ensued, but despite all these anxieties the patient was able to go to a Convalescent Home on Jan. 12, 1934. (*Fig.* 460.)

The weight of the dried and macerated tumour, innominate bone, and upper end of femur was 12 lb. 4 oz. (*Figs.* 461-463). The section shows masses of hyaline cartilage with areas of ossification and cancellous bone (*Fig.* 464).

Case 4.—Sarcoma of pelvis. Interinnomino-abdominal amputation. Death.

HISTORY—E. L., male, age 28, had fallen from a lorry eighteen months before his admission into Middlesex Hospital. The accident occasioned considerable pain in the vicinity of the left hip, which gradually passed off. A year ago the pain returned, and although the patient was at first regarded as a case of rheumatism, he was nevertheless X-rayed at a local hospital, where a diagnosis was made of tuberculosis of the left hip-joint. He was transferred to a sanatorium and treated by means of rest, splinting, and extension, but the appearance of a swelling in Scarpa's triangle led to the taking of another radiogram, which showed destruction of the ischium and pubes without any new bone formation. He was then seen in consultation by Mr. Ronald Reid, of Colchester, who at once diagnosed a malignant neoplasm, and he was straightway transferred to my care (G. G.-T.) in Middlesex Hospital.

ON EXAMINATION.—There was a hard, smooth mass present in Scarpa's triangle. It extended down the inner aspect of the thigh for about 4 in. and could be felt as an indefinite induration above the mesial end of Poupart's ligament. The tumour could also be felt in the ischio-rectal fossa, internal to the ischial tuberosity; there was no alternation in the position of the anus. The left lower limb was maintained in a position of external rotation; the knee was slightly flexed. The femoral artery could be felt just lateral to the tumour. The case was regarded as a sarcoma, and in the absence of any evidence of metastasis, arrangements were made for amputation.

OPERATION (March 3, 1934, G. G.-T.)—Anæsthesia was induced by Mr. R. E. Apperly by means of intrathecal stovaine and a Clover induction, followed by open ether. Able assistance was rendered by Messrs. P. Wiles, Roy Banham, and Alan Kekwick. Mr. E. G. Muir

kindly made himself responsible for the transfusions, as he had done in the preceding operation (*Case* 3).

The difficulties of this particular case were due to the fact that the growth had extended beyond the middle line, and the bone section had to traverse the innominate bone of the opposite side. The neoplasm was also somewhat adherent to the sheath of the prostate and the rectum, and had to be dissected off these structures. Apart from this there seemed nothing very remarkable to note; the operation was completed in sixty-five minutes and the patient left the theatre in good condition. A transfusion of 1200 c.c. of blood from two separate donors was performed during the operation. (*Figs.* 465-467.)

After his return to bed the patient began to go downhill and a further transfusion was given. This was unavailing, and death ensued two-and-a-half hours after the completion of the operation.

AUTOPSY.—At the autopsy there were no secondary growths anywhere throughout the body. The general musculature of the body was poor and anemic and the cardiac muscle was especially soft and friable—possibly a consequence of the prolonged sojourn in bed for the treatment of his supposed tuberculosis. Some obsolete tuberculous mesenteric glands were found.

MICROSCOPIC REPORT.—The section showed a growth interspersed by strands of fibrous tissue and composed of large hyperchromated cells with scanty cytoplasm. There was very little intercellular substance, *no* alveolar arrangement, and no new bone formation. The appearance was suggestive of a Ewing's endothelial myeloma of bone.

Case 5.—Sarcoma of the upper end of the femur. Interinnomino-abdominal amputation. Recovery.

W. B., aged 18. Admitted for tumour of the upper thigh, which was alleged to have been present for only three weeks.

ON EXAMINATION.—There was a large fusiform swelling at the junction of the upper and middle thirds of the right thigh; the tumour had almost attained the size of a Rugby football; it was firm but not tender. There were considerable veins coursing under the skin overlying the mass. There was no limitation of the movements of the lower limb. (*Fig.* 468.)

Radiological Report.—At the junction of the upper and middle thirds of the femur there was some rarefaction of the cortex, with periosteal reaction on both sides of the bone. On the posterior surface small spindles could be seen at right angles to the shaft. The appearances were those of a periosteal sarcoma.

The extent of the tumour, its position, and the involvement of the soft parts (*Fig.* 469) excluded any mere disarticulation at the hip-joint as an effective procedure if operation were decided upon; nothing less drastic than an interinnomino-abdominal amputation was likely to cure, if surgery rather than radiation therapy were contemplated. There was no evidence of any secondary growth in any other part of his body.

OPERATION (July 2, 1934, G. G.-T.).—Anæsthesia was by means of intrathecal stovaine (7 cgrm.) and also open ether; both were skillfully administered by Mr. Raymond Apperly. Messrs. P. Wiles, Alan Kekwick, and R. S. Handley rendered able assistance, and Mr. Lloyd-Davies kindly made himself responsible for any intravenous therapy that might be required during the operation.

Operation was simple, inasmuch as the innominate bone was nowhere invaded by new growth; the symphysis was cut through with a knife; the patient was, with the greatest gentleness, turned over toward the sound side, and to a degree that just sufficed to enable the dorsum ilii to be sawn across to the sciatic notch. It was then very easy to secure all the branches of the internal iliac vessels before they were cut, and the nerves were blocked with novocain before being divided. Every step in the operation was taken quickly and quietly; very little shock was produced, but it was deemed prudent at the very end to administer a blood transfusion of 500 c.c. The operation lasted an hour and ten minutes, and the condition of the patient at the end was surprisingly good, reminding all of *Case* 2 in this series in the excellence of his state at the termination of so severe an amputation. The pulse-rate on the return of the patient to bed was 84. Recovery was uneventful, and the wound healed by first intention.

PATHOLOGICAL REPORT.—On section a spindle-shaped tumour arising from the periosteum of the upper half of the femur, chiefly from the inner aspect (transverse diameter, 5 in.). The growth is soft, with areas of hæmorrhage, and is invading the overlying muscles; there is no evidence of bone formation, and little evidence of invasion of the bone cortex. *Spindle-celled sarcoma.* (*Fig.* 470.)

Section shows infiltration of tissues by solid

masses of darkly staining short-spindle cells. There is no evidence of bone formation.

TECHNIQUE OF THE OPERATION

It is significant of the excellence of Hogarth Pringle's description of this amputation that his account[3] has been re-read by one of us (G. G.-T.) before the performance of each of the operations on the cases narrated in the preceding pages.

Anæsthesia.—In each case spinal anæsthesia was employed in conjunction with general anæsthesia; the latter was induced by means of gas and ether in a Clover inhaler, and this was followed by open ether. *Dosage of stovaine:* probably about 7 cgrm. stovaine is an appropriate dosage, but in *Case* 3 an injection of 10 cgrm. was administered.

Incision.—Several incisions have been employed by various surgeons (*Fig.* 471). In four of the cases detailed above the incision was that recommended by Hogarth Pringle: this is a modification of Girard's incision and will be found to satisfy the requirements of most cases, save when the anatomy of the pelvis is grossly deformed by gigantic tumours, such as that depicted in *Fig.* 459 (*Case* 3). In this case the incision of Savariaud was made use of, and a long internal flap employed. Though every endeavour was made to ensure a good blood-supply to the flap, it sloughed in part. Possibly the degenerated state of the arterial system may have accounted for this.

Position.—The patient is turned slightly on to the sound side, with a sand-bag under the shoulder and another under the lower part of the thigh of the affected side. While these dispositions are being made *one of the veins* of the antecubital fossa of the upper extremity of the sound side is *rapidly exposed,* with a view to facilitate the transfusion of blood, for which previous arrangements have been organized.

The incision is carried along the crest of the ilium from behind the posterior superior spine to the anterior superior spine of that bone: it is then continued downwards and inwards 1½ in. below Poupart's ligament towards the middle of the origin of the adductor brevis. Where any doubt is experienced as to the fixity of the neoplasm on the inner aspect of the innominate bone, and as to the possibility of removal, it is well straightway to cut through the flat muscles of the abdominal wall at or above their attachments to the iliac crest, and to satisfy oneself at once as to the pathological integrity of the peritoneum, etc., before proceeding to deal with the external iliac vessels. Where no such doubts are felt, it may be of some comfort to the operator to deal with the external iliac vessels as soon as this first incision is made. Except in *Case* 3, where the femoral vessels were ligated, the external iliacs have been secured at the level of Poupart's ligament. *No* direct search was made for deep epigastric or deep circumflex iliac vessels; and they do *not* appear to have been damaged.

Poupart's ligament is divided at each end (*Fig.* 472), and the inner pillar of the external abdominal ring, thus allowing the spermatic cord to be drawn inward out of harm's way. The insertion of the rectus abdominis to the pubic crest is next divided, and, after the anterior and posterior surfaces of the pubic bone have been cleared by blunt dissection, the symphysis pubis is divided by knife, or if necessary by saw (*Fig.* 473).

The patient is then very gently turned further over on to the sound side, and an incision carried from the mid-point of the iliac crest down to the gluteal fold, which is followed to meet the lower and mesial extremity of the first incision in the cruro-scrotal sulcus. The dorsum ilii is exposed and sawn through into the sciatic notch; this manœuvre is more simple and expeditious than attempting to disarticulate at the sacro-iliac synchondrosis. If it be necessary, the small piece of the auricular surface of the ilium can be rapidly detached afterwards.

TABLE I.—Operative Mortality in Interinnomino-abdominal Amputation

Nature of Disease	Number of Cases	Recovery	Death	Percentage Mortality
Sarcoma	37	17	20	54.1
Tuberculosis	15	5	10	66.6
Non-tuberculous disease of innominate bone and hip-joint	1	1	—	—
Osteoclastoma	1	1	—	—
Unknown origin	1	—	1	—
Total	55	24	31	56.4

The anterior and posterior bone sections being now complete, the innominate bone and lower extremity can be drawn away from the pelvic peritoneum and its contents (*Fig.* 474).

The lumbo-sacral cord, the first and second sacral nerves, and the obturator can all be identified and injected with novocain before division. The obturator artery, the gluteal artery, the sciatic artery, and probably the internal pubic artery, can be secured before division, and in this manner the hæmorrhage can be greatly minimized.

The psoas is cut through above the pelvic brim, and the division of the pyriformis and the levator ani, and the detachment of the ischiocavernosus and crus penis from the ischiopubic ramus liberates the innominate bone from the last fibromuscular links which fetter it to the underlying structures; the limb and the innominate bone are free.

All bleeding is now controlled, and the peritoneum reinforced by the suture of the remains of the gluteus maximus, levator ani, etc., to the flank muscles and rectus abdominis. The skin is then sutured with interrupted stitches.

Retention of urine has followed the operation in the three of our cases that survived, and catheterization has been required.

The most important points in the conduct of the operation would appear to be: (1) The most gentle care should be taken in turning the patient: the danger from rough or excessive movement of a patient under spinal anæsthesia cannot be exaggerated. (2) The most thorough organization of blood transfusion arrangements. (3) Division of the posterior portion of the dorsum ilii with the saw is more expeditious and simple than disarticulation of the bone at the sacro-iliac synchondrosis; it is easy subsequently to ablate the auricular portion of the ilium. (4) Hogarth Pringle's incision is that most universally satisfactory; (5) It is almost unnecessary to stress the importance of minimizing hæmorrhage and shock by preliminary control of vessels before division, and of nerve-blocking before section of the trunks.

STATISTICS

One of us (P. W.) has expended much time in bringing the literature of the subject up to date, and, including the 5 personal cases placed on record in this communication, has verified the references in 55 cases in which the innominate bone and lower limb have been removed, either as a single-stage or as a plurigrade amputation. In some of the cases included in this series the removal of the innominate bone has been incomplete.

Of these 55 cases, 43 complete amputations have been performed as a primary operation. These cases are analysed in *Table I.*

It will be seen that the mortality of the procedure in the cases that we have been

able definitely to verify, has been 56.4 per cent. *Tables II* and *III* give details of cases found in the literature.

A close scrutiny of the 74 cases reported by Judin[4] in 1926 reveals the fact that no fewer than 9 of these cases were duplicates, that another patient is reported to have died whereas the case ended successfully, and there are other inaccuracies which need not be elaborated here. A certain lack of confidence is naturally created, and it becomes difficult to assess the degree of credence that should be given to those reports from the "Russian literature", to which we ourselves have been unable to gain access. *(Tables IV, V.)*

If we add these "Russian figures" to those that we have confirmed and verified, there are some additional 24 cases with 16 deaths; 16 of these operations were for sarcoma, of whom 11 succumbed to the operation.

The operation has therefore been done about 79 times, with 46 deaths, i.e., a mortality-rate of 59.5 per cent.

In judging these figures it must be remembered that unsuccessful cases are much less likely to see the light of day than are successful ones; this statement is more particularly true at the present time, when the operation is an established procedure, than formerly, when even an attempted operation of this character was indeed an achievement of note. It is almost certain, therefore, that the mortality-rate given here underestimates the real gravity of the operation.

SUMMARY

1. A short note is given of five interinnomino-abdominal or hindquarter amputations, of which three were successful. Of the two fatal cases, one undoubtedly died from a failure in the transfusion arrangements, such as would not occur to-day; in the other fatal case, death appeared to have been due to cardiac failure. In this patient it was perhaps not sufficiently appreciated how baneful an effect upon the heart muscle and on the tissues of the body had been the very long confinement to bed on a mistaken diagnosis.

2. The operation will always remain one of the most colossal in surgery, but organization of team-work and the perfecting of transfusion arrangements will bring the mortality of the amputation down to a still lower percentage.

3. An attempt has been made to bring the literature of the operation up to date.

4. A description of the operation has been included.

For the beautiful pictures which adorn this paper we have to thank our friend Mr. Thornton Shiells.

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EDITOR'S NOTE. It has not been practical to try to reproduce the Figures and Tables II to V that appeared in the original article.

Sir Gordon-Taylor KBE (1878-1960) was a leading British Surgeon until his death. Although he wrote extensively in medical history and biography, in 1935, with his then-younger contemporary Philip Wiles he reported the first series of cases (5 in number) in which hind-quarter amputation was described as a one-stage procedure. Although the operation is now performed at our leading centers whenever indicated, it still demands rather masterful surgical competence. I have included the author's cases but eliminated Tables II, III, IV and V which were merely listings of surgeons and of cases culled from the literature which had been amputated in multiple procedures before this time.

CLASSIC 31 Treatment of Fractures of the Neck of the Femur by Internal Fixation

M. N. SMITH-PETERSEN, M.D., (1886–1953)
Boston, Massachusetts

In 1931 a method of internal fixation of fractures of the neck of the femur by means of a flanged nail was published by the author. A series of 24 cases treated over a period of 6 years was reported. This trial period was deemed sufficient to justify publication of experience gained and results obtained. A new method of treatment is never perfect at the time of its inception but it improves as errors are eliminated; at the time of the publication we did not feel that the method of introducing the nail had been perfected since it was an extensive procedure, requiring wide experience with hip joint surgery; this necessarily limited its usefulness. Results obtained, however, were far superior to those obtained by other methods in our clinic.

After publication we continued the open reduction because the operative findings were such that closed reduction seemed doomed to failure in many cases. Interposition of synovia, capsule or fragments of bone was interpreted as a barrier to bony union. Later developments proved us to be wrong in this conclusion. Apparently the principle of the nail appealed to surgeons in different parts of the world but not the method of insertion. Modifications, simplifying the surgical procedure, soon appeared in the literature and excellent results were reported.

Wescott of Roanoke, Virginia, advocated closed reduction, followed by nailing through subtrochanteric incision, using protractors and anteroposterior x-ray films to guide the course of the nail. He reported a very successful series. Johansson of Gothenburg, Sweden, introduced a centrally cannulated nail which was threaded over a Kirschner wire introduced under roentgenographic control by means of a rather complex instrument of precision. Again a series of excellent results was reported. King of Melbourne, Australia, independently of Johansson, proposed the use of a centrally cannulated nail, two wire guides being introduced under the fluoroscope. He also reported a successful series. The interesting point about these three pioneers in the field of closed reduc-

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NOTE: It has not been possible to include in this reprinting the original illustrations that accompanied this text.

tion, followed by nailing through a small lateral incision, is that they all depended upon roentgenographic control. It is my feeling that they all came under the influence of the contribution of Leonard and George who introduced the curved cassette for the purpose of taking lateral roentgenograms of the hip. Even though the curved cassette has been shown to be unnecessary, credit goes to them for calling attention to the value of lateral roentgenograms of the hip in the treatment of fractures of this joint. In view of their success with the closed reduction, the theoretical objections, such as interposed structures, must be set aside.

Many other modifications have appeared during this 5 year period; the aim in general has been to render the introduction of the flanged nail less complex and, therefore, available to a greater number.

THE NAIL

The nail (Fig. 1) seemed an ideal means of fixation; it displaced a minimum amount of bone and effectively prevented motion in all planes. However, substitutes for the nail, in the form of wires, pins, screws and bolts soon appeared; their method of introduction was said to be simple, they apparently immobilized the fracture, and good results were reported. No procedure for internal fixation of fractures of the neck of the femur should be termed "simple"; it may appear so to the originator, but the novice will always find it complex. As to their efficiency: The mechanical principle of the nail is sound, more sound than that of any of the substitutes.

As to the good results reported: Bony union in fractures of the neck of the femur sometimes does not occur for a year or even more than a year. Roentgenographic evidence in this respect is unreliable. There is little or no external callus, and the amount of internal callus is difficult to estimate; more than once have we interpreted roentgenograms as showing bony union, withdrawn the nail, and obtained nonunion. In 2 cases this occurred over a year following operation. In view of this experience I have become skeptical of any roentgenographic interpretation of "bony union" in a few weeks to a few months. Any report, then, which is based on cases of less than 2 years' duration must be referred to as a preliminary report, not a report of end-results. Until we have reports on true end-results we are unable to accept wires, pins, screws, and bolts.

The serious objection to the nail has been raised that it "slips out" or becomes extruded into the soft parts in the subtrochanteric region (Fig. 2). One reason for this is that the surgeon commits the error of sacrificing the full thickness of cortex at the point of insertion of the nail. The same is apt to happen if the head of the nail is driven into the cortex, depressing it into the medulla. If the cortex is left intact and the starter properly used, this is much less apt to happen because the flanges of the nail are then gripped by the cortex. Even so, the nail is sometimes extruded, but only in the presence of absorption of the neck. In these cases this "objection" becomes an advantage, because it allows the head to stay in contact with the remains of the neck until union takes place; if the nail were not extruded, the fragments would be held apart and nonunion would result.

SHOULD THE OPEN REDUCTION BE ABANDONED?

After publication of the first 24 cases, encouraged by our results, we continued using the open reduction in 26 more cases. The results were not quite so good as in the original series: In only 70 per cent was bony union obtained, although function was most satisfactory. In the total series of 50 cases, 12 were old, ununited fractures at the time of operation; duration of nonunion varied from 6 to 24 months. In 9 or 75 per cent of these, bony union with excellent function

was obtained by open reduction and nailing. The average age was 45 years, considerably younger than in the fresh fracture cases. Just one case is reported to illustrate this series:

A young woman of 32 years entered the hospital with an ununited fracture of the neck of the femur of 19 months' standing. Roentgenograms showed a relatively dense head (Fig. 3), but there were areas apparently undergoing Phemister's "creeping substitution"; there was slight absorption of the neck. Open reduction (Fig. 4) with nailing was done; slight bleeding from the head, good bleeding from the neck. The nail was low but good relationship between the head and distal neck was obtained. After 8 weeks' recumbency, with extremity suspended, the patient was allowed up in a leather spica; crutches with increasing weight bearing were used for 8 months, followed by a cane. The nail was removed 12 months after operation. Roentgenogram 3 years later showed slight thinning of joint cartilage and mild hypertrophic changes (Fig. 5); at this time there was no pain and the function was excellent.

In cases of nonunion, without absorption of the neck, the open reduction is necessary in order to remove scar tissue and to freshen fracture surfaces; the nailing procedure is justified by the results obtained in a relatively high percentage of cases. The operation is extremely difficult and lengthy; it should not be undertaken in the aged.

Watson-Jones of Liverpool, England, is using a lateral approach with exposure of the fracture, followed by nailing (Fig. 6). This is distinctly less of a surgical procedure than the supra-articular, subperiosteal approach. He reports 91 per cent of bony union in a series of 35 cases. Any method as successful as this surely deserves consideration, in spite of the fact that it involves fairly extensive surgery.

PRESENT TECHNIQUE OF INSERTING NAIL

The procedure used in our clinic at the present time is a combination of the technique as published by Wescott, by Thornton and Sandison, and by White. There is no emergency about the operative procedure; the patient can be made comfortable by suspension of the affected extremity with 5 to 10 pounds of traction. There is very commonly a mild temperature reaction to the injury and resulting hematoma; the temperature runs between 99 and 100 degrees. Thorough physical examination, accompanied by the usual clinical laboratory tests, should always precede the operation; on the basis of such an examination the anesthesia is decided—local, spinal, or general.

Either preceding the operation or as a first step in the operating room, a roentgenogram is taken of the unaffected side with a measuring rod strapped to the skin over the greater trochanter as suggested by Wescott and Watson-Jones. This gives a means of determining the exact length of the nail (Figs. 7 and 8).

The method of reduction is essentially that advocated by Leadbetter. There is little difficulty experienced in reducing the fracture; adduction, external rotation, lateral traction and various other maneuvers have been advocated in order to "unlock" the fragments; in our early experience with open reductions we thought these maneuvers helpful, but as time went on we learned that traction in flexion followed by internal rotation, abduction and extension is most satisfactory in reducing the fracture. My personal method (Fig. 9) of applying traction in flexion is to place my forearm under the leg of the affected side with the knee in flexion; the other hand is placed on the patient's pelvis, the thumb just below the anterior superior spine, fingers under the trochanter. Before applying traction, the arm which is exerting countertraction is held with the elbow flexed; as traction is applied, the elbow is extended and the body is straightened. These two maneuvers, extending the elbow and extending the hips, furnish all the traction that is necessary. The traction maneuver is followed by internal rotation, abduction, and extension; these

three motions are performed practically simultaneously, at least one follows the other so closely that it would be misleading to say that one takes place independently of the other. With the hip extended (Fig. 10) so that the shaft of the femur is parallel with the surface of the table, an assistant maintains this position by holding the extremity with the knee flexed at 90 degrees or more; internal rotation of the hip approximately 20 degrees and abduction of about 25 degrees are carried out. This is a very secure position; with the knee flexed at 90 degrees or more and the hip abducted and internally rotated, the rectus femoris is relatively taut, thereby aiding in the apposition of the fracture surfaces. If the hip were in the adducted and externally rotated position, flexing the knee would tend to do just the opposite, namely, displace the distal fragment upward. Thornton advocates the use of a board underneath both thighs just proximal to the flexed knee joints; this is a distinct help in maintaining the position. Roentgenograms are now taken in the anteroposterior and lateral planes; if the reduction is not satisfactory, the entire procedure is repeated.

A satisfactory reduction does not necessarily mean an anatomical reduction; a slight valgus position of the head is to be desired because it represents a stable relationship for transmission of weight bearing (Fig. 11). It should be remembered, however, that if the head does go into valgus, the nail should be started lower in the subtrochanteric region in order to strike the center of the head. A varus position of the head is to be avoided; it represents an unstable position which does not stand up under weight bearing. Rotation of the head, either anteriorly or posteriorly, should not be accepted, since they both will result in limitation of hip motion.

Having obtained a satisfactory reduction, an incision (Fig. 12) 4 to 6 inches long is made over the trochanter, extending downward parallel with the shaft of the femur. Exposure of the lateral aspect of the trochanter is necessary in order that the superior attachment of the vastus externus to the inferior border of the trochanter may be defined. The vastus externus is reflected subperiosteally, exposing the subtrochanteric region. The central axis of the neck corresponds to a point three-fourths of an inch to one inch below the ridge representing the superior attachment of this muscle. At this point the nail starter is driven in at an angle previously determined by means of a protractor from the roentgenogram taken after reduction (Fig. 13). Wescott first described this method of directing the course of the nail from the subtrochanteric region.

The nail starter is intended for the purpose of going through the cortex without dulling the edges of the nail; it is advisable to direct it in the correct course. As soon as the starter has penetrated the cortex, it is removed and the nail is inserted in its place; again the direction of the nail with the lateral aspect of the femur is usually between 40 and 50 degrees (Fig. 14). The nail is now driven in, it is kept in the horizontal plane unless the lateral roentgenogram shows that the neck of the femur deviates from this plane; if it does proper correction is made. As the nail enters the medulla, if it is correctly directed, it will enter the central axis of the neck with very little resistance. If it is found that there is resistance to the progress of the nail, roentgenograms should be taken, since resistance usually indicates that the course of the nail is incorrect and that it is striking either the superior or inferior cortex of the neck. Roentgenograms taken at this time, then, will decide whether the aim is right; if there is any question about its being correct, the nail should be withdrawn and started in the corrected direction. It is at this point that White's instrument is particularly valuable (Fig. 15); in the past we

have found it extremely difficult to extract the nail once it was started on its course. With White's instrument it is very easily extracted and started over again. This instrument also serves as an extension to the nail and facilitates aiming it in the right direction.

With the hip in the abducted position the central axis of the neck of the femur intersects the femoral artery as it passes under Poupart's ligament. A lead marker placed at this point is helpful in directing the nail; I use both the protractor and the lead marker, checking one against the other.

After the nail has been driven home, anteroposterior and lateral roentgenograms are taken. If these are satisfactory, the fracture is gently impacted (Fig. 16); I still feel that impaction is important in apposing and interlocking the fragments, but it should not be overdone.

Teamwork is essential in any method depending upon radiographic control of the course of the nail. Faulty x-ray technique means loss of time and loss of the surgeon's temper. This is particularly true in the method outlined, which requires the use of one portable x-ray unit only; this means shifting of the x-ray machine for the anteroposterior and lateral films which increases the chance of error Relatively few hospitals can boast of two portable units, however; such equipment increases technical accuracy and greatly facilitates the introduction of the nail.

As already stated, many methods have been developed for closed reduction, followed by lateral nailing; the surgeon must select the one that appeals to him the most and visualize every step before he undertakes it. Our own experience with this method is limited to less than 20 cases, over a period of less than 2 years, so we cannot report end-results. The experience of other surgeons is much more extensive; their results are decidedly favorable.

POSTOPERATIVE TREATMENT

Postoperative treatment remains essentially the same as that described for open reduction. The extremity is suspended with 5 pounds of traction; exercises are started in a few days after operation, for the foot, knee, and hip. At the end of 4 weeks the patient is allowed up; crutches are used for a period of 4 to 6 months, with partial weight bearing at first. A bivalved spica is used for walking for the first 4 to 8 weeks in order to maintain abduction. If the relationship of the fragments remains satisfactory at the end of 6 months, full weight bearing may be allowed. In cases of old nonunion, crutches are used for a longer period, sometimes for as much as a year. The nail is never removed in less time than a year; it may be left in for years without doing harm.

SUMMARY

The success of any method for internal fixation of fractures of the femoral neck depends upon contributions from many sources. A satisfactory reduction can be accomplished by a simple maneuver; this was brought out and emphasized by Leadbetter. That the position is satisfactory can be verified only by taking lateral as well as anteroposterior roentgenograms; the importance of the lateral roentgenogram was first demonstrated by Leonard and George. Fractures of the femoral neck, impacted in valgus, will result in union and good function almost regardless of treatment. We feel that the principle of gentle impaction, as well as the valgus position, are important; Cotton was the first to make use of it in his impaction method; with the aid of the lateral roentgenogram his percentage of successful cases will unquestionably be higher. The mechanical principle of the means of internal fixation must be sound; the three-flanged nail has stood the test of time.

Five years have elapsed since the first report on internal fixation of fractures of the

neck of the femur by means of the flanged nail was published. The principle of the nail has been widely accepted, not so the open reduction. In view of the good results reported from the use of the closed reduction, followed by nailing through a small incision, we have come to the conclusion that the open reduction is unnecessary in fresh fractures; in old ununited fractures open reduction is indicated and good results are obtained in selected cases.

No paper on fractures of the femoral neck would be complete without referring to Dr. Royal Whitman's outstanding work. He was the first to prove that these fractures could unite by bony union and thereby he stimulated efforts to achieve better results.

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DISCUSSION

Dr. J. R. Moore, Philadelphia: It is, indeed, a privilege and an honor to have the opportunity of discussing this excellent presentation.

The principle of internal fixation in the treatment of fresh femoral neck fractures has greatly simplified one of the most difficult fracture problems. To be able to offer to the aged patient the hope of his return to a pleasant and useful existence without the extreme physical and mental sacrifice so frequently associated with past methods is enough in itself to justify its preservation. The passing of stiff joints following prolonged fixation together with apparatus adjustment; the reduction of the period of decubitus; the decrease in lung, heart, and renal problems; and in addition, a decidedly higher instance of union and earlier restoration of function—all leave one most thankful to the author for his contribution.

The open or closed method is entirely a matter for the operator to decide. The fundamental principles of fracture treatment are still as essential and vital as ever. Bone to bone contact and accurate fixation can in no way be ignored by the introduction of a metal nail. Reduction must be obtained first. This is determined by two roentgenograms, both being absolutely essential. In the anteroposterior view one determines the proper restoration of the shaft and neck relationship, eliminating coxa vara and the associated shortening. In the lateral view of the neck, the fragments are lined up, thus eliminating the usual external rotation deformity, the accompanying angulation at the site of the fracture, and the anterior or posterior displacement of the distal fragment of the neck.

The relationship as observed in the anteroposterior roentgenogram is the easiest to obtain, and because of this fact the operator is frequently inclined to ignore or omit the lateral view. The omission of this important step is probably the most common cause of failure in reduction and non-union, whether the internal fixation by nail is employed or

whether one uses any other method of reduction. I recall a case of a young woman, 22 years of age, who had what appeared to be an anatomical reduction as shown in the anteroposterior view. After 6 months' fixation in a double hip spica cast extending from the toes to the nipple line, non-union was present. The lateral roentgenogram, which had been supplanted in the beginning by the stereo-anteroposterior roentgenogram, clearly demonstrated that only slight bone contact existed. The lateral view of the femoral neck is just as important as the lateral view in a Colles's fracture.

In a series of 25 cases at the Temple University and Philadelphia General Hospitals, the so-called "blind nailing" was employed routinely in all fresh fractures in which an accurate reduction could be demonstrated in the lateral and the anteroposterior views. In those cases which could not be reduced, the open method was employed. In fractures that were 2 weeks old or older, the open method was considered imperative to insure good bone contact. The Whitman and the Leadbetter maneuvers were used uniformly to obtain reduction in the closed cases.

The period of fixation is just as important in the healing of fractures as is any other phase of the treatment. The mere introduction of the nail does not mean that bone repair is going to be accelerated. Early walking in these cases in 2, 3, or 4 weeks after reduction may be sensational, but will take its toll from the percentage of successful unions. In the above group of 25 cases, it is entirely too early to quote end results. Six known failures, however, can be attributed to either faulty reduction or permitting the patient to bear weight under the tenth week. I believe that weight bearing should be prohibited for at least 3 months, and then partial weight bearing with the aid of crutches should be insisted upon for the next 3 months. The final test of union seems to rest chiefly with the roentgenogram. One cannot be certain of union unless the fracture line is obliterated and the trabeculation pattern is restored.

Dr. Smith-Petersen has offered us a method of internal fixation for treatment of fractures of the neck of the femur. If we adhere to the fundamental principles of fracture reduction and healing, we may expect a marked improvement in our handling of this very difficult fracture problem.

DR. DEFOREST P. WILLARD, Philadelphia: Seven years ago I first had the opportunity of seeing Dr. Smith-Petersen use the flanged nail for fixation of fracture of the femoral neck. Since that time I have followed the publications on this method and its various modifications, have seen it used by other skilled surgeons, and have used it on suitable cases in our own clinics. I am convinced that the evidence that is now before us has established the fact that this form of treatment has been thoroughly tested, and that it must be given a high place among the accepted methods of treatment of this type of fracture.

It is logical that this should be so, for the procedure fully conforms to the three great fundamentals of correct treatment of any fracture—first, that anatomical replacement of the fragments must be functionally exact; second, that this replacement must be rigidly maintained until healing takes place; third, that active motion of the adjacent joints and muscles must be started within a few days after replacement. It is obvious that there is no place in the human body where it is more difficult to carry out these axioms than in fracture of the femoral neck, and as far as my own experience goes, there is no method of nonoperative replacement and fixation that can efficiently carry out these three requirements. Any method of open operation that allows full visualization of the fractured area will, of course, allow accurate apposition of the fragments, and I am entirely convinced that lack of care in this first essential is the reason for many

of our poor results. It is well known that the blood supply of the femoral head and neck, especially in adults, is extremely poor. It has also been demonstrated that the large proportion of this supply comes through the posterior part of the neck and capsule. For this reason alone open reduction with accurate alinement of the fragments gives us the best basis for the restoration of the blood supply and for ultimate recovery.

I am, therefore, not yet a convert to Dr. Smith-Petersen's latest adaptation of his method as he has described it tonight. I am still of the opinion that better results are to be obtained by full visualization of the fractured area. Certainly is this true in the cases of nonunion with which we have to deal in our clinics. It is practically impossible by any manipulative method, no matter how accurately checked by roentgenogram, to make sure that the two fragments are accurately apposed, especially as to their posterior surfaces. It is also impossible to be assured of placing raw bone in contact with raw bone in these old cases unless the fracture site is widely exposed.

The type of incision used for this open reduction is, I believe, immaterial. Any incision, or set of incisions, is efficient that will give full exposure of the fractured area and access to the external surface of the upper femoral shaft so that the nail may be easily and accurately driven. The subperiosteal flap, as first described by Dr. Smith-Petersen, or double straight incisions exposing separately the fracture site and external femoral shaft, fulfill the requirements. In many cases the double incision seems to be preferable. Local, instead of general, anesthesia may be used and much of the anesthetic shock may be eliminated. Either of these types of incision shorten the length of operation and eliminate the necessity of special roentgen-ray apparatus in the operating room.

By use of the flanged nail, the second, and third tenets of the fracture credo—rigid fixation and early motion—are, to my mind, more efficiently fulfilled than by any other method. The nail maintains the fragments in apposition, it prevents rotation, and by its rigidity it allows motion of the hip joint by voluntary muscular action earlier than other methods. This firmness of fixation has been very well shown in one of our patients in whom age and pre-existing paralysis have prevented any callus formation whatever. This patient has now been able to stand and walk for a period of over 2 years with the nail as the only support between the head and the neck of the femur.

Theoretically the criticism may be raised that the use of a foreign body, such as a nail or a pin, will cause absorption of bone and impede callus formation, but our experience is in accord with Dr. Smith-Petersen's belief that absorption in these cases has not been great enough to embarrass the healing processes.

Too much stress cannot be placed on the necessity of early active motion in this type of case. Our own experience which has been, as I have said, almost entirely with ununited fractures, convinced me that this early movement of joints and muscles plays a vital part in the restoration of blood supply in the formation of callus, and in the prevention of limitation of motion in the joints of the injured leg. It has been our custom in our postoperative treatment to use some type of balanced splint in which the leg can swing easily and to begin motion as soon as the skin wounds are healed. Plaster-of-Paris fixation is now used only in cases in which the proximal fragment is so small or so soft that there is danger of the nail tearing out.

Time does not permit of the discussion of what type of case is most suitable for this procedure or of the best moment in the posttraumatic period for the use of surgery of any sort. It is obvious that any surgical method will fall into disrepute if the proper selection of cases is not made. It is equally

obvious that each case must be carefully studied, not as a simple mechanical injury to a bone, but as a livng organism whose vital functions may be seriously interfered with by the best of surgery if such surgery is applied at the wrong moment. If these factors are borne in mind, I feel assured that the methods that you have heard described tonight will for many years hold their place among the most efficient procedures for conquering this difficult surgical problem.

Dr. Smith-Petersen is to be congratulated on two points: First, because he has presented to the profession an operation that has been well thought out and thoroughly proved; second, because he has stimulated our profession into new thinking about a condition in which the results have been far from satisfactory.

Attempts to transfix a femoral head after fracture by means of a nail driven through the trochanter started with Langenbeck in 1850. It was continued from then on chiefly by German surgeons. Lambotte and Delbet tried screws; however, the results were generally unsatisfactory in spite of an occasional success. Many further trials with bone pegs, nails and screws followed, but a lack of control of direction and subsequent rotation of the head made the method generally ineffective. In 1925 Marius N. Smith-Petersen of Boston (1886–1953) designed a 3-phlanged nail, using it under direct vision through an anterior hip incision. The 3-phlanged nail solved the problem of rotation after insertion. It was reported in 1931. In 1932 Wescott of Roanoke, Virginia, and Sven Johannson of Stockholm, both independently reported the use of the Smith-Petersen nail driven through the trochanter without arthrotomy of the hip joint—the technic of "blind nailing" under x-ray control. Following his friend Johannson, Smith-Petersen adopted the technic and presented his larger series of results in this classic report of 1937. The 3-phlanged nail which prevented rotation of the femoral head was Smith-Petersen's classic invention.

CLASSIC 32 Massive Fluorosis of Bones and Ligaments

P. FLEMMING MØLLER
AND SK. V. GUDJONSSON

In the course of a series of investigations concerning the incidence of silicosis among workers in dust-producing industries, we examined, during the winter 1931–32, seventy-eight employees of a factory where the work was very dusty, the criminous material being *cryolite,* which in the early stages of the refining process still contains a certain amount of quartz, and might therefore be thought likely to produce silicosis.

The total number of workers employed in this factory was about one hundred. Of these, twenty had been engaged in the work less than two years, and were therefore not included in the investigation. Of the remainder, 78 were examined. What immediately struck one in questioning these was the relatively short time that the men on the average seemed to remain at this work. Thus, of a staff of one hundred, only 18 had been working in the factory for more than ten years. This could not be due to unsatisfactory working conditions or poor wages, but, as the result of the investigation plainly showed, must be ascribed to the unpleasant and unhealthy character of the work itself; a conclusion which was also fully supported by the information elicited from the workers examined.

As the investigation proceeded, it revealed, in fact, a number of curious and highly interesting conditions; one of them — which shall be particularly dealt with in the present article — being an affection the occurrence of which in man we believe has not been observed or described before, though a precisely similar pathological picture has been observed — albeit not roentgenologically — after experiments on animals, notably dogs.

It was found that in the subjects examined at least *four different affections were frequent.* All these were typical occupational diseases, such as arise solely and directly from the conditions of the work on which the individual is engaged. They were: (1) *silicosis,* (2) *abnormal changes in the bones,* (3) *an acute affection of the stomach,* (4) *pronounced olighemia.*

1) *Silicosis,* the disease which we rather expected to find, was present, in various stages, in half (i. e. 39) of the subjects ex-

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From the university's roentgen clinic at the State Hospital, Copenhagen (Chief: Ass't Prof. P. Flemming Møller, M.D.), and the Occupational Hygiene Bureau of the Labor Inspectorate (Chief of the Bureau: Sk. V. Gudjonsson, M.D.)

Note: The illustrations that appeared in the original article have not been available for use in this issue.

amined. In none of them had the development gone beyond the second stage, however. Of all the seventy-eight, 25 had the disease in the second stage, and of these, 6 were severly affected. Only a few of those examined had previously worked under conditions which might be supposed to have in any way contributed to the development of the disease, and it must therefore be assumed that the latter was due to the quartz-laden dust in the factory where they were now working.

The finding of silicosis in these thirty-nine workers incidentally threw a light on several other interesting facts concerning this disease. These will be made the subject of a later, separate paper, however. We will therefore not here dwell on the results which further examination of these subjects gave as regards silicosis, but merely state that half of the workers examined showed roentgenologically demonstrable symptoms of that disease.

2) *Changes in the bones.* We have said that our first object with these investigations was to ascertain whether the workers were affected with silicosis. As the investigation proceeded it struck us, however, in studying the roentgenographs, that many of the pictures of the thorax showed a curious whiteness and density of the shadows of the ribs, claviculæ and cervical vertebræ, differing considerably from the bone-design one usually finds in roentgenographs of the lung. At the same time, we were puzzled by the unusually long exposure required for obtaining a picture with all the details clearly brought out.

We were therefore not long in coming to the conclusion that there must be some pathological change in the bones; and in order to test the matter a roentgenograph was taken also of the vertebral column of one of the subjects, as seen in the accompanying plates. (Fig. 1.)

We soon realised that the changes observed must in some way or other be connected with the inhaling of the particular kind of dust (cryolite) to which the workers were exposed; and this, as we shall show later, must be supposed to be correct. At the first glance, the absolutely milk-white shadow of the vertebral column made us think that we possibly had before us a case of the socalled »marble disease». The subsequent examinations soon showed, however, that the picture differed considerably from the picture of the latter, at the same time as the clinical symptoms were in no way the same, and that the changes were observed in the bones and ligaments were of a kind to which no analogy could be found in any former roentgenological experience.

Though, by that time, a great many of the workers had already had their lungs inspected, they were now all called back, and the bone system of each thoroughy examined, with the result that *in 30 of the 78 there were found osseous changes* of varying degree and extent. In the very severest cases the bones, especially the spongy ones, were enormously altered both in structure and outline. What first impresses one in looking at the vertebral column in *Figs. I a, b, c and d,* and the pelvis, is the almost complete effacement of the osseous structure, which has been replaced by an almost absolute milky white opacity. In a few places the structure still shines through; but such isolated beams of bone as one can see are very thick, dense, and of a woolly indistinctness. The contours of the vertebræ, too, are absolutely lacking in sharpness; and if we should compare the picture presented by some of these bones to that of any known disease it would rather be to that which one finds in cases of osteoplastic metastasis of cancer, specially after a cancer of the prostata. Nor are the changes confined to the bodies of the vertebræ alone. Also the transverse processes are plump, thick, and covered with small excrescences; and the spinous processes shine through as a dense, irregular band, that can be followed almost

without interruption all the way down through the middle of the whole column. This is partly because, in the severe cases, also the ligaments and fibrocartilaginous attachments are the seat of extensive calcifications.

The *ligaments* Fig. I d and c, e, on the anterior and lateral aspects of the vertebral bodies form, with their calcifications, actual bridges between the latter, in the same way as in severe cases of spondylitis deformans; and in some places the picture resulting from these calcifications exactly resembles that of a spondylitis ankylopoietica.

Also around the intervertebral and costovertebral articulations there are large, new-bone formations resembling osteophytes.

The posterior ends of *the ribs,* Fig. I f. especially, are covered, along the edges, with large, irregular excrescences, resembling hoar-frost needles due to calcifications in the attachments of the intercostal muscles. In the *lung picture Fig. II,* the whiteness of the ribs and the rigidity of the whole thorax, with these pronounced calcifications of the rib cartilages, are very noticeable. Of the *cartilages* in the other parts of the body it cannot be positively said whether they, too, are affected; at any rate it is not the case with the articular cartilages; nor does there appear to be any calcification of the intervertebral fibrocartilages.

If we look at the *pelvis* in Fig. III, III a, we find there the same opaqueness and density of the bone, and the same lack of sharpness in the contour. Also along the latter we notice a number of partly pointed, partly more blunt calcareous excrescences, corresponding with the attachments of the muscles. The ischiosacral ligaments are markedly calcified, and large calcifications are found also downwards, in the attachments of the adductor muscles.

In the *extremities* (Figs. IV a and b), the compact layers of bone are much thickened, and the marrow cavities narrowed. The normal cristæ are very prominent, studded with cottony calcifications and pointed excrescences, and at the points of attachment of the large muscles there are large, irregular calcifications of the fibrocartilages. The *small bones of the hands and feet* present exactly the same appearance as that of the vertebral bodies, except that the density is less.

In the very severest cases there are changes also in the *cranium* (Fig. V); but on the whole there is but little thickening in the bones of the skull.

From the description here given it will be seen that in the severe cases all the bones are affected, but that the intensity of the changes becomes less from the centre outwards toward the periphery, being always most pronounced in the vertebral column and the pelvis. It is also in these portions of the skeleton that *the first stages* (Figs. VI, VI a, VI b, VI c, Initial stages) of the densification can be discovered in the form of a fleecy thickening of the bone laminæ and an increased whiteness of the bone in the roentgen picture.

In the *second stage,* the bones begin to be actually opaque (Figs. VII, VII a, b, c, d), ridges begin to form, and as a rule there is a beginning of a greater density also in the extremities. The development is gradual, however; no sharp definition can be drawn between the different stages of the disease.

3) *Stomach affections.* The third symptom observed in these workers was an acute affection of the stomach, which, as we shall see in the following, must likewise be ascribed to the particular kind of dust which they were obliged to inhale and swallow in the course of their work. The particular complication is one which has never been heard of in connexion with any other dust-producing industry.

The principal symptoms are *nausea, lack of appetite* and *vomition.* According to the workers, these are directly due to the quantity of dust amid which they are working;

which again depends on the material, the weather conditions, and the like. The more dust, the more frequent the trouble. To these principal symptoms come several others, which occur with varying frequency in individual subjects, such as *drowsiness, excessive salivation, pressure on the heart and chest, belching,* and a somewhat *irregular functioning of the bowels,* most frequently *obstipation.* Many of the workers also complain of *shortness of breath* during the work; but this symptom must probably be ascribed rather to the inhalation of the dust, and has no connexion with the stomach affection, which, as we shall see later, is probably the result of the dust being swallowed.

The stomach affection is of an absolutely acute character, and often declares itself rather shortly after the dusty work is begun. Thus, one of the principal managers of the industry, who is only around the factory occasionally, states that if he stays more than ten minutes in one of the places where the dust is particularly thick, he is obliged to get out into the fresh air in order not to be seized by vomiting.

Of the seventy-eight workers examined, *42, or over half, suffered from these dyspeptic symptoms.* However, just as acute as the latter were in their onset, just as quickly did they disappear as soon as the person got out in the fresh air; though it would always be a quarter of an hour or twenty minutes before he could eat anything. After working hours no feeling of discomfort remained. Only in one case did we find any indication of chronic disease of the stomach (an ulcer). The only more or less protracted symptom which may perhaps be connected with the stomach troubles that affected so many of these workers is the obstipation of which some of them complained. A thorough investigation of the functioning of their stomachs could not be made, however. In the course of time, the workers become somewhat habituated to the dust, but not much. Of 60 who had been engaged in the work for less than ten years, 56.7 per cent. had ventricular symptoms; of 18 who had been at it for a longer time only 44.4 per cent.

Looking now at the three diseases together, which were found in these workers — silicosis, osseous changes and stomach affections — we are undoubtedly safe in saying that they were the result of their occupation, and arose from the extreme dustiness, inseparable from the latter. The material they were handling was cryolite, which in its crude state is mixed with a considerable amount of quartz. This explains the silicosis. The cryolite itself, which is a fluoride of sodium and aluminum, contains a great amount of fluorine — as much as about 54 per cent. Neither aluminum — which, according to MACKENZIE's investigations, does not become absorbed in the alimentary canal at all — nor sodium is known, however, to provoke symptoms like those observed in these workers. Fluorine, on the other hand, is known to be a highly toxic substance, and furthermore capable, as we shall see in the following, of being deposited in the bones. It therefore lay near to connect the pathological symptoms with the latter.

The body, especially the bones, normally contains a small quanity of fluorine. In man, abnormalities of the bones due to fluorine poisoning have never been observed, however; especially not roentgenologically. On experimental animals, on the other hand, such observations were made as far back as 1891. Sodium fluoride does not, as the Na-salts of the other halogens, become excreted in the urine immediately after ingestion *per os.* BRANDL and TAPPEINER therefore thought it possible that, as fluorine in water forms insoluble unions with calcium, which are also partly insoluble in alkalis and diluted acids, a part of the sodium fluoride administered orally would be retained in the organism as calcium fluoride. Experiments

on a dog, which they fed with sodium fluoride in increasing doses of from 0.1 to 0.5 and 1.0 gr. per twenty-four hours, proved this supposition to be correct. All was retained in the organism, nothing eliminated either through the feces or through the urine. Not until a certain accumulation had taken place, and the daily dosage had gone beyond 0.5 gr., did excretion commence, but only to become less again as soon as the doses were reduced.

The tables of these experiments left no doubt but that a constant accumulation of fluorine took place in the organism. The two investigators thought that this could not fail to have an effect on the organs, notably on the kidneys and bones. But the animal remained to all appearances normal, except for a peculiar stiff way of holding its back, especially the lumbar part of it, when running or walking. There was no albumen in its urine; no signs of either nephritis or changes in the blood. After being fed with sodium fluoride continually for a year and nine months, the dog accidentally died from coal-gas poisoning. All its organs were now incinerated, and examined with regard to the quantity of fluorine contained, and it was found that the accumulation of the latter in the organism had been so great that only 1.9 per cent. of the whole ingested quantity was lacking. In the blood, liver, kidneys and muscles no pathological changes, especially no concrement formations, were found. On the other hand, the attachments of the muscles and the fibrocartilages presented some very extraordinary changes. They were curiously rough and opaque, and entirely white; and the fracture surfaces of the cartilages and intervertebral fibrocartilages, too, were of a luminous whiteness, with a velvety sheen. The elasticity was considerably reduced, and the cartilages difficult to break. Also the bones were very white, hard and difficult to break. The teeth were defective, porous, their roots eroded, but the crowns whole. Microscopical examination showed the structure of the bones to be intact, but the Haversian canals so completely filled with numerous shiny, octahedral crystals, found to be calcium fluoride, that it was indeed remarkable that there was still any room for the capillaries.

Similar experiments on dogs have been made by RABUTEAU. He found that the administration of 0.5 gr. of sodium fluoride induced vomiting and excessive salivation, sometimes followed by drowsiness and fatigue, later by cramps and paresis, and finally by respiratory paralysis. An experiment on himself, by RABUTEAU, with a dose of 0.25 gr., produced vomiting and salivation.

ROST, too, has made similar experiments on dogs, and found changes in the bones, of an osteoplastic and osteoporotic character, exactly like those observed by BRANDL and TAPPEINER. At the points of attachment of the muscles most frequently brought into play he found deposits of bony tissue, in some places amounting to veritable ridges and bone tumors. The teeth of the animals became carious. Also MCCLURE and MITCHELL have made similar observations.

It is thus proved that soluble fluorine salts can be absorbed through the alimentation and become deposited in the organism, specially in the bones.

While it is true that in the animal experiments just referred to there was no roentgen examination, we nevertheless find exactly reflected, in the cryolite workers examined by us, all the symptoms there described as resulting from the ingift of fluorine salts — both the clinical ones and those pathoanatomical ones with respect to bones, ligaments and fibrocartilages. So far as it is possible to be at all certain at present, we therefore venture to conclude that *the osseous changes observed in these cases are due to the fluorine contained in the cryolite.*

As it was to be expected from the descriptions of the animal tests, a comparison of the

workers' journals showed the incidence of the bone changes to be in direct proportion to the time the individuals had been engaged in the work. While changes in the bones were found only in 14 (= 25 per cent.) out of 60 who had been at the work for *less* than ten year, they were found in 16 (= 89 per cent.) of the 18 who had worked there for *more* than that time; that is, in all of them except two. As regards the bone changes in those of the first group, they were pronounced in one male worker who had only been in the factory 5 years, and rather severe also in two female workers who had only been there 6 years.

In the early stages, and while the worker is still young, the changes in the bones do not give rise to any pathological symptoms. As the changes become more pronounced, and calcification begins in the fibrocartilages and ligaments, there comes a certain stiffness of the limbs, and the mobility of the spinal column, especially, becomes markedly impaired. Most of the workers do not complain spontaneously of this, however; though some of them will explain that they have been troubled with »rheumatism». As the pronounced changes in the bones occur mostly in the old workers — not because of their age, but because they have been longest at the work — it is impossible to say how much of this »rheumatism» is due to age, and how much to the pathological changes in their bones; though, in part at least, it must no doubt be ascribed to the latter.

In the two workers in whom the changes in the bones were most pronounced, and who had worked in the factory respectively 25 and 11 years, the lumbar and thoracic portions of the spine were found to be perfectly immovable, while, in the older of the two, the movements of the head still seemed to be rather natural. Both of them held their back absolutely rigid when attempting to bend over and pick up something from the floor; a task which they, on the whole, found very difficult to execute. The older of the two (Fig. I) had been aware of this increasing stiffness of his spine for the last ten years, but had not really thought of it as anything serious. During those same years he had also now and then had attacks of cephalalgia and »hammering in the head», which would sometimes become so severe that he had to leave off work for a couple of days. Except for a slight tendency to become dyspneic at any strong effort he was otherwise subjectively well, and did not complain of pain either in his back or his joints. The movements in his shoulder-, hip- and other joints were free, and could be executed to their full extent. The younger man (Fig. I d and e) had felt the stiffness of his back coming on about six years ago, and since then it had gradually increased, until his spine was now become perfectly immovable. He complained a good deal of »rheumatic» pain across his hips, also when lying down. In his case, also the mobility of the head was very slight — rotation only about 10 degrees to either side. Nodding movements could not be executed. The movements of his other joints were free.

4) *Anemia.* In our investigation we did not, of course, omit to look for the existence of other pathological symptoms as well. Especially did we think that the almost complete sclerosis of the spongy bones and, in the severe cases, the narrowing of the marrow cavities of the long tubular bones, might perhaps have affected the blood picture and produced an anemic condition, because it is possible to imagine that in sclerotic bones the red bone marrow may end by becoming destroyed. A complete examination was therefore made of the blood of all those workers in whom changes in the bones had been found. This examination was carried out, with the kind permission of Prof. K. FABER, in the laboratory of the hospital's Dep't B; Dr. NYFELDT, first ass't physician of that department, kindly lending his aid in the work of interpreting the blood pictures found.

In 14, or about half of the 30 subjects examined, the analysis showed a *reduction in the number of red cells;* and in 11 of these 14 the cell count was so low, and the color index so high — the average figures being: red cells, 3,700,000; color index, 1.02; hemoglobin, 77 per cent. — that anemia could positively be said to be present. (Normal hemoglobin percentage, corrected: males, 100—112 per cent.; females, 95—105 per cent.).

Of these 11 workers with positive anemia, 7 had severe changes of the bones, while in the 4 others the changes would be characterised as less severe. Of all the 14 in whom the red cell count was too low, 9 had severe sclerosis of the bones.

The combination of the low cell count with the relatively high hemoglobin percentage may indicate that it is the production of red cells that, on some account or other, has become diminished. In that case it probably lies nearest to suppose that the quantity of red bone marrow has become considerably reduced as a result of the strong sclerosis of the spongy bones, inasmuch as neither embryonic forms of the red cells were found in the blood, nor any basophile stippling, and the blood picture did not otherwise present any pathological abnormalities.

The *white cells* were present in normal quantities. In 18 of the 30 subjects examined there was, however, a disproportion between the numbers of non-segmentated and segmentated leucocytes; the number of the former being increased, so that the relative average percentage of the two types was as 15 to 56; the greatest counted variation being 23/35, the smallest figured with 11/70. Of the 18 subjects in whose blood pictures this abnormality was found, 10 had severe changes in the bones. Of the cause of this disproportion we do not venture any opinion. It may have been due to some affection at the site of production, as a result of which too many young forms have been carried out into the blood stream; but it may as well have been due to some peripheral cause, a focus of infection or such. During the examination of the workers no attention was given to this, and of the possible significance of the finding no opinion can therefore be expressed at present.

However, the examination of the blood brought out the interesting and important fact that in 11 (14) of the 30 cases with changes in the bones there existed a positive condition of anemia which, so far as present indications allow us to judge, must be connected with those changes and the diminution in the quantity of red bone marrow resulting from them. The general health of the workers did not appear to have been affected by the anemia.

As to the marked disproportion in the number of non-segmentated and segmentated leucocytes we would not at present venture to say whether it may perhaps also be connected with the changes in the bones, or possibly with a chronic fluorine poisoning. According to SCHWYZER, the blood of rats, guinea-pigs, dogs and pigeons shows a very high degree of coagulability, and an abnormal proportion between mononuclear and polynuclear leucocytes, when those animals are fed with fluorine. Our investigations thus show a somewhat similar condition in man; but the coagulability of the blood was not investigated, because, at the time when our examinations were made, we were not acquainted with SCHWYZER's work.

In order to get some idea of the *calcium metabolism* in the workers, we measured the amount of calcium in the blood serum of 10 of them. We found it to be, in every instance, about 12 per cent., and the conditions in that respect consequently normal. Both the calcium metabolism and the blood examination as a whole will, however, be made the subjects of further study, the results of which will be published later.

As cryolite contains, among other impurities, a certain amount of sulphuret of lead,

we thought that lead poisoning might possibly have something to do with the pathological symptoms and the changes in the bones. We therefore also sought for *basophile stippling* of the red cells, but *in no instance found any signs of plumbism.* Finally, to make absolutely sure that lead had nothing to do with the condition in the bones, we made an examination of five cases of chronic lead poisoning, but in none of the cases did we find the slightest indication of any osseous changes.

The *urinary findings* showed nothing abnormal in any of the cases. In none of the workers was there found any tendency to *concrement formations;* nor was any marked degree of *arteriosclerosis* observed in any of them, except such as might naturally be the result of advanced age. With regard to the *teeth,* which in all the animal experiments were found to be severely affected, no particular tendency to caries could be ascertained in our cases. All the workers were particularly questioned on this point, and their teeth examined; but in this respect the examination did not establish anything of a specifically pathological character.

The investigation has thus so far succeeded in establishing the occurrence, in cryolite workers, of 1) an acutely arising and acutely revolving fluorine poisoning, the principal manifestations of which are acute stomach symptoms, 2) the development of a chronic affection of the bones, and 3) in some cases pronounced anemia, but, so far as yet ascertained, no other pathological symptoms ascribable to the fluorine contained in the cryolite.

At the present stage of the investigation it is not possible to say whether the work of preparing the crude cryolite for industrial use really can cause chronic fluorine poisoning, but the possibility of this being the case cannot be positively denied; and the circumstance that it can at least induce fluorosis of the bones, ligaments and fibrocartilages made it natural to ask whether similar symptoms might perhaps be found also in workers in other industries where cryolite and other materials containing fluorine are used. A thorough inquiry into this question, especially comprising blood examination, has for various reasons not been possible so far; and such investigation as we have been able to make has therefore been directed only toward the question of possible pathological changes in the bones of such workers.

Fluor-spar (calcium fluoride) might be imagined to induce changes like the ones referred to, but in Denmark there are no workers in that mineral. From an enamel factory we succeeded, however, to get nine workers for examination. The *enamel* is made, in the factory in question, from cryolite, felspar and quartz; the three minerals being mixed, crushed and finally melted. The resulting liquid mass contains a great quantity of hydrofluorine, which is very volatile and is present in the air of the workroom to such an extent that the window panes are destroyed by it, and have to be renewed every year. These workers thus inhale great quantities of fluorine gas. The nine whom we examined had all been working in this factory for a great length of time, some of them as long as forty years. If the fluorine is capable of being absorbed through inhalation one would therefore expect to find very pronounced changes in their bones also, but *none such were detected.* In none of them was it possible to demontrate the slightest indication of abnormal sclerosis in bones or ligaments. Nor had any of them ever experienced any of the acute stomach symptoms that affect the workers engaged in handling the crude cryolite, though the mixing of the materials for the enamel before melting produced a certain amount of dust in the room where they are working.

Beside these enamel workers, we examined 5 *glass workers,* whose special occupation was the etching of glass ware. This process consists in immersing the glass, which is coated with paraffin, in which the

desired design has been traced, in a hydrofluoric acid solution; and in performing this task the workers are exposed to inhaling the fluorine vapors, and to their action in general, to such an extent that one of the men whom we examined, when he had been engaged in the work only for six months had developed severe eczema of the face and scalp, which were unprotected; while his hands, that were protected with rubber gloves, had not suffered. At the same time, the men, who had now been doing this work for several years, had never had any symptoms of acute fluorine poisoning such as the cryolite workers; nor was the slightest sign of sclerosis found in the bones of any of them.

Finally, we examined 6 workers from a *sulphuric acid factory,* where sodium silicofluoride was one of the by-products of the manufacture. Of the six, 5 were engaged in tasks that did not produce dust containing fluorine, but in which they were exposed to inhaling fluorine fumes. The sixth, whose occupation was with the drying of the sodium silicofluoride, felt some slight, acute symptoms in his stomach when the dust was particularly strong, but there were no signs of any changes in his bones. He had only been working in the factory for eighteen months, however. None of the others had ever noticed any discomfortable sensations arising from their work, nor were there any signs of sclerosis in the bones of any of them. They had all been engaged in their present work for from 4 to 9 years.

There was thus not the slightest sign of pathological changes in the bones of any of these 21 workers, though some of them had been working for as long as forty years with substances containing fluorine. Here it must be remembered, however, that they, in their various occupations, had mostly been exposed only to breathing an air, or fumes, saturated with fluorine, while the cryolite workers not only inhaled the dust, but also got it into their mouths and swallowed it. It is undoubtedly to the last circumstance that the acute stomach symptoms are due. What happens is probably that part of the fluorine in the dust particles under the action of the hydrochloric acid in the stomach becomes converted into hydrofluorine. This causes a slight, acute corrosion of the mucous lining of the organ, and the nausea, vomiting and lack of appetite are the results. Also those less contantly observed, minor symptoms such as drowsiness, inordinate flow of saliva, etc., must be ascribed to the same cause (cf. the symptoms observed in the animal experiments). Finally, it must be supposed that the fluorine, perhaps after undergoing still further change, becomes absorbed in the alimentary canal and deposited in bones and fibro-cartilages as calcium fluoride. This, too, would agree with the results of the animal experiments. That the fluorine cannot become absorbed through the linings of the respiratory tract seems to be indicated by the fact that none of the twenty-one workers from the glass-, enamel- and sulphuric acid industries whom we examined had had any symptoms of acute poisoning or showed any signs of pathological changes in the bones. Only one of them spoke of having felt some slight symptoms of poisoning, and he, precisely, worked in a place where the atmosphere was charged with fluorine dust. *We therefore feel safe in concluding that the changes are due to the cryolite dust, and are caused by the dust being swallowed, and the fluorine absorbed through the alimentary canal.*

As a further means of studying the changes in the bones we have also made some *experiments on animals,* feeding young rats, 30 days old, with cryolite. Up till now, we have not succeeded in producing the disease experimentally, the reason undoubtedly being that the quantities of cryolite we have hitherto given the animals have been too large, so that they died before the disease had time

to develop. The experiments are still being carried on, however, and we have observed the same symptoms of poisoning as have been found in other animal experiments with fluorine. The cryolite lowered the animals' appetite very considerably, they became thin, did not grow, and in very short time their condition became one of extreme marasmus. The animals were being kept in separate cages, and »feed-mixture no. 4» used as base of their feeding. The control animals were given this exclusively; for the experimental animals it was mixed with finely powdered cryolite in the proportions of 1, 0.5 and 0.25 per cent. Water and feed were given *ad libitum,* the feed being weighed before it was given, and the animals themselves were weighed every week. The average loss of weight in the animals fed with cryolite, as compared with the control animals, is shown in the following curve.

We have also made the experiment of feeding animals with rickets-producing food mixed with cryolite, and found that on this feed the animals tolerated enormous quanties of cryolite without any trouble or loss of appetite. On the other hand, animals that were given this feed + vitamin D tolerated the cryolite just as badly as others. As this is, however, an abnormal type of diet, the experiments are of minor interest in the present connexion, and shall therefore not be described in detail here. The results of them will be published later, together with those of the other animal experiments.

What these experiments have thus confirmed is the fact that cryolite, ingested *per os,* is a toxic substance, the first effect of which shows itself in a lowering of the appetite; a phenomenon which, as we have seen, was also very marked in the case of the workers, even though in them it was only a passing symptom. As an additional information it may be noted that hens kept around the cryolite mines are said to die when they eat of the mineral.

The curious sclerosis of the bones observed in these cases, which does not cause the affected subject any trouble so long as the ligaments and muscular attachments have not yet become involved, has also suggested the idea whether it would not be possible to use the cryolite or some compound of fluorine, notably sodium fluoride, *therapeutically,* especially in such bone diseases as imperfect osteogenesis, brittleness of the bones, osteomalacia, disseminated fibrous ostitis and the like, which result in pronounced osteoporosis. If it were possible by cautious administration of pulverised cryolite or sodium fluoride, given on a full stomach — beginning perhaps with such small doses as from 0.5 to 0.10 gr., and eventually increasing to just below the quantity that might cause inconvenience in such forms as nausea and the like — to obtain the deposition, in the diseased bones, of so much calcium fluoride as would produce an incipient sclerosis, it might perhaps be possible to restore to the bones of those unfortunate sufferers such a degree of firmness that further troubles arising from their disease would be avoided. Experiments to that effect are being carried out at present, but of the results that may come from them nothing can be said as yet.

Also in tuberculosis of the bones it is possible to imagine that a fluorine therapy might be effective, not only by contributing to a more rapid circumscription of the process, but perhaps also, through the markedly disinfectant property of the fluorine, by causing the processes to heal more rapidly; seeing that, according to the animal experiments, the calcium fluoride becomes deposited in the Haversian canals. Inhalation of fluorine vapors has been tried before, as a therapy in pulmonary tuberculosis, precisely on account of the disinfectant properties of the fluorine, but was soon abandoned; nor can there, of course, after what we have seen in the foregoing, have been

any resorption of the fluorine through the respiratory tract.

A survey of the literature shows that a fluorine therapy for bone diseases has already been proposed by BRISSEMORET;[1] but unfortunately we have been unable to find here either the original or any summary of his publication on the subject.

Finally, the markedly increased coagulability of the blood noted by SCHWYZER in his experiments on rats, guinea-pigs, dogs and pigeons might suggest the advisability of trying a fluorine therapy in diseases of a hemophiliac character.

Our investigations are, however, as yet far from completed, and these various suggestions concerning a fluorine therapy are included here only for the sake of greater completeness, in what must be regarded merely as a preliminary communication. The many interesting problems concerning the fluorine in the organism and its action on the various organs, arisen out of the experiences here recorded, will be taken up for more thorough investigation, the results of which will be presented in a later, more complete publication.

SUMMARY

The authors record the results of their examination of 78 workers engaged in the crushing and refining of cryolite. Beside silicosis — to as much as the second degree — which was present in 39, the following three diseases were found to be common in these workers:

1) a curious sclerotic affection of bones, ligaments and muscular attachments, probably due to the deposition of calcium fluoride in the bones. The authors believe that the occurrence of this disease in man has not been described before. It was found in 30 of the workers examined.

2) an acutely arising and acutely revolving affection of the stomach, supposedly due to a slight corrosion of the mucous lining of that organ, owing to some of the fluorine contained in the swallowed cryolite-dust being changed by the hydrochloric acid of the stomach into hydrofluorine.

3) a pronounced oligemia, found in 11 of the 30 workers in whom pathological changes in the bones were observed.

These changes in the bones are described in detail, and the causes of their occurrence, as well as that of the other symptoms, and the connexion of these with the fluorine contained in the cryolite, are discussed.

The results of the investigation are compared with those of an investigation made of 21 other workers from industries where fluorine and materials containing fluorine are used.

Also animal experiments, with feeding with cryolite, are spoken of; but a more detailed description of these is reserved for a future communication.

Finally, the authors speak of experiments with a fluorine therapy for certain bone diseases, and suggestions for such a therapy; but also those experiments are in the nature of a preliminary communication.

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[1] BRISSEMORET recommends a fluorine therapy, »dans les fractures pour hâter la solidification du cal dans la tuberculose pour favoriser la reminéralisation de l'organisme chez les femmes pendant la grossesse et l'allaitement contre la carie dentaire» but says nothing about his own results of the treatment, except that he has observed »une amélioration très nette» in cases of the last-named disease. (Added in the proof.)

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P. FLEMMING MØLLER

This paper by Møller and Gudjonson of Copenhagen was the first report of the effect of exposure of the human skeleton to fluorine in industry. Previous purely chemical studies had been performed on dogs. This paper, appearing in a prominent journal of roentgenology, introduced the subject for the first time to orthopaedic literature. To the orthopaedic surgeon, the subject is of diagnostic importance and rightly so.

CLASSIC 33 A Physiological Study of the Blood Supply of the Diaphysis

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The first systematic studies of the circulation of the blood in bone were carried out by Lexer, and the anatomical findings established by him and his colleagues stand out today as unchallenged and beautifully demonstrated facts. In the article by Lexer, Kuliga and Turk, stereophotographs of x-rays of the various bones injected with mercuro-turpentine emulsion give us a visual demonstration of the vascular network of the bones which has not been equalled in any later contributions. The normal anatomy of the blood vessels in bone has, therefore, been established for over twenty years. However, in the course of studying and teaching bone pathology, the anatomical facts of the circulation have not proved an entirely satisfactory basis for the clear understanding of pathological changes.

The controversy about the rôles of the various portions of the bone in the healing of fractures brought into prominence the physiology of bone as distinct from its anatomy. Many other problems of bone pathology have served to emphasize the importance of the physiological point of view in our attempts to fathom bone diseases and to plan a rational therapy for them. One specific example of the beneficent effect of the physiological outlook has been the greatly improved treatment of bone cavities resulting from destructive osteomyelitis. However, in dealing with injuries and diseases of the bone we are confronted with so many and such difficult mechanical problems that, as a general rule, we have paid too little attention to the physiology of the tissues with which we are dealing. Therefore, working from the mechanical side, we have been too content with our anatomical knowledge only and have questioned too little the physiological problems.

Certainly, very little work has been published in English dealing with bone physiologically, with the exception of a considerable literature on the fate of bone grafts. In the foreign literature there is not much additional information to be gained, though Müller's recent book, devoted to the normal and pathological physiology of bone, is most interesting and should stimulate a similar approach in this country. Even in this typically comprehensive work there is, however, very little to be found concerning the circulation of the blood in bone beyond the anatomical facts established by Lexer, and a description of the development of hyperemia at the site of fracture or sarcoma.

*From the Surgical Hunterian Laboratory, Johns Hopkins University, and the Bowles Research Fund, Children's Hospital School, Baltimore.

In short, there is practically no exact information about, or even interest in, the physiology of bone and its blood supply, which supply is certainly one of the most vital necessities in repair of injury or combat of disease.

The recent work of Petersen at Johns Hopkins has shown the importance of the proper chemical balance between calcium and phosphorus in the circulating blood to the healing or non-union of fractures. It seemed, therefore, of real value to get some definite idea of the physiology of the vascular network by which the building materials for repair are carried to the fracture, or the defensive troops and war material transported to the trenches in the fight against disease. It appeared probable that some factor other than blood chemistry was responsible for the occurrence of the vast majority of non-unions in a few definite locations. These poor results have long been attributed to vascular factors without, however, any real knowledge of the basic circulatory changes. It, therefore, was in hopes of throwing some light on the physiology of the blood supply in bone that the following experiments were carried out.

Anatomically there are three distinct vascular systems which supply the diaphyses of the long bones. First, the *nutrient artery* piercing the cortex and sending a large branch in the marrow cavity toward each bone end. Second, the *metaphyseal* system of a number of small vessels entering and penetrating the cortex and branching profusely within the marrow of the metaphyseal region. Third, the *periosteal* system encircling the whole surface of the shaft. It was our immediate task to determine the extent of the vascular field of each system and the compensatory anastomotic adaptability of each system to carry on the work of the other two. To do this we employed two methods: (a) injection with India ink along the usual anatomical lines; (b) study of the bone physiology and pathology in connection with the viability of the cells of the cortex and the marrow, and the progress of bone repair in drill holes made in the cortex.

The following is the plan of the experiments. (1) To study the extent of the vascular tree of the *nutrient artery* and the efficiency of its anastomotic twigs; the periosteum was stripped from the shaft and the medullary cavity blocked off with wax plugs at the metaphysis to cut off the metaphyseal vessels. Dogs were sacrificed, injected, and gross and microscopic study of bone defects carried out. The dogs utilized in this way will be considered collectively as Group 1. (2) To study the extent of the *metaphyseal* vessels and their anastomotic ability, the periosteum was stripped up, the nutrient artery ruptured and only the metaphyseal region of the shaft left undisturbed. Dogs were similarly sacrificed, injected and studied. These constitute Group 2. (3) To study the extent of the *periosteal blood supply* and its anastomotic connections, the nutrient artery was ruptured and the medullary canal blocked with wax plugs inserted through a drill hole at each end of the diaphysis. Dogs were similarly sacrificed, injected and studied. These are Group 3.

In each group one dog was sacrificed immediately, one dog in four or five days, one dog in two weeks, one dog in three weeks, and one dog in four weeks.

Dogs killed immediately were studied together comparatively as Class A; dogs killed in four or five days were similarly treated collectively as Class B; dogs killed in two weeks constitute Class C; dogs killed in three weeks constitute Class D; and dogs killed in four weeks constitute Class E. To avoid confusion let it be emphasized that the term "Group" refers to the differentiation according to the three different blood supplies, and the term "Class" according to the time interval before sacrifice. Each *class* has been studied separately to get a comparison at set time intervals between the extent of the individual vascular systems and their effi-

	Group 1 Nutrient	Group 2 Metaphyseal	Group 3 Periosteal
Class A Immediate	Dog 14 Right leg	Dog 14, left leg Dog 15, left leg	Dog 15, right leg
Class B Four days	Dog 3 Right leg	Dog 13 Left leg	Dog 2 Right leg
Class C Two weeks	Dog 9 Right leg	Dog 8 Right leg	Dog 11 Left leg
Class D Three weeks	Dog 5 Left leg	Dog 10 Right leg	Dog 4 Left leg
Class E Four weeks	Dog 12 Left leg	Dog 6 Right leg	Dog 7 Right leg

ciency in promoting repair. Each *group* has been studied separately to get a serial story of the physiological changes taking place following the isolation of the shaft, except for a single vascular supply. Findings in the study of the specimens according to both class and group constitute the general conclusions reached.

Description of the operative technique and the details of the gross, x-ray and microscopic findings in each experimental animal are given at the end of this paper. The summaries of each class and group are as follows:—

SUMMARY—CLASS A—IMMEDIATE

The results obtained from immediate ink injection showed that a maximum pigmentation of the diaphyseal medulla was obtained when the nutrient artery was alone intact. The metaphyseal vessels and their anastomotic branches gave the second best injection of the medullary portion of the shaft. Injection of the periosteal system, however, was practically ineffectual below the surface of the cortex. The cortical bone in all instances was not discolored to any appreciable degree and no gross injection was to be seen, so that no distinct cortical demarcation could be shown by immediate injection, but this will be demonstrated in the microscopic findings of the later classes.

These findings represent the immediate and fundamental basis from which to start the study of the pathological physiology of the repair process in the later stages of the experiments.

SUMMARY—CLASS B—FOUR DAYS

1. The absence of adequate injection of the cortex in any section indicated that there is little likelihood of an early effectual anastomosis between medulla and periosteum via the cortical vessels of the shaft.
2. The medullary callus was the earliest and most active factor in the repair of cortical defects.
3. This reparative reaction was particularly active in the case of the undisturbed nutrient artery (Dog 3) which was shown to carry an adequate supply of blood for efficient repair.
4. The metaphyseal supply was successful in maintaining the viability of the marrow unaided, but the repair reaction, especially in mid-shaft defect, was not as active as in the controls.
5. The nutrient artery recovered from trauma and revascularized the medulla rapidly in Dog 2.
6. There was no revascularization of marrow by the periosteal supply through the defects, as each of these was occluded by a complete layer of unorganized blood clot in Dog 3.
7. Cortical necrosis indicated that the outer one-third of the cortex is supplied by the periosteum, while the medullary vessels care for the inner two-thirds, with the nutrient artery being the main factor except close to the metaphyses.

SUMMARY—CLASS C—TWO WEEKS

1. There was poor injection of the cortical vessel in all experiments of this class, showing that anastomosis through the dense bone of the cortex is not to be relied upon as a source of collateral supply even after two weeks.
2. Revascularization and recolonization of

the cortex occurred slowly and was not well marked in two weeks.

3. The medullary callus was again the most active agent in repair of defects, though, when only the periosteal supply was left (Dog 11), this response was naturally delayed until revascularization via the defects had taken place and was consequently much less advanced than normal.
4. The metaphyseal and the nutrient blood systems were quite adequate to replace each other and prevent medullary necrosis, while the periosteal supply was hopelessly unequal to doing so.
5. Cortical necrosis zones showed that, roughly speaking, the outer half of the cortex is dependent on the periosteal supply, while the inner half is supplied from the medullary vessels.
6. The periosteum attached slowly and was not active in bridging the defects with bone. Periosteal callus over and in the defects was chiefly fibrous, though when in contact with the surface of the cortex the reaction was osteoid.
7. New bone formed much earlier along the side walls of the defects in contact with the old cortical bone, even though this was necrotic, than in the centre of the defects where it was almost uniformly fibrous and somewhat umbilicated.

SUMMARY—CLASS D—THREE WEEKS

1. The nutrient artery, unaided, was able to supply sufficient blood to allow active and well advanced repair at all defects.
2. The metaphyseal circulation was adequate, alone, to maintain viability of the medulla and inner layers of the cortex and to institute repair, which, however, was not as active or efficient as in the case of the nutrient artery.
3. The periosteal supply did not prevent marrow necrosis when the medullary supply was completely blocked, as shown by 4-X-3 (Fig. 14), but revascularization through the defects did take place and bone repair started, though very much delayed and feeble.
4. The nutrient artery readily resumed function when the foramen and canal were not occluded with wax, even when the extent and degree of periosteal stripping about the foramen showed clearly a rupture of the vessels and severe traumatization of its entrance to the canal.
5. Periosteal repair of large defects was typically umbilicated, its reaction being more and more fibrous in character towards centre of defect.
6. Injection and viability findings indicated that the cortex was supplied from the medulla in its inner two-thirds, and from the periosteum in the outer third.
7. Findings at the end of three weeks differed little from those at two weeks, except that the canals of the cortex had become widened by absorption, and the revascularization and recolonization had progressed markedly in the cortex. The callus in the defects was, of course, more abundant and advanced with denser bone lamellae.

SUMMARY—CLASS E—FOUR WEEKS

1. The intact nutrient artery gave the best injection of the medulla and the most advanced repair of defects.
2. The metaphyseal supply was sufficient to maintain medullary viability, but reparatory activity of the medulla was delayed and depressed.
3. The periosteal supply had served to revitalize the bone via the defects, though there was still some evidence of medullary necrosis.
4. The periosteal new bone was only exhuberant where the periosteum had been stripped or traumatized. Where left intact it was thickened but not profusely productive.

5. The cortex showed wider areas of necrosis with more extensive absorption and revascularization at this stage (four weeks) than previously, and there was considerable recolonization of empty lacunae about the enlarged canals.
6. The cortical absorption and revascularization had proceeded so far that a collateral, transcortical supply of some sufficiency had been established at this stage.

Group 1. Nutrient Artery.
Summary of Serial Findings.

Immediate injection showed in the gross the extent of the nutrient field, i.e., there was complete injection of the marrow cavity between defects No. 1 and No. 3 with ooze of ink from all three holes. The visible injection of the cortex was practically nil.

Starting from this point we found that in four days the periosteum had not yet firmly reattached to the cortex. During this time necrosis of the outer layers of the cortex had taken place and only the inner layers near the medulla were viable. The medulla, itself, was viable throughout. The defects were well filled with medullary callus, which was just as active and extensive in the experimental leg as in the control. Extent of injection was essentially unchanged, showing that there had been no establishment of collateral supply and no increase in the vascular field of the nutrient artery itself.

In two weeks: The periosteum had reattached and was forming new bone over the surface, but as yet very little change in the condition of the cortex was to be noted. There was no real signs of porosis of the cortical bone, and revascularization and revitalization of the necrotic layers were just beginning. The medullary injection was complete, but practically no cortical injection was visible. Medullary repair was as active as, or more active than in control.

In three weeks: Increasingly abundant periosteal new bone formation had taken place. Porosis of the cortex with process of revascularization and revitalization was much more evident, though not extensive even yet. Medullary injection was very marked and indicated a distinct hyperemia of the medulla with very active callus formation which now filled the whole defect. Medullary injection was more marked than in the control.

In four weeks: There was extreme periosteal new bone formation. The cortex was very porotic at this stage with revitalization actively progressing. Injection of the cortex was well marked. The medulla was also very well injected and repair processes were still very active and, if anything, more efficient than in the controls.

Group 2. Metaphyseal Vessels.
Summary of Serial Findings.

The immediate injection of Dog 15 showed distribution of the ink throughout the whole medulla when only the metaphyseal vessels were intact. In the animals allowed to go longer the injection and cellular viability of the medullary tissues demonstrated a collateral circulation within the medulla, which is both immediate and efficient in maintaining normal nutrition. The reparative processes in defects No. 1 and No. 3 of this group seemed to be somewhat slowed down, though this was not a constant finding, while the delay at defect No. 2 was distinctly more marked. While the injection of the medulla in all cases was complete there was evidently a delay in the hyperemia which restricted the proliferation of the medullary callus, the restriction and delay being greatest at defect No. 2 which was farthest from the metaphyses. The presence of defects No. 1 and No. 3 probably accentuated this delay by unavoidable trauma to the medulla at operation, and by subsequent partial plugging of the canal by callus at these two points. However, on the whole, one was struck by the efficiency of the collateral circulation and the rapidity and extent of the medullary repair.

The cortex retained viability, as a rule, in

its inner one-third, but the cortical revascularization was slower than was the case in Group 1.

All these findings showed an appreciable depression in the response of the medullary tissues of the diaphysis depending solely on the metaphyseal collateral supply as compared to Group 1, or the controls.

Group 3. Periosteal System. Summary of Serial Findings.

In the immediate injection the lack of any ink in the medullary canal showed that there was insufficient collateral anastomosis through the cortex to allow ink to penetrate. This was also borne out by the findings at operation on the other dogs of this group. In each instance there was no bleeding from the defects after the nutrient and metaphyseal supplies had been cut off.

The microscopic and the injection findings in the dogs which were saved over varying periods were not so definite and clear cut as had been hoped. This was largely due to the technical difficulty of making certain of the avulsion of the nutrient artery from the foramen and the permanent blocking of the foramen with wax. Owing to its position on the outer posterior aspect of the tibia it was not possible to clearly expose the vessel and dissection had largely to be done blindly. In each case the foramen was identified by the tip of the elevator, and a rough scraping of soft tissues from the bone was done for a considerable area about this point. While the periosteal thickening always found, postmortem, about the entrance of the foramen showed that the periosteum had been roughly stripped and the vessel torn, the foramen itself was only once found plugged with wax, and then only partially, so that a rapid reestablishment of a severely traumatized or even torn nutrient artery was not definitely preventable. This reestablishment certainly did occur, as shown by the injection tests. However, in spite of it we can gather from the evidence of injection and microscopic sections the following facts.

There was no immediate collateral supply to the medulla from the periosteum via the cortical vessels. The nutrient artery soon became reestablished even in the face of a great deal of local trauma (outside the nutrient canal). The outer one-half or less of the cortex only was kept supplied via the periosteum. When the nutrient and metaphyseal supply was completely cut off there was medullary necrosis, as shown in 4-X-3 (Fig. 14).

The medullary callus was much delayed in most instances. The revascularization of the medulla via a defect did not begin to take place until after five days at least, but later on this was a big factor in the formation of the callus in the bottom of the defects.

Observations of a General Character Made During the Course of the Experiment.

Traumatization in the form of rough stripping up, stimulated the periosteum markedly to new bone formation. Periosteal new bone formation, however, was well and quickly produced only when the new bone was laid down upon a foundation of old bone. Periosteum did not bridge a dead space, such as a defect, well and the reaction here was largely fibrous and only became osseous close to the side walls or at the base where there was a contact against old bone. The centre of the defect, which relied on periosteal repair, was always umbilicated. The medullary callus was the most rapidly formed and prolific agent in the early repair of cortical defects, and welled up rapidly from the bottom to fill the dead space. Medullary callus did not seem to pass through a cartilaginous stage but ossification proceeded directly from conversion of fibrous type of callus. Periosteal callus was often seen to be cartilaginous.

Bone wax could not be made to adhere to the cortical surface, but when rubbed in as evenly as possible was found at autopsy to be collected into small masses and surrounded with dense fibrous tissue, acting as an irri-

tant which increased periosteal reaction and new bone formation. The bone wax plugs which were placed in the central canal always seemed to cause an exuberant periosteal new bone formation on the surface which gave rise to an external fusiform enlargement at these points.

The use of fine silver wire as a subcuticular skin suture was a great technical improvement over the ordinary silk closure. The legs were very greatly and extensively traumatized by the operative procedure necessary, and in all cases the silver wire held despite considerable tension and swelling and was a great help in preventing postoperative wound infection in these animals.

The following diagrams express as graphically as possible our conclusions, both as to the extent of the immediate collateral anastomotic powers of each of the three vascular systems of the diaphysis, as shown by injection and cellular viability, and as to the influence that each system has upon the progress of bone repair. This repair is our best index of the physiological status of the bone existing in the various regions of the diaphysis. The diagrams indicate the extent to which each separate vascular system is able to maintain the viability of the cells in various regions of the diaphysis, as shown by the presence of shading. The density of the shading indicates the degree of physiological activity of the cells as tested by their ability to produce bone repair.

CONCLUSIONS

To express our conclusions verbally as well as diagrammatically, the following statements are made.

1. The nutrient vessels maintain viability throughout the medulla and supply the inner half of the cortex. Repair is active when the nutrient vessels alone are intact.

2. The metaphyseal vessels maintain viability throughout the medulla and the inner half of the cortex, but repair is not as active as in the controls except close to the metaphyseal ends, being notably delayed in the middle region of the shaft.

3. The periosteal system does not normally supply more than the outer half of the cortex and is unable to afford an effectual collateral supply to the medulla of the diaphysis under four weeks' time. The periosteal repair is relatively poor in the healing of cortical defects.

4. Regarding the shaft as a whole, the nutrient vessels are the most important, the metaphyseals next, and the periosteal system the least.

5. In all conditions affecting the diaphysis, the blood supply is a most vital factor, and with the above experimental, anatomical, and physiological data clearly established we are in a better position to rationally study and deal with such problems as non-union, delayed union, massive bone transplants, acute osteomyelitis, and kindred diseases.



ROBERT W. JOHNSON

Robert W. Johnson (1891–1969) was born in Baltimore, Maryland. he received his M.D. from Johns Hopkins Medical School in 1917. He joined Drs. Baer and Bennett on its orthopedic staff, eventually becoming Professor of Orthopaedic Surgery. The essay published here appeared as the Classic in Volume 56 of *Clinical Orthopaedics and Related Research*, an issue edited by Marshall R. Urist in honor of Johnson's 77th birthday.

CLASSIC 34 Symmetrical Synovitis of the Knee in Hereditary Syphilis

H. H. CLUTTON (1850–1909)
Assistant-Surgeon to St. Thomas's Hospital

The fact that the condition of which the title of this paper gives the most prominent feature has been little noticed in our surgical literature tempts me to make a few remarks as to its clinical features. I have myself but little doubt that it is due to hereditary syphilis, for the subjects of this symmetrical synovitis who have come under my observation have always given other evidence, either past or present, of the disease. My own cases, of which the notes have been carefully kept, are seven in number. Mr. Nettleship, who has also taken a great interest in these cases, has kindly given me the notes of three others, which I have myself seen at the time they were under observation in the eye department at St. Thomas's Hospital. Mr. Lawford has also supplied me with another case during the last six months, which brings the total to eleven. I have, I am sure, seen many more of which I can find no accurate record; and I well remember, some years ago, soon after I began to take an interest in this subject, that Dr. Greenfield, who was then my colleague, drew my attention to several cases which had occurred in his practice. It must be remembered that my own cases were all out-patients, one or two only being admitted for a time to test the efficacy of splints and rest. The difficulty of keeping any notes in the out-patient room must be my excuse for this deficiency. The disease is, I am sure, a rare one, so that only a few cases will come under the observation of any one surgeon; for since my attention has been directed to this condition I have been on the look out for such patients, and have only met with quite a small number.

The average age of the patients recorded in the accompanying table was about thirteen, but they were mostly between the ages of eight and fifteen. The predominant features of the disease were the symmetry of the affection, the freedom from pain, the long duration of the symptoms, and the free mobility of the joints on passive movement throughout the course of the disease. Its symmetrical character first led me to look for a constitutional cause, and there was no difficulty in seeing that the patients were the subjects of hereditary syphilis. I do not mean to say that no other constitutional diseases could possibly have produced such a symmetrical condition, but I do think that other joints besides the knees would probably have been at some time and in some of the cases affected in a similar manner if such diseases as rheumatism, gonorrhœa, or gout had been

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the cause. I have never seen both knee-joints fill with fluid, causing scarcely any pain or discomfort, whilst other joints remain quite free from any signs of inflammation, except in cases where there was distinct evidence, either past or present, of hereditary syphilis. The patient generally complains of stiffness in one knee, which is then found full of fluid, but not tense: on careful examination the other knee is also found to contain fluid, but not to the same extent as the one for which advice is sought. So that it is fair to assume that the knee to which attention has been directed by the patient has been affected some little time before he has felt any inconvenience. In a few instances there has been an interval of some months before the second knee has given the ordinary signs of synovitis; and in one case (No. 5 in table), which was that of the patient aged twenty, there was an interval of two years. All the other joints have been at the same time carefully examined, to make sure that such an insidious chronic synovitis has not been overlooked, but no joint affection could at any time be discovered elsewhere; nor was there any history pointing in that direction in any of the cases which are here recorded, except in No. 11 in the table. The swelling in some of the cases was accompanied by considerable thickening of the synovial membrane; and in one instance (No. 8) recorded by Mr. Nettleship, the observation is made that in some places it gave the "impression of loose bodies in the joint." But in the greater number this swollen condition was not so noticeable a feature as in the synovitis which may occur as one of the later manifestations of the acquired disease. The chief part of the swelling in the cases now under consideration seemed to be produced by an increased quantity of synovial fluid. The joints were never tense, but gave a sensation of flaccid fluctuation, as if they were only half full of fluid. The bones in the immediate neighbourhood were not enlarged, and in only a small proportion of the cases was there any articular tenderness. Nodes were occasionally found, but generally some little time after the onset of the swollen joint and at some little distance from the affected articulation. The peculiarly chronic nature of the synovitis is still further shown by the fact that in all the cases referred to in this paper the swelling has remained with scarcely any alteration for from three to six months, and in one instance for twelve months. In one case (No. 10) the symptoms followed a more acute course, but were distinctly attributed to a fall on the knees a week previously to the admission of the patient. Treatment by splints and rest in bed seemed to influence the course of the disease very slightly, for those that were treated in this way were as slow in getting well as those that had no local treatment whatever, for as soon as the splints were removed the effusion returned. The ultimate result in all the cases that came under my observation was the perfect recovery of the joints, the most important part of the treatment appearing to be the exhibition of anti-syphilitic remedies—mercury and iodide of potassium; but these drugs had not the same marked effect that they have in the acquired disease.

The facts as to hereditary syphilis are as follows. Of the eleven cases, active keratitis was present in nine, and in one other the corneæ bore traces of a former attack, so that in only one had the corneæ escaped. Five had the central incisors marked in the manner characteristic of the disease. Four had nodes on the tibiæ, and two were afflicted with absolute deafness of recent origin. The latter symptom was in each case devoid of any other obvious cause, and must, I think, be attributed to hereditary syphilis. Thus, every one of the cases quoted had two or more of the symptoms which, taken together, may be fairly held to establish the presence of the disease in question. Less reliable symptoms, such as those presented by the features, have not been mentioned;

Eleven Cases of Symmetrical Synovitis of the Knee.

No.	Sex.	Age.	Joints.	Duration of symptoms.	Evidence of hereditary syphilis.	Family history.
1	M.	10	Both knees.	4 months.	Double interstitial keratitis; typical teeth; ostitis of both tibia.	No notes.
2	F.	8	Both knees.	6 months.	Double interstitial keratitis; ostitis of one tibia.	No history.
3	M.	11	Both knees.	6 weeks, and then ceased attending.	One typical central incisor; nodes on tibia; snuffles and skin eruptions in infancy.	Mother had two still-born children before patient.
4	F.	9	Both knees.	3 months.	Interstitial keratitis of one eye of two weeks' standing, with no further notes; one typical central incisor.	No history.
5	F.	20	Both knees (two years apart).	6 months each.	Remains of double interstitial keratitis; ostitis of both tibiae, which are very large.	No history.
6	F.	10	Both knees.	7 months.	Double interstitial keratitis; typical teeth.	Father syphilitic; no evidence in family beyond patient.
7	F.	15	Both knees, and right articular tenderness.	6 months.	Double interstitial keratitis under Mr. Nettleship; incurable deafness of one month's standing.	No history.
8	M.	14	Both knees, articular tenderness.	3 months.	Interstitial keratitis; typical teeth; deaf.	No notes.
9	M.	12	Both knees.	2 months, and probably more.	Interstitial keratitis.	Well-marked history of mother being infected, and then having miscarriages.
10	F.	8	Both knees acute and painful one week after fall on knees. One joint tapped. Recovered with good joints.	4 months.	Double interstitial keratitis.	Doubtful history.
11	M.	21	Both knees. History also of both ankles having been swollen at commencement.	12 months.	Double interstitial keratitis for nine months; still under observation.	Patient is third child; fourth, fifth, sixth, and seventh children died in infancy; eighth under observation for interstitial keratitis.

but they existed in most of the children who came to the out-patient room with symmetrical synovitis of the knee. The family history is proverbially difficult to obtain in this department of the hospital, and although in a few instances it tended to confirm the opinion already formed, it may be stated generally to have been of a negative character. I do not think that this disease has any relation to epiphysitis, which is so common in syphilitic infants, for there was no apparent enlargement of the bone, as has been already stated, and the swelling was quite uniform in outline. In epiphysitis the swelling is always more or less unilateral, for although the whole joint may be enlarged by consecutive synovitis, one side will generally be found larger than the other, with increased tenderness on the side affected; whereas in the symmetrical synovitis, to which allusion is here made, the joint is uniformly enlarged, and the synovial membrane appears to be the only part affected.

To recapitulate in a few words the principal features of the condition which was demonstrated by these few cases, one would say that the synovitis was symmetrical, affecting only the knees, that was of a chronic and painless character, and that all the patients were the subjects of hereditary syphilis. I can offer no satisfactory explanation of the facts here recorded, but must content myself with drawing attention to a few clinical symptoms. At the same time I would like to point out that if the condition which is now under consideration be really due to hereditary syphilis, the similarity between interstitial keratitis and this symmetrical synovitis is so marked as scarcely to require any lengthened explanation. Both knees, like the eyes, are, in my experience, sooner or later affected, and often with an interval between the commencement of the symptoms in each joint. Both diseases are exceedingly chronic, and produce little or no destructive changes in the tissues involved, neither suppuration nor adhesions having occurred in any of the cases that came under my observation. They are also both liable to relapses, and not very amenable to treatment. The age of the patients is another and striking point of similarity, for seven out of the eleven were between eight and twelve years of age. In two cases the symptoms arose at a much later date, but this also occurs in interstitial keratitis, so that even in its rarer forms it corresponds with that disease in this particular—that of the age of the patient. I am at a loss to explain why the knees should be affected in preference to other joints. It is probable that, with further observation, the knees will not be found to occupy this solitary distinction, and that other joints will be seen to be affected in a similar manner. But up to the present time I have not seen this chronic symmetrical synovitis, which appears to be associated with hereditary syphilis, in any other joints besides the knees. That it should be symmetrical is only what one expects from our knowledge of the similar manifestations of the disease at this period of life.



Henry Hugh Clutton (1850-1909), a London surgeon, published this description of bilateral symmetrical hydrarthrosis of the knees in children in 1886, recognizing its luetic origin. For several decades following this, until the lessening of syphilis in the civilized world, following the introduction of modern antibiotic therapy, "Clutton's joints" were not a rarity in pediatric or orthopedic case books.

CLASSIC 35

Sur la dysostose cleido-cranienne hereditaire

(On Hereditary Cleido-cranial Dysostosis)

PIERRE MARIE (1853–1940)
AND
PAUL SAINTON*

In May of 1897 and in May of 1898 we presented to the Medical Society of Hospitals two groups of subjects afflicted by a singular congenital malformation which we believe had not as yet been described. These cases had been to our knowledge studied by P.-A. Pierre[1] who devoted to them his inaugural thesis in June 1898. In the present report we propose simply to give a general idea of the principal characteristics of this curious malformation and to better achieve this we add reproductions of hitherto unpublished photographs.[2] As to the details of these observations we refer to the work of P.-A. Pierre.

The malformation we are discussing appears with the following essential characteristics:

A. An exaggerated development of the *transverse diameter of the cranium* coincident with a *retarded ossification of the fontanelles.*

B. An aplasia more or less pronounced of *the clavicles.*

C. *Hereditary transmission* of these malformations.

We will review each of these characteristics and try to understand the chief causes, recalling that up to the present only four cases are in question; therefore, our description will be necessarily incomplete.

It is the *appearance of the head* which above all has attracted our attention; it is this which puts one most easily on the track of diagnosis. One is immediately struck by the *transverse enlargement of the diameter* of the cranial vault, and measurements with a caliper show that this enlargement is actual. After the examinations made by P.-A. Pierre under the direction of M. Manouvrier, the transverse diameter in one of our males was 174 mm. compared with a mean normal hardly ever above 159.6 mm. in males. In a female the figure found for the transverse diameter is 171 mm.; and in her daughter, aged 19½ years, it is 157 mm.; the figure of the average normal in females was only 149.3.

This exaggeration of the transverse diameter of the cranium gives to the patient a *facies* which is singularly pronounced if one takes into account the fact that the frontal

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* Translated by Edgar M. Bick.

[1] P.-A. Pierre, Dela dysostose cleido-cranienne herediataire. These de Paris. 1896.

bosses are very prominent and separated one from the other by a vertical depression more or less pronounced (metopic suture), that the parietal bosses are also very accentuated to the point of giving the cranium a fetal aspect. Add that the face presents a certain degree of flattening, at least in appearance, and that it lacks height in relation to the dimensions of the cranium. The eyebrows appear to us in all our cases notably raised and arched. Finally, the ears are found more or less spread out from the head and at one point so marked in two of our male cases that the auricle formed an obtuse angle with the lobe.

The *disturbances of the ossification of the cranium at the fontanelles* are equally one of the factors which concern us. We have already spoken of the persistence of the metopic suture, but the failure of ossification could be more marked and persist up to an advanced stage of adult life. This persistence is obvious in a woman of 47 years in whom the characteristic pulsations are perceptible in the cranium. In other cases one does not see the pulsations, but palpation of this area discloses that the ossification is incomplete, and a membranous area of the cranium persists.

In reference to the deformities of the head, it is proper to indicate again the state of the *roof of the palate* and the *teeth*. In one of our cases (A . . . father) a very severe fissure of the roof of the palate was present due to a failure of fusion of the bone. His son did not present this palative fissure but a very remarkably arched palate. The same was noted in the other group of our cases, in mother and daughter; the formation of the palate was excessively arched.

Dentition is disturbed from several points of view: the teeth are placed very irregularly; moreover, in our two adult cases cavities were present in almost all of them. The two children present the following disturbances: The 12-year-old boy had very small teeth; his incisors had more or less the dimensions of very small canines; and his canines were cup-shaped; one or two teeth were already broken on the way to destruction. As to the girl aged 9½ years, her teeth had been delayed; she still had most of her baby teeth, except for the medial incisors of the inferior jaw (mandible); the incisors were quite separated from each other.

With these different malformations of the head coincided a very singular *aplasia of the clavicles*. To give an idea of this we will repeat the description of each of our four cases:

A . . . father: the left clavicle is relatively well enough developed except in its inner third; the right clavicle presents in its middle third a depression into which the fingers penetrate deeply; it appears as though there were two fragments, perhaps united or a fibrocartilaginous portion.

A . . . son: the internal half of the right clavicle is atrophic; the left clavicle is divided into two osseous portions separated by a fibrous intersection, permitting considerable movement of the two fragments in relation to each other.

E . . . mother: one finds on each side a small rudimentary clavicle extending from the sternum about three centimeters long and giving a sensation of cartilage, it ends in a point and is then lost in fibrous tissue; the outer portion of this rudimentary clavicle is very mobile.

As for E . . . , the daughter, one feels extending from the sternum an indurated module in the position of the clavicle, extending 5 centimeters and losing itself in the fibrous tissue which seems to replace the clavicle, and on which the aponeuroses insert. A roentgenographic examination confirms the finding of palpation.

A bizarre fact is that none of our cases suspected any abnormality of their clavicles; it was during our examination that their attention was drawn to this particular abnormality. Nevertheless, these malformations of the clavicle presented no functional difficul-

ties: E . . . , the mother, remarked that she could not lift heavy objects in a horizontal position; alone, she could not lift a mattress in making a bed; and it was always difficult or even impossible to hold her infants on her arm as usual with nursing mothers; on the other hand, she was capable of lifting a bucket full of water and could carry it quite far. E . . . , the daughter, except for weakness in carrying out these same movements, presented the ability to carry her shoulders in front of her chest; if need be, she could bring them almost together, if it were not for the fat of the anterior thorax.

Obesity seemed to favor certain points as part of the picture of the syndrome, since it occurs in three out of four of our cases.

The last characteristic which we would like to emphasize is that of heredity. Chance had it that our four cases were thus distributed: one father and his son, one mother and her daughter; the first two had no relationship whatsoever with the second two. The heredity influence is therefore incontestable, but it does not appear to be one of those frankly familial syndromes that are perpetrated for several generations and in a large number of individuals. As a matter of fact, A . . . , the father and E . . . , the mother, had brothers and sisters, all of whom were unaffected and whose children showed no trace, so that we could reassure a son of E . . . , the mother. Another interesting fact from the viewpoint of hereditary influence in this syndrome is that the children we examined tended to present the deformities to a lesser degree than their parents.

In our first communication based on the cranial aspect particularly we sought to place these findings under the class of hydrocephalics. That attempt was criticized, notably by Chaslin and by d'Astros; we recalled by ourselves that they actually had nothing to do with ordinary hydrocephaly; therefore, a special classification appeared to be necessary. We have chosen that of "*dysostose cleido-cranienne*," in which the word "dysostosis" has no other pretension than to designate a "disturbance in the ossification" which is its nature.

Pierre Marie (1853-1940) and his associate Paul Sainton, both Parisian physicians, presented four cases of a heretofore undescribed congenital deformity of the clavicles, the palate and the cranium in 1898. They named it cleido-cranial dysostosis, which term was retained in all subsequent references. They generously gave original credit for recognition of this singular dysostosis to P.-A. Pierre who made the syndrome the subject of his Doctoral Thesis at the University of Paris in 1896. However, the subject might well have been lost among the thousands of Doctoral Theses literally buried in the university libraries of Europe (and the United States) had not Marie and Sainton brought the material to the attention of the practicing profession in Paris. I believe that this is its first English translation.

CLASSIC 36 The Formation of Bone Under the Influence of Epithelium of the Urinary Tract

C. B. HUGGINS, M.D. (1901–)

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The relative frequency of stones composed chiefly of calcium and phosphorus in the urinary tract as compared with their occurrence in other excretory systems such as the lower intestine, biliary and pancreatic systems and the salivary glands has made a study of the local metabolism of these elements by the urinary tract of some importance. I[1] have indicated elsewhere in a preliminary report the rather unexpected action of the urinary tract on certain connective tissues in the production of bone. These observations will be discussed in detail in this article, and further observations relative to osteogenesis will be presented.

The presence of bone elsewhere than in the skeleton has been of considerable interest to the students of osteogenesis. An extensive literature dealing with this subject exists, of which a few striking examples may be cited. Apparently the most frequent site of heteroplastic bone is the sclerotic artery;[2] next in order possibly comes calcified foci in the lung, and it is not infrequently seen in the dura mater.[3] Not rarely it forms in the eye[4] following severe destructive processes. It has been described in squamous carcinoma of the skin[5] and in carcinoma of the breast, in the fallopian tube,[6] lymph nodes, tonsils and liver, in fibromyoma of the uterus and in laparotomy scars.[7] It has been stated[8] that any area of calcification is likely to be replaced by bone no matter what tissue is involved.

New formation of bone occasionally occurs in the urinary tract in man or in connection with urologic procedures. Bone was first described in the pedicle attachment of a renal calculus to the pelvis by Phemister,[9]

* Published by Arch. Surg. 22:377, 1931.

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1. Huggins, C. B.: Experimental Osteogenesis, Proc. Soc. Exper. Biol. & Med. 27:349, 1930.

2. Poscharissky, J. F.: Ueber heteroplastische Knochenbildung, Beitr. z. path. Anat. u. z. allg. Path. 38:135, 1905. Bunting, C. H.: The Formation of True Bone with Cellular (Red) Marrow in the Sclerotic Aorta, J. Exper. Med. 8:365, 1906. Buerger, L., and Oppenheimer, A.: Bone Formation in Sclerotic Arteries, J. Exper. Med. 10:354, 1908.

3. Halstead, A. E., and Christopher, F.: Calcification and Ossification of the Meninges, Arch. Surg. 6:847 (May) 1923.

4. Poscharissky (footnote 2, first reference).

5. Nicholson: Ossification in Calcified Epithelioma, J. Path. & Bact. 21:387, 1917.

6. Asami, G.: Heteroplastic Bone Formation in the Fallopian Tube, Am. J. M. Sc. 160:107, 1920.

7. Lewis, D.: Myositis Ossificans, J. A. M. A. 86:1281 (May 5) 1923. Gruca, A.: Myositis Ossificans Circumscripta, Ann. Surg. 82:883, 1925.

8. Wells, H. G.: Chemical Pathology, ed. 4, Philadelphia, W. B. Saunders Company, 1920, p. 439.

9. Phemister, D. B.: Ossification in Kidney Stones Attached to the Renal Pelvis, Ann. Surg. 78:239, 1923.

in two cases. It has been described in the abdominal wall following operations on the bladder by Lewis[10] and others.[11] Chauvin and Rouslacroix[12] described five cases of ossification observed by them in three years, subsequent to cystotomy, in the abdominal wall.

BONE FORMATION IN THE URINARY TRACT UNDER EXPERIMENTAL CONDITIONS

Blessig[13] first observed calcification in the kidney of rabbits killed from four to six days after ligation of the left renal artery. Salkovsky (1866) described calcium deposits in the kidney of rabbits poisoned with mercuric chloride; this has been confirmed by many observers.[14] Litten[15] and others[16] have described extensive calcification in the kidney, regularly following temporary arrest of the renal circulation. A demonstrable deposition of calcium[17] may be present as early as thirty-six hours after a temporary anemia of one hour. The calcification occurs in and around necrotic tubules chiefly in two zones, one beneath the cortical surface and the other at the base of the pyramids. Wells[17] stated that calcification produced by temporary anemia as well as by certain poisons is probably analogous to calcification of organic material in urine rather than calcification of tissues with lime salts direct from the blood, since the epithelium and tube-cast deposits seem to contain calcium only as phosphate with no demonstrable carbonate. When the necrosis and calcification involve interstitial tissues, carbonate can be demonstrated.

An important experiment leading to the formation of bone and bone-marrow in the kidney through permanent ligation of the vascular pedicle was reported by Sacerdotti and Frattin[18] in 1901. These observers described bone occurring in three of four rabbits from seventy-four to eighty-five days after ligation. In two cases the ureter was also included in the ligation. In one experiment at autopsy, some of the pelvis epithelium persisted, and bone formed in spite of the ligation of the ureter; in the other no bone was formed, and the pelvic epithelium had completely disappeared. Poscharissky[4] found bone in three of five animals in which the renal vessels had been tied. Maximow[19] found bone as early as five weeks after ligation of the renal pedicle and described the process in connection with his studies on histiogenesis of blood cells. Liek[20] confirmed the foregoing observations in a series of sixteen rabbits, in four of which he had made a high ligation of the ureters as well as of the vascular pedicle. No bone formed in the latter four. He stated that the necessary requirements for bone formation, namely young connective tissue near calcium depos-

10. Lewis (footnote 7, first reference).

11. Kretschmer, H. L.: Myositis Ossificans Following Suprapubic Prostatectomy, J. Urol. 20:477, 1928.

12. Chauvin and Rouslacroix: J. d'urol. 27:465, 1929.

13. Blessig: Ueber die Veränderungen der Niere nach Unterbindung der Nieren Arterie, Virchows Arch. f. path. Anat. 16:120, 1859.

14. Weichselbaum: Centralbl. f. allg. Pathol. u. path. Anat. 2:9, 1891.

15. Litten, M.: Ueber pathologische Verkalkungen und Kalkmetastasen, Virchows Arch. f. path. Anat. 83:508, 1881.

16. von Werra: Ueber die Folgen des vorübergehenden und dauernden Verschlusses der Nierenarterie, Virchows Arch. f. path. Anat. 88:197, 1882. Eisendrath, D. N., and Strauss, D. C.: The Effects on the Kidney of Temporary Compression of Its Vessels, J. A. M. A. 55:2286 (Dec. 31) 1910.

17. Wells, H. G.; Holmes, H. F., and Henry, G. R.: Studies in Calcification and Ossification, J. M. Research 20:373, 1911.

18. Sacerdotti, C., and Frattin, G.: Ueber die heteroplastische Knochenbildung, Arch. f. path. Anat. u. Physiol. 168:431, 1902.

19. Maximow, A.: Ueber experimentelle Erzeugung von Knochenmarks-Gewebe. Vorlaufige Mittleilung, Anat. Anz. 28:24, 1906.

20. Liek, E.: Experimenteller Beitrag zur Frage der heteroplastischen Knochenbildung, Arch. f. klin. Chir. 80:279, 1906; Ein weiterer Beitrag zur heteroplastischen Knochenbildung in Nieren, ibid. 85:118, 1908.

ts, were met following renal pedicle ligation and commented on the relation of the bone to the persisting pelvic epithelium but did not associate the two factors.

This problem has been studied in great detail from a histiogenetic standpoint by Asami and Dock.[21] All observers have noted that bone occurs in thin lamellae in the connective tissue immediately beneath the mucosa of the renal pelvis, and, if of any extent, is exactly parallel to it. It is never found in the scar tissue of the renal cortex, although calcification is constantly present in this location. All authors have stressed the concept of metaplasia of connective tissue into bone through some unknown influence. Asami and Dock concluded "that bone formation in the kidney with ligated pedicle takes place in three ways: (*a*) through the activity of young fibroblasts which accumulate to form a membrane-like structure (resembling periosteum); (*b*) subsequently by direct ossification of hyaline connective tissue in continuity with prepared bone; (*c*) through erosion of lime plaques and laying down of lamellar bone by cells derived from fibroblasts (osteoblasts)."

Pearce[22] observed bone formation following excision of the lower pole (approximately one-half) of the kidney with suture of the defect in six of nineteen kidneys. Bone developed in connection with epithelial buds of the pelvic mucosa. He commented: "For this peculiar localization there is no explanation."

I have observed bone formation beneath the pelvic mucosa in two of three dogs forty days following fulguration of the renal pelvis with an electrical current of high frequency. This was observed once fifty-two days following the application of 95 per cent phenol.

Strauss[23] observed the formation of bone in experimental reconstruction of the ureter in dogs by means of a modified end to end suture of a pedicle flap consisting of the transversalis muscle, fascia and the peritoneum to the ends of the divided ureter. He stated that the peritoneum became replaced by transitional epithelium and the transversalis fascia by bone, and he thought that possibly the tissues became infiltrated with acid from the urine which caused sclerosis and was followed by bone formation.

BONE FORMATION IN THE URINARY BLADDER

Neuhof,[24] in a study of fascia transplantation into vesical defects in eighteen dogs, observed that bone constantly developed in the surface of the fascial patch bordering on the urine and was invariably confined to this fascia. His opinion was that bone formation could be explained only by a metaplasia of connective tissue, and that the genesis of this bone depended on the deposition of lime salts in the necrotive tissue of the fascial patch in contact with the urine. Apparently, he felt that an imbibition of calcium salts took place which stimulated the surrounding connective tissue to build up the most powerful barrier possible, that is, bone. Cartilage was found once in these experiments.

This experiment of Neuhof was repeated, and the observation of bone was confirmed by Phemister[9] who extended his observations to the rabbit and sheep, which are herbivorous animals with alkaline urine as opposed to the acid urine of the dog. In these animals the fascial patches in vesical defects did not ossify, and he felt that the acid reaction of the dog's urine had something to do with the formation of bone.

21. Asami, G., and Dock, W.: Experimental studies on Heteroplastic Bone Formation, J. Exper. Med. 32:745, 1920.

22. Pearce, R. M.: Notes on the Later Stages of the Repair of Kidney Tissue (Dog) with Special Reference to Proliferation of Pelvic Epithelium and Heteroplastic Bone Formation, J. M. Research 20: 3, 1909.

23. Strauss, A. A.: An Artificial Ureter Made from the Abdominal Wall, Surg. Gynec. Obst. 18: 78, 1914.

24. Neuhof, H.: Fascia Transplantation into Visceral Defects, Surg. Gynec. Obst. 24:383, 1917.

Concerning Neuhof's experimental observations, Leriche and Policard[25] commented "In certain places but on the bladder particularly, and constantly the aponeurotic graft gives rise to a plaque of true bone. It is easy to reconstruct the progress of these phenomena. In contact with the calcareous urine, the fascia necroses and is calcified. Around the borders of the old transplant, a proliferating tissue is formed. In proximity to a calcium collection, it ossifies. It is always the same fundamental process. And these experiments undertaken without preconceived ideas are a rigorous demonstration of the mechanism which we have advanced."

Thus it will be seen that certain clinical and experimental observations relative to the formation of bone in connection with the kidney pelvis, ureter and bladder have accumulated. The pathogenesis of this bone was unknown. The following experimental work was undertaken in an endeavor to throw some light on this phase of the subject as well as on the general subject of bone formation.

Axhausen[26] transplanted the gastric and vesical mucosa to the peritoneal cavity in sixteen dogs. The transplants were made to the outside of the stomach or bladder and lasted from fourteen to seventy days. At autopsy he described the formation of cysts lined by epithelium. The fluid in the cysts lined by mucosa of the bladder was dark red, sanguineous in color, as opposed to the light opalescent fluid in gastric cysts. Bone was apparently not observed, for it is not mentioned in this article.

EXPERIMENTAL OSTEOGENESIS

Dogs were used throughout the experiment, except when otherwise indicated. The surgical procedures were carried out under aseptic precautions, ether anesthesia being used. Whenever transplantation of tissue was done, this was autotransplantation. The animals were kept on a varied stock diet. The wounds were sutured with 00 white silk throughout.

EXPERIMENT 1.—This was a critical experiment to ascertain whether the urine played a rôle in the formation of the bone in the fascial transplants to the bladder.

The abdomen was opened; both ureters were isolated and through a stab incision were transplanted to the skin in the groin just above the inguinal ligament. The dome of the bladder was then opened and dried with gauze. A circular piece of fascia 2 cm. in diameter from the anterior sheath of the rectus muscle was then sutured to the edges of the opening in the bladder with a continuous silk suture (fig. 1*).

After fifty-five days, the specimen was removed, and along the intravesical portion of the graft a dense button of bone was found strictly confined to the fascial transplant. The transplant was dimpled.

Microscopic examination (fig. 2) showed that the surface of the fascial transplant was covered with the transitional epithelium of the bladder. Beneath the epithelium, but separated from it by a small amount of areolar tissue, there was bone in parallel anastomosing plaques with haversian canals containing bone-marrow, connective tissue and blood vessels. On either side of the transplant at its junction with the wall of the bladder, there had been an ingrowth of epithelial cells in the form of finger-like processes continuous with the epithelial lining of the bladder and the transplant. In the transplant adjacent to these processes, in many places, there were islands of bone (fig. 3), but in the wall of the bladder adjoining this epithelial invasion, there was no bone in any of the sections. This observation is of considerable importance, as will be seen subsequently. The bone was covered with large numbers of the cells commonly called osteoblasts, indicating an advance in the osteogenetic process. Wherever there was an island of bone, there was an area of vesical epithelium in the immediate vicinity. However, the converse does not hold, for in some of the sections islands of epithelium were seen without accompanying bone.

This experiment was repeated in three dogs, with the same results; it established conclusively

25. Leriche, R., and Policard, A.: The Normal and Pathological Physiology of Bone; Translated by Moore and Key, St. Louis, C. V. Mosby Company, 1928, p. 194.

26. Axhausen: Die freie Schleimhautüberpflanzung im Experiment, Arch. f. klin. Chir. 102:121, 1913.

that urine is not a factor in the production of bone in this location.

EXPERIMENT 2.—Since the urine is not a factor in the osteogenesis in fascial transplants to the urinary bladder, the bone must arise from some anatomic abnormality such as poor circulation or from the influence of some intrinsic element in the wall of the bladder acting on the connective tissue. This experiment was devised to attempt to determine which of these factors was responsible for the osteogenesis.

The abdomen was opened, and a circular area of the muscular coat of the bladder was removed intact by sharp dissection from the smooth glistening mucosa. When this had been done, the shining mucous membrane was moistened with saline, and the remaining filaments of cottony connective tissue were removed as far as possible. All this was done without opening the lumen of the bladder. The mucosa was then incised, and the area of denuded epithelium (2 cm. in diameter) was excised and transplanted on the sheath of the right rectus abdominis muscle, where it was sutured in place with a continuous suture of silk. Similarly, on the sheath of the left rectus muscle the remaining elements of the wall of the bladder, free from epithelium, were sutured in place. The incision in the bladder was then sutured. After sixty days, the first animal was killed.

In the right rectus sheath, a cystic structure was found. The superficial aspect of the cyst was covered with bone, whereas the deep surface was soft, was free from bone, and fluctuation could be demonstrated. The cyst was opened, and 3 cc. of blood-stained fluid was removed. Microscopic examination of the cyst (fig. 4) showed it to be lined by transitional epithelium, histologically not different from that of the bladder. Surrounding one surface of the cyst (that nearest the skin), there was a plate of bone consisting of anastomosing plaques of living bone with fibrous and hemopoietic marrow in the haversian canals. At either end of the cyst (fig. 5) there were finger-like projections of epithelium that were completely surrounded by bone.

In the left rectus sheath, no bone was found, and it was impossible to determine accurately the site of the transplant except by the presence of the silk sutures.

This experiment has been repeated forty-four times with essentially the same results: bone is present in close relationship to the epithelium which has formed a cyst; the bone never completely surrounds the cyst (fig. 4). The presence of epithelium is necessary for the formation of the bone. The bone in all these experiments formed superficial to the cyst. Bone never forms in association with the fibromuscular elements of the wall of the bladder and invariably forms in association with the epithelial transplants, provided the animal lives twenty days or more. In several instances, marked infection of the wound occurred; nevertheless small areas of bone could always be found on careful search. Of course, if the infection were to destroy the entire graft, no bone would form, but this has never been observed. The vesical epithelium is particularly hardy and favorable for transplantation.

EXPERIMENT 3.—A brief outline of the histogenesis of bone derived from bladder transplants in connective tissues is given.

In a series of eight dogs, a circular area of mucosa of the bladder was denuded of its muscular coat and transplanted as in experiment 2. The specimens were excised at various time intervals for microscopic examination.

At seven and nine days, the epithelium was seen to have formed an epithelial lined spheroid containing fluid (fig. 8). The newly formed epithelium was considerably lower than the transplanted epithelium and consisted of a single or double layer of flat or cuboidal cells. At fourteen and sixteen days, the epithelium had formed its more characteristic appearance (fig. 9), and it was difficult to differentiate between the newly formed epithelium and the transplanted mucosa. At this period the connective tissue surrounding a portion of the cyst appeared edematous, and under high magnifications the edema was fibrillary in type. This connective tissue was more eosinophilic and contained fewer nuclei than connective tissue surrounding other portions of the cyst and was presumably a preosseous stage in the process.

Nineteen days after the transplant, the first spicules of bone were seen adjacent to the newly formed mucosa. In all transplants older than this, bone was constantly found in connection with the epithelial transplants, and it reached its height about two months after the transplantation.

The bone showed little tendency to atrophy and had been observed persisting as late as three hundred and sixty days after the transplant. At this age, however, the bone is not greater in amount than at sixty days.

The bone is typically lamella membranous bone with haversian systems and contains bone-marrow.

EXPERIMENT 4.—Can the location of the bone which forms around a part of the circum-

ference of the cyst developing after a transplant of the mucosa of the bladder to rectus sheath be altered?

In this experiment mucosa of the bladder was transplanted to the sheath of the rectus muscle in two equal strips each about 2 cm. in length. A strip was sewed in the right rectus sheath so that its free surface (intravesical portion) faced in the direction of the skin as in experiment 2. On the left rectus, a strip was sewed in so that its deep surface faced the skin, and its free surface faced the peritoneal cavity (fig. 10).

At the end of fifty days, the animal was killed. Each cyst was partly surrounded by bone. The cyst which had formed on the right rectus sheath had bone covering its superficial surface, whereas that which had formed on the left rectus sheath had bone covering its deep surface (that is in the direction of the peritoneal cavity). This experiment was repeated six times, with constant results. The bone formed always in the vicinity of the newly formed epithelium rather than about the transplanted mucosa.

EXPERIMENT 5.—Can cysts lined by mucous membrane from the urinary bladder be developed which will be surrounded entirely by bone?

In this experiment the urinary bladder was opened through an incision in the vertex; the outer portion of the anterior sheath of the rectus abdominis was then split into its two component layers of fascia for a short distance. The mucous surface of the bladder was then lightly scraped with a sharp knife, and the blood-scrapings thus obtained were deposited in the connective tissue envelop (fig. 11). About one half of the bladder was thus treated, and the hiatus in the rectus sheath was closed by suture. The bladder was then closed.

The dog was killed after forty-nine days; an ovoid multilocular cyst 2 by 2 cm. had formed which was completely surrounded by bone (fig. 12). The cyst was filled with a dark brown serosanguineous fluid.

Microscopic examination showed that the mass was composed of two rather large cysts the bony walls of which were continuous. In the bony walls of these large cysts there were numerous smaller cysts surrounded by bone (fig. 13). All of these cysts were lined by the mucous membrane of the bladder, which in most places was much thinner than that found in the contracted bladder, as if the contained fluid had been under increased tension and had flattened the epithelium. This experiment was repeated four times with similar results, except that the cysts were in no instance as large as in the original experiment. Grossly, however, the cysts derived from transplantation of scrapings from the bladder were entirely surrounded by bone in every instance, and the bone was in intimate association with the transplanted mucosa.

The factor making for the formation of bone around the entire surface of the cyst seems to be the innumerable small scraping-grafts which must have assumed many different positions, allowing the osteogenetic effect of the proliferating mucosa of the bladder to act in many directions instead of in one as in the previous experiment; in other words, in this experiment there was far greater surface area of proliferating epithelial cells exposed to the fascia.

EXPERIMENT 6.—Transplantation of the ureter and kidney pelvis to the parietal fascia will produce epithelial-lined cysts partially surrounded by bone, but similar transplantation of the cortex or medulla of the kidney or of the prostate does not lead to osteogenesis.

1. The kidney and ureter of a dog were excised, through a median abdominal incision, and pockets were prepared in the fibrous sheath of the rectus abdominis muscle for (*a*) renal cortex, (*b*) renal medulla, (*c*) pelvis epithelium and (*d*) whole ureteral wall. All transplanted tissues were sewed in place by means of silk sutures. The fascia was then closed over these transplants.

After fifty days, the dog was killed and the specimens examined. As has been demonstrated by Didier and Guyon, the renal cortex and medulla did not lead to the formation of bone; the grafts entirely disappeared, and no vestige of them could be found.

The grafts of the renal pelvis and ureter behaved exactly like those from the epithelium of the bladder. Epithelial-lined cysts (figs. 14, 15, 16) formed, surrounded in part by bone; the bone was located in the region of the newly formed epithelium and was comparable in amount with the vesical grafts of the same age. This experiment was repeated and confirmed in two dogs.

2. In seven dogs the peritoneal cavity was opened through a right rectus incision extending almost to the pubic bone. The bladder was delivered, and the fatty tissue around the prostate was opened by blunt dissection. The prostate was thus exposed and a cuneiform area of prostatic tissue removed, care being taken not to open the urethra. The defect in the prostate was sutured with a continuous silk suture. The prostate graft was then treated in one of the several

ways: either transplantation in toto by suture to the split rectus sheath, or after morcellation with sand or by a sharp knife, the fragments were deposited in the fascia. The former method gave better results. The transplant was examined ten, fourteen, fifty-four and seventy-two days later. The prostatic tissue usually survived and grew (fig. 17). Bone was not observed associated with prostatic transplants in any case.

EXPERIMENT 7.—Control experiments: Epithelial transplants were made from the adrenal, gallbladder, stomach, jejunum and colon to the rectus sheath.

The right adrenal gland was removed in three dogs and the cortex was divided into two portions, one of which was transplanted in a puncture wound of the right kidney and the other sewed in the sheath of the rectus abdominis. Section at eighteen, twenty-two and thirty-five days demonstrated the survival of the graft by the presence of yellow tissue, microscopically composed of vacuolated cells arranged in cords. No bone formed (fig. 18).

Free transplants of the gastric mucosa in four dogs (fig. 19), of the wall of the gallbladder in two and of the mucosa of the jejunum and colon in one dog, to the abdominal fasciae failed to produce bone in any of the experiments. Small epithelial-lined cysts containing cloudy fluid formed in every instance.

A transplant of the dura mater which was obtained through the elevation of a button of the parietal bone by means of a crown trephine to the rectus sheath failed to cause the development of bone in two cases.

In three instances, thin shavings of bone measuring about 1 by 1 by 0.2 cm. were transplanted to the rectus sheath; these did not lead to osteogenesis. The bone had disappeared in seventy days in two animals, and had diminished greatly in size in the third.

A piece 2 cm. square of the synovia of the knee joint, including the joint capsule, was transplanted to the rectus sheath in two animals; section at sixty days failed to reveal the presence of bone.

The results of the experiments in which bone and periosteum were transplanted as a free graft to fibrous tissue are in accord with the work of Phemister[27] and others, and those of the experimental transplantation of gastric mucosa are somewhat similar to the experiments of Axhausen.[26]

EXPERIMENT 8.—Further evidence indicating the necessity for a proliferating epithelium in the osteogenesis resulting from the influence of the mucosa of the bladder on connective tissue is given.

The abdomen of a dog was opened and the bladder delivered from the wound. With a sharp knife the muscularis and adventitia and peritoneal covering of the bladder were removed in toto from a circular area of the wall of the bladder 2 cm. in diameter, leaving the shining mucosa of the bladder unopened. A piece of fascia from the rectus sheath was then secured to correspond with the excised portion of the wall of the bladder. This fascia was sutured with silk to the adjacent muscular wall of the bladder to fill the defect (fig. 20). After seventy-six days, the bladder was removed. The transplanted fascia was recognizable by a slightly depressed dimpled area and by the silk sutures. There was no formation of bone in this experiment or in five similar experiments lasting from forty-six to eighty-seven days.

This experimental evidence indicates that a necessary requirement for bone formation is a proliferating epithelium or its products especially since it is known from experiment 4 that bone formed only adjacent to the newly formed epithelium.

Comment.—It seems established by these experiments that proliferating mucosa of the kidney pelvis, ureter and bladder has the power of exciting osteogenesis in the parietal fasciae, and that as far as the tissues described in the group of transplants reported in experiment 7 are concerned, it is a specific effect of the epithelium of the upper urinary tract.

I shall next attempt to establish the fact that there are more factors concerned in this bone formation than proliferating mucosa of the urinary tract and any of the connective tissues and to present evidence that there is a difference between certain connective tissues, so far as they do or do not ossify under the influence of this proliferating epithelium.

EXPERIMENT 9.—The question to be answered by this experiment is whether the combination of proliferating vesical mucous mem-

27. Phemister, D. B.: The Fate of Transplanted Bone and Regenerative Power of Its Various Constituents, Surg. Gynec. Obst. 19:303, 1914; Free Tissue Transplantations, Surg. Gynec. Obst. (Internat. Abstracts Surg.) 18:333, 1914.

brane and connective tissue will always produce bone. The experiment is described in two parts.

1. A strip of mucous membrane of the bladder was excised and transplanted (*a*) in the rectus muscle four times, (*b*) on rectus sheath eighteen times, (*c*) in the subcutaneous fatty tissue three times, (*d*) on fascia lata twice and (*e*) on fascia covering the sacrospinalis muscle twice. The animals were killed after a period of from forty-nine to eighty-five days. In each instance, an epithelial-lined cyst developed surrounded in part by bone. The only variation in the results seemed to be quantitative; that is, when the transplant was made between fascial layers or in muscle tissue, more bone formed than when the transplant was made between fat and fibrous tissue or wholly within fatty tissue. This might be expected to have occurred, since there is less connective tissue in the subcutaneous fatty deposits than in the muscle or muscle sheaths.

A similar strip was inserted in the synovial cavity of the knee joint in three dogs and allowed to remain from forty-one to fifty days; the wound was closed in layers and a plaster cast was applied for ten days. The mucosa became attached to the synovial membrane forming a plaque of bone, near the patella, in two cases laterally and in the third medial to that sesamoid. At the conclusion of the experiment, a slight increase of synovial fluid was found. In no case were there loose bodies.

2. A strip of mucous membrane was excised from the bladder and placed in the parenchyma of (*a*) the kidney, (*b*) the liver, (*c*) the spleen and (*d*) the lung. Each experiment was done in three dogs.

The animals were killed from thirty-five to ninety-six days after the transplant was made. In no instance did bone develop.

In the lung, the transplant invariably became infected, and a chronic abscess of the lung was found at autopsy.

In the kidney, liver and spleen (figs. 21, 22, 23) well formed epithelial lined cysts were found. Microscopic examination showed that the cysts were lined by transitional epithelium and had been surrounded by connective tissue. From histologic evidence, it was impossible to see any difference in either the epithelium or the connective tissue, and in cysts of the same age in the sheath of the rectus. Here obviously the difference between bone formation in these parietal connective tissues and its absence in the organs mentioned must lie in a chemical or physical difference in the connective tissues, since the epithelium and the morphologic appearance of the fibroblasts are the same.

EXPERIMENT 10.—Since it has been reported that transplants of connective tissue to the dome of the bladder in the rabbit will not ossify (Phemister[9]), the question arose whether free transplants of mucosa of the bladder into fascia will form bone in this animal.

In six rabbits the urinary bladder was opened and the dome excised; the bladder was then closed by a continuous Lembert suture, followed by a purse-string suture which held in place the inverted dome of the bladder. The excised dome of the bladder was then sewed in the sheath of the rectus abdominis muscle with silk. In two of the animals infection followed operation, and here a tumor the size of a hen's egg was palpable beneath the skin. One of these animals was killed at the end of thirty days and the other after a hundred and forty-five days. Necropsy showed the tumor to be composed of a dense mass of yellow caseous tissue, thoroughly inspissated, from which bacteriologic examination showed *B. subtilis* in almost pure culture. In the animal killed after one hundred and forty-five days, the wall was calcified. There was no evidence of the mucosa of the bladder in either experiment. The tumors were chronic pyogenic abscesses. The remaining four animals were killed after sixty, seventy-one, eighty-four and ninety-five days. All the experiments were negative for bone except that lasting ninety-five days. In each a cyst was found lined by epithelium of the bladder containing fluid and surrounded by connective tissue. In the animal killed after ninety-five days, a plaque of bone 1 cm. in diameter was found adjacent to the vesical mucosa in the rectus sheath resembling the observations on the dog.

EXPERIMENT 11.—Since the mucosa of the bladder of the rabbit forms bone only under exceptional circumstances when transplanted to the rectus fascia, is the failure of bone deposition a local or a general process? Experiment 10 was repeated with the addition of the administration of large doses of viosterol or of parathormone.

Seven rabbits were operated on as in the last experiment. From three to six days later, viosterol in oil 1,000 D, was given to the rabbits in doses of 2 cc. daily by stomach tube. This was given every second day.

One rabbit died after three doses and one after five doses. The remaining rabbits were given between eight and fifteen doses. Necropsy after from thirty-five to forty-nine days revealed

the usual observations of massive doses of viosterol in rabbits, such as a marked deposition of calcium in the aorta and somewhat less in the kidney and other organs. The usual epithelial-lined cysts were found, but bone was not present. It is interesting that necropsies of the animals four and five months after the feedings with viosterol were stopped showed virtually no regression in the calcification in the aorta.

Two rabbits were similarly treated, except that six units of parathormone given subcutaneously every second day was substituted for the viosterol over a period of thirty days. Three rabbits were similarly treated, except that eight units of parathormone was administered every second day for ninety-eight days.

Autopsy of the five rabbits showed well formed cysts lined by mucosa of the bladder and containing the usual sanguineous fluid in four; in the fifth no trace of the transplant could be found (infection?). No bone was found in any of the experiments. Thus the agents that will cause the deposition of bone in man or rickets produced experimentally or that will normally raise the blood calcium did not induce ossification; this is interpreted as evidence that in the rabbit the failure of the epithelium to stimulate bone formation in the rectus sheath is due to local conditions in either the epithelium or the rectus sheath rather than to general causes such as a lack of vitamin D or hypocalcemia.

It is known from the earlier observations in the literature[28] that under certain conditions bone forms in the urinary tract of rabbits (and my work would suggest strongly that it is due to the action of the proliferating pelvic mucosa) as well as in the single instance cited in experiment 10. Therefore it would seem as if the rectus fascia of the rabbit were lacking in the attributes necessary for bone formation when epithelium of the urinary tract is transplanted to it.

EXPERIMENT 12.—If the epithelium of the bladder influences at times the laying down of bone in certain connective tissues, why is bone a rare observation in the bladder itself where proliferating, epithelial processes are common as a result of infection, stone, operations, etc.?

In three dogs, the bladder was opened through an incision in the vertex. With a knife, the mucosa of the bladder was dissected from the parietal tissues. This is technically an easy procedure. The musculature of the bladder was thus denuded of epithelium except for a triangular area in the trigone and an irregular ring around the urethrovesical junction. Hemostasis was secured by the aid of a hot gauze pack inserted in the bladder and pressure from without on the pack. After hemostasis was complete, the incision in the dome of the bladder was sewed with two rows of silk, with care not to encroach on the denuded muscularis more than was necessary. In one of the animals it was found that a sheet of mucosa 8 by 5 cm. had been thus removed and in the others relatively large areas. These animals were killed after eighteen, thirty-five and forty-one days.

It was interesting to observe that the musculature of the bladder denuded in this manner was competent to prevent leakage into the peritoneal cavity. At thirty-five and forty-one days it was found that the epithelium (figs. 24 and 25) had completely regenerated, lining the bladder. The wall was considerably thicker than normal, and distention was limited. The macroscopic and microscopic studies will be presented elsewhere. It is sufficient to state here that bone did not form in the wall of the bladder which is probably in a similar class with the other tissues that do not ossify under the influence of proliferating mucosa of the bladder.

Comment.—It will be seen that there are apparently two classes of fibrocytes which react differently to the presence of adjacent proliferating epithelium of the bladder, one which is susceptible of being ossified and the other which is not. In the first class (ossifying), are the connective tissues of the fatty-fibrous subcutaneous tissue, of striated muscle, of the fasciae (rectus sheath, fascia lata, fascia covering sacrospinalis muscle) and capsule of the knee joint in the dog and the fibrous tissue that forms beneath the proliferating pelvic epithelium after ligation of the renal vessels in the rabbit.

In the second class (nonossifying) are the fibromuscular wall of the urinary bladder and connective tissue stroma surrounding transplants of mucosa of the bladder in the liver, spleen and kidney in the dog and the fascia of the rectus sheath and the fascia lata in the rabbit.

The physiologic difference between these fibroblasts which under the microscope seem

28. Poscharissky (footnote 2, first reference). Sacerdotti and Frattin (footnote 18). Maximow (footnote 19).

identical is not apparent, but it seems clear that such a difference exists.

EXPERIMENT 13.—Will fascia introduced into the fluid contained in cystic epithelial transplants of bladder to rectus sheath, in part surrounded by bone, ossify?

The result of this experiment are incomplete. Five experiments have been conducted as follows: A circular area of mucosa of the bladder 2 cm. in diameter was excised and transplanted between the internal and external oblique muscles; after bone had formed as determined by palpation through the skin, a second incision was made exposing the cyst, which was entered through a small incision in its surface that was not surrounded by bone. A small piece of fascia was then excised from the rectus sheath and inserted in the lumen of the cyst, the wall of which was then closed by a silk suture.

In dog 212, the original transplant to the rectus sheath was made on Oct. 30, 1928. An easily palpable plaque of bone about 3 cm. in diameter formed around the cyst. A small piece of fascia was inserted in the cyst two hundred and ninety-eight days later. Examination forty-seven days after this second operation showed an irregularly spherical mass of bone about 4 mm. in diameter lying free in the cyst fluid. Gross examination showed that the mass consisted of a shell of bone completely surrounding a core of fibrous tissue. Microscopic examination demonstated the fibrous tissue core as living and surrounded by true bone. The bone, however, was lamellar with haversian system. The microscopic appearance of the bone (fig. 26) is thus different from areas of bone known to be growing in "tissue culture," such as the osteocartilaginous loose bodies sometimes observed lying free in joints in man, which are known to be growing free in the synovial fluid. However, the presence of the loose body of bone with a central core of fibrous tissue would strongly suggest that the introduction of the fibrous tissue played a part in the formation of this shell of bone; it probably became attached to the wall in some way, later coming loose after bone had formed.

In two other animals, at necropsy thirty-one and thirty-seven days after the introduction of fascia, the fascia was found intact but not viable and not surrounded by bone. In two animals at necropsy forty-one and ninety-three days after this procedure, no fascia was found.

EXPERIMENT 14.—Will the introduction of a silk suture in the lumen of an epithelial-lined cyst of the mucosa of the bladder lead to the deposition of salts on it as frequently occurs around nonabsorbable sutures in the lumen of the bladder?

The presence of stone around a silk or linen suture in the bladder is an extremely common experimental and clinical observation. It was with some interest, therefore, that a piece of sterile silk 3 cm. in length was introduced as a loose body into the fluid secreted by the vesical epithelium in these cysts partly surrounded by bone. It was done three times, and the experiment was allowed to run thirty, thirty-seven and forty-seven days.

Examination in the thirty and forty-seven day experiments showed that a part of the thread had become surrounded by bone in the wall of the cyst to which it was attached. In the thirty-seven day experiment the entire thread was found lying free in the lumen of the cyst, as a part had been in the first two animals. In no case had gross precipitation of calcium salts occurred on the threads.

EXPERIMENT 15.—This experiment was a study of the fluid in epithelial-lined cysts resulting from transplantation of the mucosa of the bladder to the sheath of the rectus abdominis muscle, especially of the calcium and phosphorus content. (The chemical determinations were made by Dr. E. L. Compere.)

When a circular area of the wall of the bladder 2 cm. in diameter is transplanted to the rectus sheath, a cyst forms containing a dark brown, sanguineous fluid, which does not clot spontaneously in three hours. Microscopic examination shows it to be made up chiefly of erythrocytes in various stages of degeneration, with a few leukocytes and desquamated epithelial cells. The amount of the fluid is rarely more than 4 cc., usually about 2 cc.

It seemed of interest to determine the calcium and inorganic phosphate content of this fluid and to compare the results with similar simultaneous determinations on the blood serum. In addition, in some experiments the hydrogen ion concentration and the carbon dioxide content of the fluids were determined.

The fluid was aspirated through the skin with an 18 gage needle and drawn under oil. Calcium was determined by the Collip[29] modification of the Kramer and Tisdall[30] method in

29. Clarke and Collip: J. Biol. Chem. 63:461, 1925.

30. Kramer and Tisdall: J. Biol. Chem. 47:475, 1921.

TABLE 1. Hydrogen Ion Concentration, Calcium and Phosphorus Content of the Fluid Found in Epithelial Lined Cysts of the Bladder Mucosa (Experiment 15) as Compared With Similar Values of Blood Serum in the Dog

			Cyst Fluid					Blood Serum				
Dog No.	Date	Days Transp.	Cc. of Fluid	Ca*	P*	CO_2†	pH	Ca*	P*	CO_2†	pH	Ossification in Cyst
256	9/10/29	62	3.0	15.9	11.0	....	6.32	10.4	5.16	43.16	7.51	++++
212	9/10/29	47	3.6	15.6	9.6	....	6.45	10.98	3.44	49.2	7.57	++++
215	9/14/29	80	5.4	10.77	8.23	....	6.35	10.77	4.91	....	7.43	++++
543	11/18/29	29	2.6	13.35	....	....	7.35	10.34	....	....	7.42	++++
543	12/18/29	59	10.0	10.72	5.9	....	6.97	11.07	5.33	....	7.53	Cyst fluid contains pus
689	2/ 3/30	33	2.2	....	....	16.4	7.27	11.6	5.3	45.3	7.44	++++
724	2/ 3/30	57	5.0	....	....	18.3	7.02	10.8	5.71	51.5	7.45	++++
986	2/ 3/30	35	9.0	11.04	4.4	28.6	7.17	11.2	5.16	51.3	7.44	++
821	3/10/30	62	0.5	16.3	....	....	....	11.6	6.15	....	....	++++
986	3/10/30	69	0.8	15.2	....	....	....	11.6	6.2	....	....	++++
928	2/ 3/30	100	6.0	....	....	114.7	7.69	12.20	6.66	55.9	6.92	+ Cyst grossly infected
873 506	3/10/30	49 62	0.65	17.4	....	....	....	11.86	6.25	....	....	++++
212	6/24/29	267	3.0	23.5	....	....	....	10.5	....	....	....	++++
821	4/16/30	113	1.5	18.2	5.22	....	....	12.6	6.67	....	....	++++
689	4/16/30	118	1.8	16.6	3.0	....	....	12.6	6.67	....	....	++++
869	4/11/30	67	2.4	16.0	16.8	....	....	10.46	6.4	....	....	++++

* Milligrams for each 100 cc.
† Carbon dioxide content per cent by volume.

most instances. In three of the determinations, the organic material was destroyed by heating with concentrated sulphuric acid before using the foregoing method, with approximately the same results. Inorganic phosphates were determined by the method of Fiske and Subbarow.[31] The carbon dioxide content of the serum and cyst fluid was determined by the manometric method of Van Slyke and Neill.[32] The bicolormetric method introduced by Myers[33] and Hastings[34] was used for the hydrogen ion concentration.

The results are tabulated in Table 1. In ten of thirteen determinations, the calcium was decidedly elevated above the blood serum calcium. In five of eight determinations, the inorganic phosphate content of the cyst fluid was markedly increased over the values for blood serum. In eight of nine determinations, the cyst fluid was more acid than the blood serum. The carbon dioxide content of the cyst fluid was much less in three of four determinations than the normal values obtained at the same time from the blood serum.

In three rabbits the phosphorus content and the hydrogen ion concentration of the blood serum and of the fluid of the bladder cyst were determined. Table 2 shows the results in tabular form. The phosphorus content and p_H did not vary strikingly from the values for blood serum.

In all of these determinations it must be realized that small amounts of fluid were necessarily used, so that the possibility of error is greater than if larger amounts could have been obtained. In three transplants in dogs, large amounts of fluid were obtained; these cases were probably not true cysts lined

31. Fiske and Subbarow: J. Biol. Chem. 66:375, 1925.
32. Van Slyke and Neill: J. Biol. Chem. 61:523, 1924.
33. Myers: J. Biol. Chem. 54:675, 1922. Myers, Schnitz and Booher: J. Biol. Chem. 57:209, 1923.
34. Hastings and Sendroy: J. Biol. Chem. 61:695, 1924.

TABLE 2. Hydrogen Ion Concentration and Phosphorus Content of the Blood Found in Cysts of the Bladder Mucosa in the Rabbit, as Compared With Blood Serum (Experiment 15)

Rabbit No.	Date	Days Transp.	Cyst Fluid: Cc. of Fluid	Cyst Fluid: Ca*	Cyst Fluid: P*	Cyst Fluid: CO2†	Cyst Fluid: pH	Blood Serum: Ca*	Blood Serum: P*	Blood Serum: CO2†	Blood Serum: pH	Ossification in Cyst
348	12/30/29	50	0.75	....	7.16	....	7.32	....	7.02	....	7.35	No ossification
353	12/30/29	50	0.6	....	7.4	....	7.34	....	6.7	....	7.39	No ossification
362	12/30/29	50	1.0	....	6.7	....	7.35	....	7.04	....	7.34	No ossification

* Milligrams for each 100 cc.
† Carbon dioxide content per cent by volume.

by transitional epithelium, but abscesses, since gross pus was seen. However, in each of the abscesses bone was found, but in two cases it was small in amount; this showed that the graft had apparently survived, at least in part. Ruling out these cases of gross infection, it will be seen that in the remaining cases the calcium content of the cyst fluid was markedly elevated above the value for serum calcium.

COMMENT

The proliferating mucosa of the kidney, ureter and bladder is a sufficiently strong stimulus to certain connective tissues in the dog and rabbit to induce the formation of bone. Certain other fibrocytes do not react in this way. The exact physicochemical change thus affecting the fibrocyte is unknown, as well as the mechanism of resistance to bone formation on the part of tissues in which bone does not form.

It seems logical, since the cyst fluid in most cases contained much more calcium and phosphorus than did the blood serum, to assume that this has a bearing on the problem, especially since in certain cases, as in experiment 1, a cyst did not form, and the fluid secreted by the cells must have been disposed of in the tissues themselves. It must be granted as proved that the mucosa of the bladder in this position secreted[35] calcium and phosphorus into the lumen of the cyst.

It is possible that the newly formed epithelium, lining the cysts which form when mucosa of the urinary tract is transplanted to the rectus sheath in the dog, is more permeable to the fluid secreted by the epithelium than the older mucosa. This would explain the occurrence of the bone in the vicinity of the proliferating epithelium.

Since this osteogenesis occurs invariably (barring severe infection), this method affords a way of studying osteogenesis that offers certain advantages over that of osteogenesis from preexisting bone, periosteum or cartilage. The exact duration of the osteogenic stimulus is known in this experiment. Moreover, a fluid is present which may aid in the study of osteogenesis.

The production of bone under the direct influence of epithelial cells is proved for the first time by the experimental method. The observation of epithelial cells infiltrating bone is common in certain osteoplastic processes in the skeleton resulting from tumor invasion. This is frequently seen in man in the metastases of prostatic carcinoma to bone, and is seen in the hyperostosis overly-

35. Further unpublished studies by F. H. Entz in this laboratory indicate that the mucosa of the bladder normally secretes calcium and phosphorus.

ing cranial meningiomas,[36] as well as in other tumors.

Two views have been expressed regarding the pathogenesis of the bone in tumor metastasis. Von Recklinghausen and others explained this process as due to a stimulation of new bone by passive hyperemia due to venous obstruction by tumor cells. The second view has been advocated by Axhausen and others who believe that the new bone forms as a result of stimulation of the surrounding osteogenic elements by chemical substances formed by the tumor cells.

These experiments, which demonstrate a direct relationship between osteogenesis and certain epithelia, favor the second hypothesis, especially for metastases of carcinoma from the prostate, because of the ontogenetic relationship of the prostate to the urinary tract. Osteogenesis, however, has not occurred about prostatic transplants. It is possible that the reason for the failure of prostatic epithelium to stimulate bone formation in connective tissues is the difficulty in dissociation of the epithelium from its stroma, and it is known that the stroma of the bladder will not ossify in the presence of regenerating epithelium of the bladder.

This study indicates also the nonspecificity of periosteum and the osteoblast and that certain other connective tissues under an altered environment may acquire osteogenic properties.

SUMMARY

1. The direct influence of certain epithelial cells on connective tissue stimulating bone formation in it is shown experimentally.

2. Bone forms in a fascial transplant to the bladder of the dog in which the urine has been diverted. It is in close relationship to the epithelium and occurs only in the transplant.

3. Bone forms around a transplant of bladder, ureter and renal pelvis epithelium to certain parietal fascias (rectus sheath, fascia lata, subcutaneous tissue) and to muscle and synovial membrane in the dog. This is true spongy bone with haversian canals containing fibrous and hemopoietic bone-marrow.

4. These fibrocytes can be differentiated functionally from other fibrocytes (those which form around an epithelial transplant from the urinary tract into the kidney, liver and spleen, and those forming from the connective tissue of the wall bladder) which appear anatomically similar but do not participate in the formation of bone.

5. Transplants of the epithelium of the bladder to the sheath of the rectus abdominis fascia in the rabbit did not lead to bone formation, except in one animal. This fascia also therefore can be differentiated from the connective tissue about the renal pelvis, which after ligation of the renal vessels proliferates and forms new bone. Viosterol and parathormone do not aid in ossification in epithelial transplants to the rectus sheath in rabbits.

6. It is the newly formed epithelium and not the nonproliferating part of the transplant that is the essential factor in this osteogenesis.

7. A secretion of fluid containing a relatively large amount of calcium and phosphorus occurs into epithelial-lined cysts of the mucosa of the bladder in the rectus sheath of the dog. It is a probable factor in bone formation.

8. Osteogenesis does not occur following similar transplantation of gallbladder, gastric, jejunal and prostatic epithelium into fascia.

9. Since the osteogenetic power of the mucosa of the renal pelvis has been demonstrated, it is most probable that this is the factor causing bone formation after ligation of the renal pedicle in the rabbit's kidney, especially since this rarely occurs following ligation of the ureter.

36. For a complete description of this process, see Phemister, D. B.: The Nature of Cranial Hyperostosis Overlying Endothelioma of the Meninges, Arch. Surg. 6:554 (March) 1923.



CHARLES BRENTON HUGGINS

Charles Brenton Huggins (1901), Distinguished Service Professor at the University of Chicago was born in Halifax, became interested in the frequency of ectopic osteogenesis in the urinary tract. Although his original short experimental report appeared a year earlier (Proc. Soc. Exper. Biol. and Med. 27:349, 1930) this paper continuing his studies became one of the classics of experimental ectopic ossification and a landmark in its literature. A graduate of Harvard (1924) he received the Honorary Fellowship of Royal Colleges of London and Edinburgh among his many honors.

CLASSIC 37 Die Marknägelung von Knochenbrüchen

(The Intramedullary Nailing of Fractures)

DOZENT DR. MED. HABIL. GERHARD KÜNTSCHER (1900–)
Chief of Clinic. From the Surgical University Clinic, Kiel

Hip nailing has been discussed in many Congresses in the past year. But these discussions have had one object, hip nailing has arrived! Indeed, because of its indisputable advantage over all other procedures. By means of the nail the fragments are held together, the pain relieved, the invalid may sit up the day after the operation and turn on his side. Because of this the dangers of pneumonia and circulatory failure are lessened, the danger of decubitus, which especially belonged to plaster casts, is absent. This applies mostly to the elderly who are most susceptible to these dangers. Decubitus, the chief contraindication for plaster of Paris, is the indication for nailing. We have seen a whole series healed even in very old people after nailing. After a few days the operated patient can already actively move the limb. There follows no joint stiffness, no muscle atrophy, no circulatory failure in the extremity and therefore the danger of thrombosis and emboli is lessened.

Nailing is the method of choice in fractures of the neck with vertical fractures since here, as Pauwels has shown, damaging pulling and shearing stresses affect the fracture line. Here the nail eliminates these stresses, indeed the more effectively the steeper the fracture line. Fractures with horizontal lines are more favorable to callus formation. These fractures would hold even without nails. In pertrochanteric fractures the callus lies quite outside the line of stress. The majority of authors, therefore, are of the opinion that these fractures should not be nailed since they will hold. The Zürich Clinic (*Nicole*) goes so far as to exclude medial and lateral fractures with horizontal or almost horizontal fracture lines from nailing. The Kiel Clinic does nail pertrochanteric fractures for the reason that certainly this fracture lacks a clear mechanical-biologic indication and that the advantage of the method is so great as to be superior to plaster of Paris and traction.

Intraarticular hip nailing is of course operative fracture therapy, but because of the special anatomic conditions it has not its dangerous disadvantage. The danger of infection is very limited because we do not open the fracture line, or expose the haematoma, etc.

The incision lies at least 6–8 cm. from the fracture. An infection of the fracture is only possible with the guide wire or nail. Even when these are contaminated with germs an infection would not be easily introduced since the bacteria would be wiped off by entry of the instrument into the bone. The innocuousness of the nail metal appar-

ently hinders the carrying of an infection from the wound to the fracture line. We have experienced purulent infection about nine times in 132 nailings. These abscesses healed quickly and did not reach the deeper fracture line. We have had only one exception to these experiences, that is, the danger of infection of these fractures lies well under 1%. This infection was not fatal. Other statistical reports were the same. In the operative management of other fractures one finds quite another story. They fluctuate between 3 and 30% with correspondingly high mortality the closer the fracture (*to the wound*). The decisive progress, in my opinion, lies in the introduction by Sven Johansson of extra-articular nailing. It also permits prolonged fixation which otherwise would be criticized in fracture surgery. Hip nailing is an ideal method of fracture management which offers the advantage of primary union, presents an ideal restoration of anatomic form, and it should be employed whenever possible.

The fracture of the femoral neck represents a special case with extraordinarily unfavorable conditions. The support of the bone structure is bad, the fracture line is mechanically unfavorable, it occurs mostly among the elderly. If in spite of this so excellent an anatomical and functional result may be achieved with nailing, it implies that similar results should be obtained for most of the other fractures, those of the shafts of long, tubular bones.

In my opinion, with the previous knowledge of the causes of favorable results, such a method must fulfill three conditions in order to oppose former procedures (plaster of Paris, traction, surgical):

1. Fixation of the fracture fragments must be such that immediately a functional mobility is possible, similar to that after hip nailing.
2. Fixation of the fracture must be held so firmly that the fragments will not part, also that the healing of the incision will be obtained as far as possible away from the fracture line.
3. The manner of healing must offer the same favorable conditions for callus formation as appears in hip nailing.

Finally, the procedure must be simpler than hip nailing if it is to be applied to the majority of all common fractures.

The first demand can be fulfilled only by the application of steel, as the fixation is subject to strong stresses and only in the medullary canal is there enough space to place the fixation. This is suitably accomplished with a long nail in the medullary canal. This is of supple construction, introduced through a bored hole above or below the fracture in direction of the fracture line and tightened by a screw and so converts the bone into a rigid structure which is extraordinarily firm to withstand stress. Thereby the second of the above demands is fulfilled. This "supple-rigid" nail may be introduced in all tubular bones.

A large series of trials in human femurs has succeeded astonishingly well in which a rigid nail was driven in from the tip of the trochanter major. In twelve cases of femoral fractures previously treated, the medullary canal was broad and straight enough to make nailing possible without further widening. A moderate existing curvature of the femur may perhaps be straightened out through the fracture area, in which case the thin diameter of the nail will yield somewhat.

First of all, some serious considerations exist regarding a therapy whereby fractures are united by means of metal nails introduced into the medullary canal. The question is whether the introduction of such heavy metal nails into the bone is injurious or not, because with about the same diameter the nails are two to three times as long as hip nails. The reply to this question is, that with the use of pure V2A steel such injuries are negligent, appearing rarely and only after a long time of the steel's presence in the body. Among 132 hip nailings in the Kiel Clinic I saw only one case where, after one and a half years when the fracture already had

firmly set, a resorption seam about 1 m/m wide appeared around the nail. In all the other cases, not the slightest abnormality could be identified, in spite of the fact that the observations covered a period of over six years. Therefore, in order to save very old persons from this small surgery the Kiel Clinic does not favor the removal of hip nailing, as it is not necessary. It is a principle in a great number of clinics to remove the hip nail after six months to a year. In general, for shaft fractures it is not necessary to leave the nail in for such a long period as these fractures become firm much sooner. Even if no important local injury can be found caused by the hip nails—up to 16 cm long—in this short period, yet it should not be assumed that two or three times as long metal nails might cause much bigger changes. No general injuries due to V2A steel placed in the body are known to me.

The second objection that could be made is the injury in the medullary cavity and the endosteum, causing a pronounced disturbance in the healing progress. Everybody remembers the sorry experiences with shaft fracture bolts using ivory pins or bone pegs. However, the conditions are here completely different, and this for various reasons:

1. The pins fill the medullary cavity completely so that no vessels on the inner side can reach the callus and the osseous tissue near the fracture.

2. The endosteum is destroyed and crushed by the pin. However, in spite of this the bone bolts usually heal as they form a firm union with the osseous tissue. A span across the fracture line with callus was not achieved due to the fact that the rigidly wedged and healed bone peg spreads the fracture open and has here the same effect as the intact fibula in the spaced out pseudarthrosis of the tibia. The cleavage prevents favorable pressure effect on the callus. When the broken limb is heavily used, due to notch effect a permanent or fatigue fracture of the bone bolt appears.

For the lamellar nail the situation is different. Such a nail does not completely fill the medullary cavity, instead it touches the endosteum only in three spots (usually due to tiny bends of the shaft, etc. only two). Because of the sharpness of the edges these spots often are extremely narrow. The eventual injury to the endosteum and the callus consequently can be caused only by these edges. Even if in an extension of 1 m/m all around the edges a complete destruction of tissue would ensue, this would be of no mechanical importance. It would in no way reach the periosteal callus which plays the most important role in the fracture healing. The callus is so far removed from the edges that it is actually not involved.

The medullary tissue seems to be much less sensitive to V2A steel than the bone itself. A series of tests with intramedullary nailing was executed on dogs. Even with complete destruction of the medullary cavity no disturbance of the endosteum callus could be observed. On the contrary, a very strong callus formation in the endosteum appeared which completely encircled the nail so that the cross section reproduced the precise diameter of the nail.

The periosteal callus plays the principal role in the fracture healing. However, only under favorable mechanical conditions is this callus ossified. Convincing proof of this has been given by *Pauwels* in his calculations of hip fractures. By means of experimental and measuring tests this writer was also able to prove the progress of the strength on the bone. For ossification it is most favorable if the callus is under pressure stress, and if pushing and shearing stress as well as *excessive* pulling stress are avoided as much as possible. This refers to the changing pressure stress which originates in muscle contraction. As mentioned, this is the basic principle of the hip nailing, but it is also applicable to all other fractures. The rigidly sitting ivory bolt or bone peg due to the opening hinders and prevents stress effect on

the callus, often also on *Lane's* plate. Furthermore, the well introduced lamellar nail leads to the same kind of loosening as mentioned in connection with the hip nailing so that through muscle pulling the fracture ends are pressed onto each other. *From the mechanical-biologic point of view this method represents the most favorable of all fracture therapy.* Pressure stress affects the entire fracture line while the nail absorbs all injurious pushing, shearing and bending stress.

In 1933 *Müller-Meernach* presented a method for the introduction of lamellar nails in the medullary cavity and achieved good results. However, basically his procedure differs from the one mentioned above. It is the usual sanguineous method with all its risks and disadvantages. The fracture is opened and after filing of the bone, the nails are introduced. The second big advantage was that the nails could never be removed. *Müller-Meernach* did not proceed according to the above described principles for hip nailing. His desire was to find in the operative fracture therapy a good method of commissure replacing the use of screws, plates, etc.

The use of intramedullary nailing on dogs after breaking their thighs with the osteoclast, gave surprisingly good results. Eight days after the nailing the animals were able to stand by themselves on their hindlegs (even stand upright). The course of the healing was rapid, and ideal anatomic results showed strong callus formation. Even a complicated infected fracture healed, in spite of purulent infection.

On human beings the method was used for eleven fractures of the upper thigh as well as for shank fractures and upper arm fractures. As an example of the use of the supple-rigid nail a twenty year old patient is mentioned. Here it refers to a shank fracture which could be connected but in spite of traction and plaster the reposition did not hold so that rapidly an ad latus dislocation appeared. When the nail had been placed there was a good fracture position and no need for plaster or traction.

For the eight first upper thigh fractures the trochanter major was laid bare through an incision in the outside part of the upper thigh, and a hole was bored in the tip of the trochanter. After placing a guide wire the medullary nail was driven in under strong abduction. During this procedure the patient lies on a traction table; the reposition and the advancing of the nail is examined through radioscopy. Care must be taken that the partly entered nail holds the upper fractured fragment in a firm grasp as if it were held by a hand, and places it upon the lower fractured fragment. When the nail has been driven in, the wound is sewn together. In the latter cases the trochanter was not bared and *the nail was driven in only percutaneously.* By means of radioscopy the direction of the medullary canal can be marked on the skin in two planes, and on basis thereof a metal pike can be partly driven in through the skin into the top of the trochanter. If the pike is in the right position the nail is then driven in on the pike. The trochanter is so soft here that it is not necessary to bore a hole. As an example of such a hip nailing with a rigid nail may be mentioned a ten year old patient G. L.

The risk of infection is small with this method. No infection of the fracture line appeared in any of the cases. It brought no disadvantage to the healing process, as practically neither the periosteum nor the fracture haematoma are touched. In many cases it is even possible, through the use of intramedullary nailing, to avoid the sanguineous opening of the fracture with its great dangers and disadvantages. The principle indicated for this incision is not the fact that it is impossible to re-set the fracture but that it is impossible to hold the fracture in the reposition. However, even if the sanguineous incision can not be avoided, as in an osteotomy, due to a badly healed fracture, muscle interposi-

tion, etc., the intramedullary nailing is to be recommended because of its advantages of early mobility. Furthermore, the fixation usually is easier to place and holds considerably better than wire or tape lacings or the *Lane* plates. Besides, the plates cause injury to the periosteum on which they lean. With the exception of the *Magnus* wire, the medullary nails are considerably easier to remove than all these appliances. The introduction of the medullary nail can easily and quickly be made without the use of an X-ray machine. The long metal pike is introduced upwards into the opened medullary canal; within it then bores through the tip of the trochanter and can be felt through the skin. By means of a prick incision the nail is pushed over the tip of the pike, hammered in and it can be seen with the naked eye when placing it in the lowered fractured part.

The spontaneous fracture is a special case. Strangely enough, for tumors and metastasis it is usually subtrochanteric. In cases of inoperable tumors, for the rest of their life the patients are confined to bed with plaster bandage because in spite of all measures, such fractures do not want to heal. In these cases the intramedullary nailing may make up for the lost stability of the leg, even when there no longer is hope that the fracture will ever heal.

Finally, mention is made of the 61 year old patient F. W. In this case it referred to a pertrochanteric and subtrochanteric fracture. The femoral neck was fractured laterally, and the trochanteric massive was destroyed. Naturally, such a fracture can not be held either by means of intramedullary nailing or by hip nailing as there is no hold for it in the shaft. The above described principle of fixation within the bone fracture is applicable only through a combination of both nailings in such a manner that the patient can enjoy the immediate mobility and the early use. According to experience, in spite of plaster casts or traction, such fractures usually heal with a great coxa vara position. Here a double nailing was used, which in a way formed a mechanical cross between an intramedullary and a femoral nailing. The patient could walk already after three days. The healing led to a good mechanical and functional result.

Intramedullary nailing is applicable to all transversal fractures, to sloping fractures and to most spiral fractures of the shaft. The majority of fractures belong to these categories. There is, of course, also an amount of fractures where it would not be of help, as for instance all fractures of the joint-ends or the joints. Intramedullary nailing will also be very difficult for badly crushed parts, inasmuch as the principle of this method is that the fractured parts can slide somewhat along the nail and that they then, by means of the muscle contraction, press onto each other. Such sliding would have to be prevented through special devices so that both outside fracture fragments be spread open. On the other hand when it refers to fractures where a third broken fragment exists, such fractures are suitable for intramedullary nailing. If the fractured piece is in the shape of a ring, the intramedullary nail is driven through the ring. However, if it is in the shape of a bowl, then the upper and the lower fractured parts have more or less wide surfaces of contact which then are pressed upon each other. In cases where the contact surfaces are very small the patient must be careful not to get out of bed too soon. In order to prevent the injurious consequences of the other methods of therapy for bone fractures, intramedullary nailing is sufficient also in such cases where the patient leaves bed first after a few weeks. For such fractures an immediate load in order to preserve the functional characteristics, does not seem to be necessary. The same as in a patient suffering from pneumonia, his resting in bed does not by itself cause stiffness in the knees. The opinions about the time needed to remain in bed are very diverse when it refers to hip nailing. Many clinics let the patient get up already

after a fortnight. In this regard the Kiel Clinic is careful and according to the nature of the fracture lets the patients go up first after 8 to 12 weeks. Consideration is here taken to the character of the fracture; if it refers to medial, lateral or even pertrochanteric fractures, the position of the fracture lines and the condition of the bone.

When it refers to intramedullary nailing it is not necessary to be so uneasy, as the conditions are far more advantageous. First of all, the nail is completely encompassed by an extended surface of very thick, hard compact tissue. This can not be cut through by the nail in the same way as the crumbling meshes of the spongioid femoral neck and femoral head by which the nail is surrounded everywhere. Actually, when it refers to the femoral neck, the nail often cuts through. Furthermore, in hip nailing the stress on the nail is much greater. The position of the nail is more or less transverse to the flow of force and is exposed to shearing and bending. This is the reason why, with an early load, fractures appear or snapping of the nail. With intramedullary nailing there is less stress on the nail. It is not exposed in the same heavy way to shearing and bending. Its position is in line with the flow of force. For this reason, so far no movement of the intramedullary nail has been observed, as is the case in hip nailing. The part of the tubular shaft remains intact, absorbs most of the stress and conducts it through the fracture which leads to a very advantageous pressure effect on the callus with regard to ossification.

Experiences have shown that in hip nailings the intramedullary nails can be extracted rather easily. (Only in one case was it necessary to use considerable force). This means that the fractured parts may slide against each other in longitudinal direction and with each muscle movement they are severely pressed against each other. The intramedullary nail prevents bending of the shaft and thus pulling stress of the callus. Furthermore, the intramedullary nail can not be distorted as was evidenced when intramedullary nails were removed as well on human beings as in all tests with dogs. The reason for this is that endosteal bone formation is stored between the lamellae of the intramedullary nail, which occurs at an early stage. As soon as the nail has been driven in, a rubbing of the fractured pieces against each other is not possible. If the nail is sufficiently long this is prevented on the approximate fragment of the nail head and on the distal of the spongiform which fills the distal part of the shaft. However, also with shorter nails a distortion is prevented inasmuch as the nail with its lamellae fastens itself into the numerous irregularities in the medullary canal. (If one doubts the possibility of such a distortion in a special case because perhaps a nail that was too short or too thin was used, then it would be preferable not to put any stress on the leg in the first three to four weeks and let the patient get out of bed only after such a lapse of time, i. e. until the endosteum callus has appeared which definitely prevents distortions.)

In all cases of intramedullary nailing the quick appearance of a thick and tight callus formation was striking, so that it always gave the impression of a premature and copious ossification. Here too the conditions are different from those in a femoral neck which, of course, the same as the spongious bone parts forms very little callus. This too, is of importance with regard to getting out of bed. In cases where the intramedullary nailing is used, due to the direction of the flow of force, getting out of bed is more advantageous to ossification than in hip nailing, practically similar to the "fixation" of a shank fracture with retarded fracture healing in a plaster cast. This is an experience that has been known for a long time, and it is due to the same circumstance why in animals living in the wilderness pseudarthrosis appears so rarely. The leg is shortened until the distal fractured part finds a kind of resistance against which it is pressed through any muscle activity in the limb. After a few weeks finally with the use of an intramedullary nail,

the callus is capable of contributing considerably and safely to the mechanical stability, quite in contrast to the femoral neck where, for instance after six weeks, it shows no important mechanical firmness.

Immediately after the nailing not one of the patients had fracture pains. At the latest on the third day the leg could be moved and the hip and knee joints could be bent. Patients with femoral fractures as a rule could leave bed after three weeks, frequently sooner, in some cases on the third day. There was no kind of limitation in joint movements and there was no evidence of atrophy of the muscles.

Precisely this is the essence of the method!

For the healing of a bone fracture it is absolutely necessary to have the fractured fragments attached to each other for a sufficiently long period so that by means of new ossification they be firmly joined together. With regard to shaft fractures, which is the majority of all bone fractures, with the method used until now this is possible only by means of more or less firm fixation of the muscle cross section that surrounds it all and the neighbouring joints, which leads to the serious damages described. The removal of these risks—if this is at all possible—causes many difficulties and trouble and takes a very long time. Apart from the diminution in the capability to work for a living, earning an income, etc. With the intramedullary nailing only the fracture itself is fixed and not the surrounding soft parts and injured joints, so that the damages can not set in. The entire after-treatment can be dispensed with. The care is also very much simplified. The continuous careful checking that plaster cast and traction method demand, does not exist. No special fracture beds and no specially trained personnel is needed; after a few weeks the patients can be discharged. *These are advantages which are of greatest importance when fracture cases are frequent, as for instance in wars.* In no case was there evidence of any kind of general injuries due to the nailing, as for instance injury to the bone marrow. Three children with nailed femoral fractures showed a moderate degree of eosinophilia which disappeared after extraction of the nails.

The patients are asked to return for the extraction of the nail. Due to the risk of refracture the nail should not be extracted too soon, i.e. in a femoral fracture after about three months. Leaving the nail in a bit longer, asking the patient to return for extraction first when his condition warrants it, presents no risk. For hip nailing cases the Kiel Clinic, contrary to most other clinics, is of the opinion that the nail should be taken out only if an extraction is indicated; in the majority of cases it is left in place for good. However, when it refers to an intramedullary nail there are doubts. If the intramedullary nail is left in for a long period an undesirable, functional reconstruction in the shaft, or something similar might occur. As explained, the extraction is usually very easy. All intramedullary nailheads are provided with a hole so that extraction instruments can be attached. Screw-threaded forceps seem to be most suitable, or a mallet with an angular notch can be introduced into the hole and the nail driven out. In an emergency it may be pulled out with strong wires passing through the hole of the nail. Another advantage is that the intramedullary nails are made in a slightly conic shape, so that from its head to its point the nail gradually tapers off by the fraction of a millimeter. This facilitates its extraction if, when the nail was driven in, the distal, fragmented piece was missed.

Whether a complicated fracture should also be nailed can not be judged in advance but be decided only on the basis of long experience. The above mentioned advantageous experience with an infected fracture was gained in experiments with animals. In spite of severe purulent infection the nail was completely encompassed by new bone, which of course encourages the use of this method in complicated fractures on human beings.

It is, however, necessary to state that the dog generally has much more resistance against these infections than a human being, and that in such infection tests a single case signifies only one thing: that a healing is possible. However, the experiences with hip nailings too, where in spite of infection of the outside wounds the infection practically never penetrated deeply along the nail, speak for the use of intramedullary nailing in human beings suffering complicated fractures.

This would be of greatest importance in war where so many shot fractures occur.

Finally, reference must be made to another factor which is noticeable in all cases of intramedullary nailing: this is the extremely careful reposition which must be exact to the millimeter so that the fracture line is almost unrecognizable on the X-ray made for checking purposes. The above is the character of the method. While good and bad repositions and positions of the nail in fractures of the femoral neck occur, for the intramedullary nailing there is only one position, namely the one in the medullary canal and this demands an extraordinarily exact reposition. As to the healing, this is an extremely important moment because the narrower the fracture line is which the callus has to bridge, the quicker and firmer the joining will be.

Besides for treatment of bone fractures the intramedullary nailing is also suitable for other incisions, as for instance subtrochanteric and osteotomies; for the lengthening of bones, arthrodesis etc. and finally also for the treatment of pseudarthrosis.

The nails and instruments for intramedullary nailing are manufactured by the well-known corporation for surgical instruments Ernst Pohl in Kiel.

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Although experimental work directed toward the obvious procedure of intramedullary nailing of fractures of the shafts of long bones had been conducted by German surgeons during the twentieth century, an effective method appeared only in 1940 with the publication of Gerhard Küntscher's (1900–) report. This appeared in the German literature during the opening months of World War II. It was first seen by non-German surgeons among hospitalized German prisoners of war in France in 1945. The results were so dramatic that within a short time literally thousands of cases were reported for fractures of all bones of the extremities. As in all spectacular new surgical procedures the method was perhaps at first overused but after its first decade settled down into a controlled but important new addition to the resources of fracture therapy. This classic report of Küntscher appears here I believe as its first translation into English.



GERHARD KÜNTSCHER

CLASSIC 38

Orthoroentgenography as a Method of Measuring Bones of the Lower Extremities

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Accurate measurement of the length of the lower extremities is often indicated. For many purposes clinical measurements suffice, but they are admittedly grossly inaccurate. The usual method of teleoroentgenography, although allowing more accurate records of comparative lengths, produces an increasing degree of magnification and distortion as the extremities grow (Fig. 1 A).

In a study of growth by the Harvard Infantile Paralysis Commission, it was found necessary to develop a method of measuring the lower extremities which would meet the following requirements:

1. Measurement of the bones should be sufficiently accurate to record the comparative true lengths at any one examination.
2. The precision of measurement should remain constant for varying bone lengths, in order to compute accurately the true increments of growth.
3. Sufficient detail should be delineated to allow the detection of abnormalities in the bones and visualization of the epiphyseal lines.

The method to be described has been designated "orthoroentgenography". It has met these requirements while in use over a period of four years, during which time over 2,200 recordings have been made.

METHOD

The method employs three separate exposures for the lower extremity (Fig. 1 B). The central ray is directed successively over each of the three joints, and the three exposures are processed on a continuous film,* fourteen inches in width and of any desired length up to forty-four inches. The technical factors may be varied between exposures, according to the thickness of the soft tissue over each part. A target-to-film distance of six feet is always used.

A tunnel for a long cassette (fourteen inches by forty-four inches) has been devised, into which have been incorporated two sliding metal shields (Fig. 2). Such a device allows an exposure to be made over any one third of the film, while the other two thirds are protected from exposure.

From the Harvard Infantile Paralysis Commission and The Children's Hospital, Boston, Mass.

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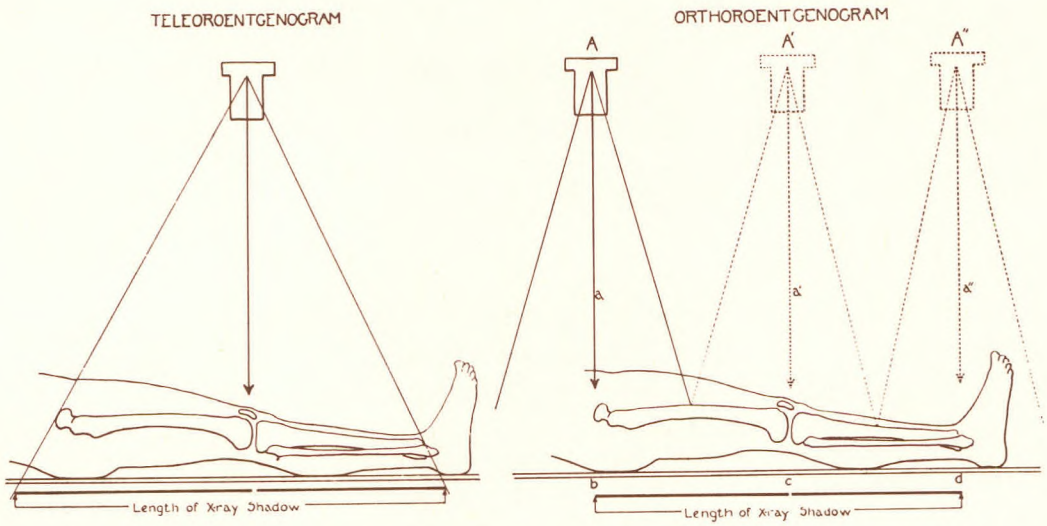
* The film is purchased in rolls seventy-five feet long and stored in metal containers. Just before exposure, the film is cut to the length required for each orthoroentgenogram. The cost for each individual averages $2.10, if a roll of film is purchased and only the necessary length of film is used.



Schematic representation of the relative lengths of shadows of the same bones filmed with a one-exposure and with a three-exposure technique. Fig. 1A: Divergent rays produce magnification in teleoroentgenography. Fig. 1B: Perpendicular rays intersect the ends of the bones in orthoroentgenography, recording the true length.

The patient is placed on the cassette holder in the supine position, with the hips level and the extremities parallel; straps are fastened over the lower thighs and over the ankles to hold the limbs in the proper position (Fig. 3).

Three exposures are made in sequence. In the first, the tube is centered over the hip joint with both shields in the distal position; in the second, the tube is over the knee joint with one shield in the proximal position and the other in the distal position; in the final exposure the tube is centered over the ankle joint, with both shields in the proximal position.

The centering of the tube in each exposure

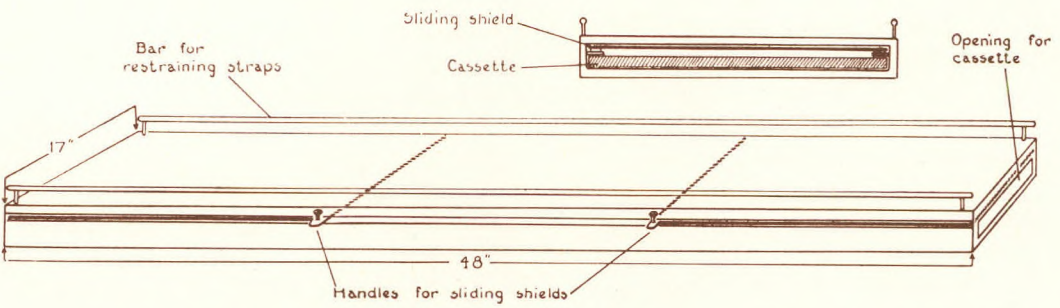


FIG. 2: Diagram of cassette tunnel used for orthoroentgenograms. The frame of the tunnel is constructed of welded channel, one and one-half by three inches, which is milled to form suitable grooves in which the cassette may slide and the shields be shifted. On one side of the long dimension of the frame is a narrow slot, through which the handles of the shields protrude. The top is made of polished bakelite, one-eighth of an inch thick, and is fastened to the frame with screws. The shields are made of cold rolled steel and are mounted on tracks in order to be moved alternately into the central opening. Steel rods, one-half inch in diameter, are mounted on either side, one-quarter inch above the bakelite surface, to permit the attachment of restraining straps.

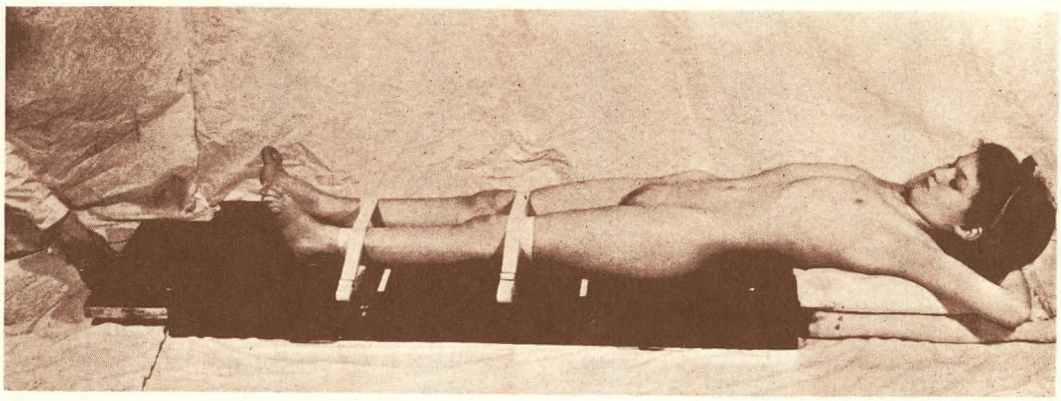


FIG. 3. Patient in position for orthoroentgenogram. The extremities are steadied by restraining straps, and the cassette is being slid into the tunnel.

is checked by a long metal marker, placed horizontally at right angles to the side of the cassette. One end, pointing at the level of the joint to be exposed, extends over the cassette far enough to cast a shadow on the film; the other end indicates the position of the tube stand for the exposure. In this way, the exact level of focus is permanently recorded on the finished orthoroentgenogram (Fig. 4 B). The distance of six feet from tube to film decreases any slight inaccuracy occasioned by imperfect centering.

OTHER TECHNIQUES

In teleoroentgenography the divergence of the rays from the tube produces considerable magnification, even when a distance of six feet from tube to film is used. The amount of magnification is variable, depending upon the length of the bone, the distance of the bone from the film, and the centering of the tube (Table I). Although teleoroentgenograms do not give the true lengths of bones, they do allow fairly accurate estimates of the relative lengths of the two extremities at a single examination. If they are used for serial measurements of growth, however, a variable distortion arises which makes them unsatisfactory, since the magnification becomes greater with the growth of the individual. This increased distortion is produced both by the increase in the bone-to-film distance, resulting from the thickening of the posterior structures, and by the increased length of the bones themselves, which places the bone ends nearer the periphery of the diverging roentgenographic beam.

In part, the error of magnification in teleoroentgenographic mensuration can be corrected mathematically by triangulation. Difficulties in computation arise from the fact that the two ends of a given bone vary in height from the film. Furthermore, the computations are time-consuming and the results are inaccurate, since the distances of the bones from the film can only be estimated.

The accuracy of the measurements of teleoroentgenograms might be improved by the use of a radiopaque ruler, placed parallel to the bones and at an equal distance from the film, following the principle used in the Thoms method of roentgen pelvimetry. In practice, however, it was found impossible to place the ruler precisely enough to warrant its use. Teleoroentgenography, or one of its modifications, was considered not sufficiently accurate for our purposes.

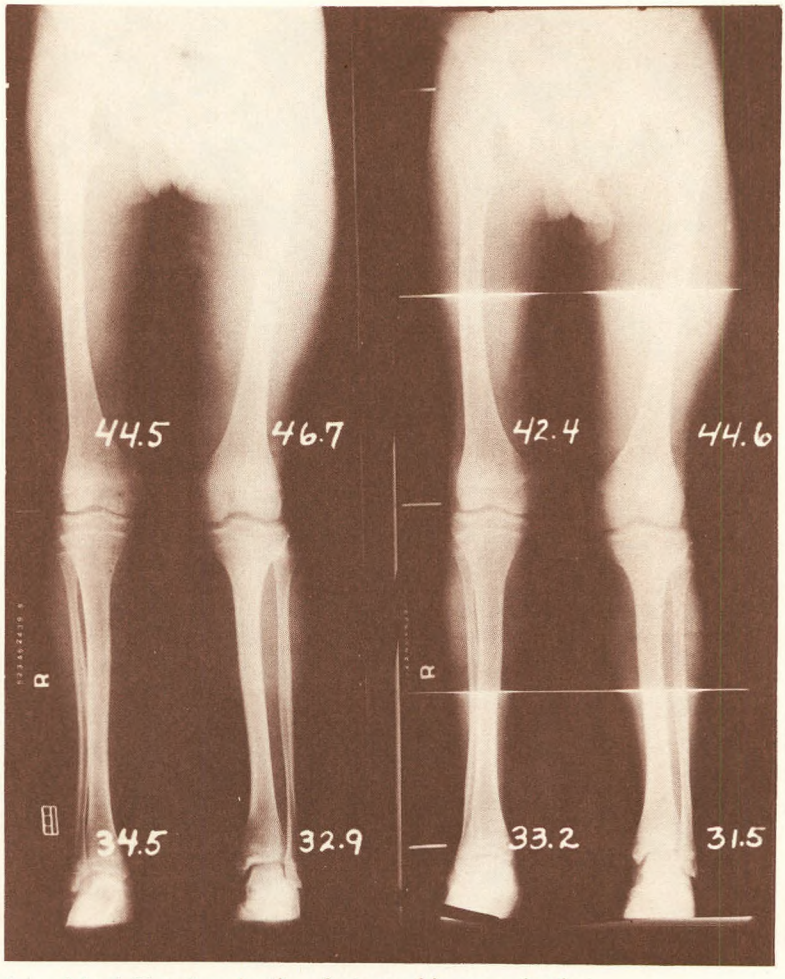
Merrill described a method which allows more accurate measurement than does teleoroentgenography. He used three exposures on separate films, and measurements were made from a superimposed numbered metal-

lic scale. This method does not allow visualization of the full length of the bones, no technique of checking the accuracy of focus was provided, and the focal distance used was only forty-two inches.

Consideration was given to the use of some adaptation of the slit scanogram.[3] It was decided, however, that an exposure of the necessary length and intensity would be unduly wearing on the roentgenographic tube, and the available equipment precluded any experimentation along these lines. Gill and Abbott have since described a modification of the slit-scanographic technique in the measurement of the bones of the lower extremities. They obtained films of good quality which recorded the exact length of the bones.

ORTHOROENTGENOGRAMS

Orthoroentgenograms give a permanent, verifiable record of the lengths of the bones of the lower extremities. Because only perpendicular rays are directed at the ends of the long bones, magnification of length is eliminated, and visualization of each undistorted epiphyseal line is possible. The accuracy obtained with this method is such that increments of length can be reliably mea-



Comparative roentgenograms of the same child, taken by two different methods.

FIG. 4A: In the teleoroentgenogram, note the variability in visualization of the bones. The upper ends of the femora are poorly shown. The combined length of the bones in the right leg is 79.0 centimeters; in the left leg, 79.6 centimeters. Fig. 4B: In the orthoroentgenogram, note the greater evenness of visualization. The combined length of the bones in the right leg is 75.6 centimeters; in the left leg, 76.1 centimeters. The difference in extremity lengths, as measured by the two films, is 3.4 centimeters on the right and 3.5 centimeters on the left. This represents the magnification produced in the teleorentgenogram. The position of the metal marker can be seen opposite each joint on the right leg; it is much more easily visualized in the original film than in the photographic reproduction.

TABLE I

Comparative Measurements of the Lower Extremities in Twenty Cases by Orthoroentgenography and by Teleoroentgenography

Variations in the Measured Length of Bones as Obtained from Orthoroentgenograms with Those Obtained from Long Teleoroentgenograms (One Exposure of the Whole Lower Extremity on a Single Film) and from Short Teleoroentgenograms (Separate Films for the Femora and Tibiae)

FEMORA				TIBIAE			
Ortho. (Cm.)	Long Teleo. (Cm.)	Difference (Cm.)	Teleo. / Ortho.	Ortho. (Cm.)	Long Teleo. (Cm.)	Difference (Cm.)	Teleo. / Ortho.
30.0	31.1	1.1	1.037	20.4	21.0	0.6	1.029
32.4	33.6	1.2	1.037	22.7	23.4	0.7	1.031
34.2	35.5	1.3	1.038	24.0	24.7	0.7	1.029
36.7	38.2	1.5	1.041	26.6	27.3	0.7	1.026
38.4	39.7	1.3	1.034	28.2	29.0	0.8	1.028
40.0	41.5	1.5	1.038	30.5	31.4	0.9	1.030
42.2	43.8	1.6	1.038	32.3	33.2	0.9	1.028
44.7	46.6	1.9	1.042	34.9	35.9	1.0	1.029
46.5	49.3	2.8	1.060	35.6	36.7	1.1	1.031
45.5*	49.2*	3.7	1.081	37.0*	38.5*	1.5	1.040
Ortho. (Cm.)	Short Teleo. (Cm.)	Difference (Cm.)	Teleo. / Ortho.	Ortho. (Cm.)	Short Teleo. (Cm.)	Difference (Cm.)	Teleo. / Ortho.
29.4	30.4	1.0	1.034	20.9	21.7	0.8	1.038
32.9	34.3	1.4	1.042	23.4	24.3	0.9	1.038
34.0	35.5	1.5	1.044	25.0	26.0	1.0	1.040
36.8	38.4	1.6	1.043	27.5	28.6	1.1	1.040
38.3	40.2	1.9	1.050	28.7	29.9	1.2	1.042
40.3	42.2	1.9	1.047	30.0	31.4	1.4	1.047
42.2	44.3	2.1	1.050	33.0	34.5	1.5	1.045
43.9	46.2	2.3	1.052	34.4	35.9	1.5	1.044
46.7	49.3	2.6	1.056	37.7	39.3	1.6	1.042
45.5*	48.2*	2.7	1.059	37.0*	38.6*	1.6	1.043

*Measurements are from roentgenograms of skeletons. Focus on long teleoroentgenogram of skeleton was at the knee; compare magnification with other long teleoroentgenograms, where focus was over the femur.

sured in growing children over an interval as short as three months.

The true length of each bone can be measured directly from orthoroentgenograms without computation; there is no significant magnification of length due to the divergence of the rays, because the focal spot is placed exactly over each joint.† Special high-speed roentgenographic equipment is not necessary for these films; the strain on the tube is no greater than it would be in filming separately a hip, a knee, and an ankle.

Comparison of the lengths of bones, using orthoroentgenograms and teleoroentgenograms, has always revealed a considerable degree of magnification in the teleoroent-

† Although orthoroentgenograms record the exact distance from one end of the bone to the other, slight shortening would occur if the bone were not parallel to the film. In the femur, for example, a minimal amount of shortening must occur, due to the oblique position of the bone. This could be corrected by elevating the knee and ankle to the same level as the head of the femur. The error involved is, however, so slight that such a procedure was thought undesirable, as it would be overbalanced by the loss of bone detail due to the increased distance of the object from the film.

genogram (Table I). This occurs whether the teleoroentgenogram is made on a long film with a single exposure for the entire lower extremity, or on two short films with separate exposures for the femora and the tibiae. The magnification is greater with the longer bones, although it is modified by the relative thickness of the soft tissues, which in turn modifies the distance of the bones from the film.

Whereas the magnification of the femur in the long and the short teleoroentgenograms is essentially the same, the tibia shows somewhat less magnification in the long film. This arises from the fact that in the long teleoroentgenogram the tube is centered over the lower femur to provide better visual detail. The rays intersecting the two ends of the femur are thus similarly divergent in the two types of film. However, in the long film, since the tube is centered over the femur, the rays intersecting the upper end of the tibia tend to produce some foreshortening. This illustrates one of the difficulties in the use of teleoroentgenograms for serial study, since variation in the points of focus affects the length of the shadows obtained.

The measurements obtained from orthoroentgenograms show little deviation from the real length of bones. Orthoroentgenographic measurement of a dissected adult femur, 45.7 centimeters long, gave a length of 45.5 centimeters; that of an adult tibia, 37.0 centimeters long, was 37.0 centimeters by orthoroentgenogram. The lengths of these bones, as recorded on a long teleoroentgenogram centered at the knee, were 49.2 centimeters for the femur and 38.5 centimeters for the tibia; on short teleoroentgenograms they were 48.2 centimeters and 38.6 centimeters, respectively. In these exposures the bones were placed at a distance from the film comparable to that which would exist in a patient.

Since the whole of both lowerer extremities is presented on a single film in an orthoroentgenogram, details of the structure of the bone and any factors of deformity can readily be evaluated. The only loss of visualization is produced by the overlapping of shadows at the junction of the shields, but this point can be placed at the mid-shaft, where it is of little consequence. The amount of bone not visible on the film is that which represents the magnification produced in a teleoroentgenogram.

Some distortion in length can occur in the orthoroentgenogram, if the tube is not centered over the end of the bone. For this reason the exact points of focus are recorded on each film with a metal marker. If the focal spot should be significantly above or below the end of the bone, the film could be repeated. In practice this has seldom been necessary, and the marker serves primarily as a verification of technique.

Motion of the patient between exposures must not occur. This is controlled by placing the patient in a comfortable position, by strapping the legs, and by the vigilance of the technician. If the cooperation of the patient is secured, the factor of motion offers no more difficulty than in any other roentgenographic procedure.

If there is a marked discrepancy in the length of the two extremities, there will be a small amount of relative distortion in the measured length of the bone over which the tube is improperly centered. In such cases, the two extremities may be exposed separately.

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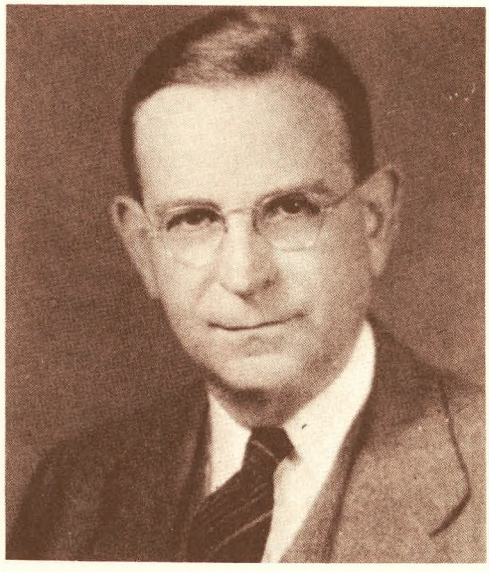


WILLIAM T. GREEN

CLASSIC 39 Man's Posture

Its Evolution and Disorders (Lecture 1)

Given at the Royal College of Surgeons of England

PROFESSOR SIR ARTHUR KEITH, F.R.C.S., F.R.S. (1866–1955)

Conservator of the Museum

Lecture I. Theories Concerning the Evolution of Man's Posture (Abstracts)

The true story of how anatomists abandoned the belief that man's body was a special creation and became converted to the theory of evolution commences in 1809, the year of Darwin's birth—when England and France were striving for mastery in the Spanish peninsula. The new idea was born in Paris—not, as one might well expect, in the famous schools of human anatomy hid amongst the crowded streets on the south bank of the Seine, but in the Museum of Natural History, situated in the neighbouring Jardin des Plantes. Three officials of the Museum—Cuvier, the Professor of Comparative Anatomy, Geoffroy St. Hilaire, who had charge of the collection of Vertebrate animals, and Lamarck, who was responsible for the Invertebrata—were effecting, amidst war and political change, a complete revolution in man's conception of the animal kingdom.

In 1809 the magnificent Cuvier, then in his fortieth year, standing, so far as concerned the public eye, head and shoulders above his colleagues, was bringing together the material for his famous work on *Ossements Fossiles,* awakening men to the knowledge that boundless ages of teeming life had come and gone before the present era began. While Cuvier was thus unconsciously enlarging man's conception of the past, his colleague, Geoffroy St. Hilaire, somewhat Cuvier's junior in years, was seeking for the common plan or design on which the bodies of vertebrate animals were built, thus preparing the way for those who were to preach the doctrine of a common descent for all living things. Lamarck, the least favoured of the three in the estimation of the learned men of his time, was twenty-five years Cuvier's senior. In the hustings of contemporary science he could scarcely make his voice heard, but we now know he had probed deeper into the secrets of Nature than either of his two colleagues. All his life long he had been a retiring but systematic student of

living things and of the conditions under which they live. He was already an old man —a man of 65—when in 1809 he published two small volumes under the title of *Philosophie Zoologique*, in which we see that this retiring pioneer, as a result of a half-century of patient study, had reached the conviction that all the living things to be found on the earth today were but the twigs of a common tree of life, whose branches, trunk, and roots were buried deeply in the past ages of the world. It is in this work, written in the seclusion of the precincts of the Museum, away from dissecting rooms, and during stirring years of war, that we find the first clear statement of the belief—now universally held by human anatomists—that man's posture of body has been evolved from one which was simian or ape-like.

LAMARCK'S THEORY

To do Lamarck full justice it would be necessary to make lengthy extracts from those chapters which deal with the evolution of man, but the following quotation (vol. i, p. 349) will give a just estimate of the manner in which he explained the evolution of man's posture:

> Indeed, if any race of primates (quadrumanes) whatsoever, particularly the more highly evolved of them, were to lose, either from force of circumstances or any other cause, the aptitude for tree climbing and of grasping the branches with their feet, as with their hands, for security of grip; and if the individuals of this race, for a series of generations, be obliged to use their feet only in walking, and cease using their hands as feet; then there is no doubt, from the evidence produced in the foregoing chapters, that these apes would finally be transformed into man (bimanes) and that the great toe would no longer be separated from the other toes like a thumb, the feet serving merely the purposes of progression.

From this passage we see that, in the first place, Lamarck supposed man to have been evolved from a chimpanzee-like anthropoid, for we know that of modern and living anthropoids he regarded the chimpanzee as "the more highly evolved." The gorilla, it may be mentioned here, was not discovered until 1847—eighteen years after Lamarck had been laid in his grave. In the second place we note that Lamarck regarded the erect posture as a result of the chimpanzee-like ancestor having abandoned an arboreal mode of life for one in the open country. In the third place we note that he held the belief—one which we still regard as unproven—that the progress made by one generation in accommodating itself to an erect posture would, age upon age, be transmitted to the next generation. He was fully alive to the fact that any anthropoid which had acquired the human mode of progression had gained an enormous advantage; it would no longer be confined to tracts of tropical jungle but would have the whole length and breadth of the earth open to it.

DARWIN'S THEORY

Lamarck was a pioneer, but so far as concerns the evolution of man he did not induce a single anatomist of his own or of a succeeding generation to follow in his footsteps. We have to pass to the year 1871, when the *Descent of Man* was published, to find the first effective step in the development of our modern knowledge of man's evolution. The Philosophy of Zoology had remained sixty-three years in neglect, and Charles Darwin, who declared he had read and studied the book to no profit, was then 62 years of age. We turn at once to the *Descent of Man* to see what conception Darwin had formed concerning the evolution of the human posture. At page 76 of the first edition the following passage occurs, which contains an explicit statement of Darwin's explanation:

> As soon as some ancient member (elsewhere defined as some species of anthropoid like the chimpanzee) in the great series of the Primates

came to be less arboreal, owing to a change in its manner of procuring subsistence, or to a change in the surrounding conditions, its habitual manner of progression would have been modified, and thus it would be rendered more strictly quadrupedal or bipedal. . . . Man alone has become a biped; and we can, I think, partly see how he has come to assume his erect attitude, which forms one of his most conspicuous characters. . . . As the progenitors of man became more and more erect, with their hands and arms more and more modified for prehension and other purposes, with their feet and legs at the same time transformed for firm support and progression, endless other changes in structure would have become necessary. The pelvis would have to be broadened, the spine peculiarly curved, and the head fixed in an altered position, all which changes have been attained by man. . . . It is very difficult to decide how far these modifications are the result of *natural selection* and how far of *the inherited effects* of the increased use of certain parts, or of the action of one part on another. No doubt these means of change often co-operate.

When the explanations advanced by Lamarck and by Darwin are compared it is at once seen that, as regards the manner in which the human posture has been evolved, there is much in common. (1) Both supposed that man had been evolved from a chimpanzee-like anthropoid and in the course of evolution the anthropoid posture had become human. (2) Both agree that the transformation had been initiated by a change from an arboreal to a terrestrial mode of existence. (3) Both believed that the results of habit or of function, acquired by one generation, could be inherited by the next generation. Darwin, however, made important additions: (1) he applied the law of natural selection—the tendency for successful individuals to survive and prosper; (2) he recognized the action of sexual selection; (3) he perceived that there was a law of correlation of parts—an obscure mechanism by which a number of structures were modified together to suit some particular function of the body. We now realize—or rather begin to realize—that the development and modification of various systems of structures are regulated or influenced by various internal secretions or "hormones." Darwin's law of correlationship of parts is but an intelligent anticipation of the more recent discoveries of physiology. We expect that fuller knowledge will yield the key to many problems in the evolution of posture which are at present unexplained.

In their bald outlines the explanations given by Lamarck and by Darwin of how man came by his erect posture have much in common. Why was it that for sixty-two years the one was regarded as an idle curiosity, while in the course of ten short and strenuous years the other had spread into every anatomical workroom throughout the civilized world, revolutionizing the worker's point of view and endowing his labour with a new aim and a new zeal? Both *Philosophie Zoologique* and *Descent of Man* were founded on a lifetime of inquiry and observation, but Darwin conquered—as men always will conquer—because he permitted a masterly array of facts to tell their own story, while Lamarck always wished to tell the story of his facts. However that may be, there is no doubt of the fact that the *Descent of Man* is the starting point of our modern knowledge of all that pertains to the origin and evolution of the human body. The student of history will also note the fact that neither Lamarck nor Darwin was a professional anatomist, and yet they did more to alter our conception of the human body than any professional anatomist of their time.

How the Theory Now Stands

Much has happened in the fifty-two laborious years which followed the publication of the *Descent of Man.* The time has come, so it seems to me, for a fresh survey of our knowledge of all that relates to man's posture in order that we may ascertain how far it is now necessary to modify, extend, or amplify Darwin's explanation of its evolution. My aim in this lecture is to pass in

brief review recent inquiries and investigations which throw fresh light on how, when, and where man came by his erect attitude. I have also another object in view—to show that the problems relating to the evolution of posture have a very direct bearing on medical and surgical practice; many of the obscure and distressing conditions which require treatment are in reality manifestations of a disturbance or derangement of the elaborate mechanism which regulates and maintains the remarkable posture of the human body.

EVIDENCE FROM FOSSIL REMAINS

The fossil remains of man, so far as they have become known to us in recent years, do not provide any certain clue as to the date, place, or manner in which the human posture was evolved. We cannot say that any fossil form of man yet discovered shows a foot in a stage intermediate to that of anthropoid and man. The most important discovery for our present purpose is that made by Dr. Eugène Dubois during 1891 and 1892 when he was resident in Java. He discovered the remains of a strange and distinct genus of man, to which he gave the name of *Pithecanthropus erectus*. No part of the foot, leg, or trunk was found, only three teeth, the roof of the skull, and the left thigh bone. The thigh bone leaves us in no doubt as to the posture of body; it is human in all its characters; we cannot explain its characters unless we suppose that Pithecanthropus was human in posture and gait. The stratum in which the remains of Pithecanthropus were found belongs either to the beginning of the geological epoch which precedes the present—the Pleistocene—or to the end of the still older epoch—the Pliocene. We thus know for certain that the human posture was fully evolved at least before the beginning of the Pleistocene period. There are many reasons, however, for supposing that Pithecanthropus represents a persistence of a primitive type which had appeared long before the beginning of the Pleistocene; in size of brain we must regard him as representative of man at the beginning rather than at the end of the Pliocene period. The thigh bones show that the lower extremities were used as in us, but the characters of the skull are incompatible with the poise of head seen in modern man. In the fossil man of Java the head was hafted to the neck as we see in living anthropoids—so that the head is carried with a forward slouch.

In recent years we have greatly extended our knowledge of that peculiar and extinct type of human being now known as Neanderthal man. The bones of the foot, leg, and thigh all show certain features which manifest a closer resemblance to the corresponding parts of the gorilla than do the same bones in modern man. The head was set on the neck in a manner which clearly represents a modification of the anthropoidal fixation. The earliest trace of Neanderthal man so far discovered is the Heidelberg or Mauer mandible, which was found in 1907 by the late Professor Otto Schoetensack in a stratum belonging to the older deposits of the glacial or Pleistocene period. The Heidelberg mandible clearly belongs to a very primitive type of Neanderthal man; the more humanized type became extinct long before the close of the Pleistocene period, and apparently long after men of the modern type had come into existence. There thus persisted into the Pleistocene period a race or species of man in which the body was less perfectly adapted for holding the head and body erect than is the case with modern man. Yet in the Piltdown type of man, who, in a geological sense, was the contemporary of Pithecanthropus, the head was carried almost as in modern Europeans. The conformation of his mastoid process and the muscular impressions of his occipital bone leave us in no doubt as regards this matter. Thus, in recent geological periods there have been races or types of mankind showing de-

grees in their adaptation to the posture and gait of modern man.

A survey, then, of our present knowledge of extinct forms of man permits us to make only a guarded statement as regards the date and manner of the evolution of our posture and gait. It is apparent that the adaptations which permitted the head to be balanced on the neck are comparatively late acquisitions; they appear to have been evolved since the commencement of the Pleistocene period. The lower limbs assumed a human form at a much earlier date. Pithecanthropus had a fully evolved human femur, and we must infer that the foot was equally human. If I am right in regarding Pithecanthropus as representative of mankind at the beginning rather than at the end of the Pliocene, then it is in the strata of an older period, at least the Miocene, perhaps the Oligocene, that we must look for those ancestral forms which will show us the anthropoid foot and leg assuming the characters which we regard as human. "We are far," says Darwin, "from knowing how long it was since man first diverged from the Catarrhine stock, but it may have occurred at an epoch as remote as the Eocene period." We see, then, that Darwin was prepared to find fossil remains showing changes in the foot and leg such as I have just mentioned in even earlier formations than the Oligocene.

EVIDENCE FROM THE ANATOMY OF ANTHROPOIDS

Having thus surveyed the evidence afforded by the fossil remains of man I propose now to inquire how far our present knowledge of the structure and habits of man's nearest allies—the anthropoid apes—will assist us in solving the problems of human posture. Our knowledge of these allies, both living and extinct, has greatly extended since Lamarck and Darwin formulated their theories, and we realize that both of these great men grossly underestimated the complexity of the problem and failed to realize that the structural adaptations which made plantigrade progession possible for man were not sudden transformations produced for man's particular benefit, but had come into existence during the evolution of the anthropoid body. It is in the evolution of the early anthropoids that we have to seek for the rise and development of the chief postural modifications of man's body. This truth was brought home to me very forcibly over thirty years ago when, as a medical officer and naturalist attached to a mining company exploring the mineral wealth of the Malay Peninsula and of Siam, I was drawn into a study of the apes and monkeys living in the jungles of these countries. They were regions in which malaria was endemic, and I set out to ascertain if the apes of the jungle suffered as much from fever as did the people of the villages. There were in my neighbourhood wandering troops of three kinds of ape, all of about the same size—weighing from 15 to 20 lb.: (1) the gibbon, the smallest and by far the most primitive of anthropoid apes; (2) various species of Semnopithecus, best known by their Indian cousin—the langur or holy monkey; (3) various species of the macaque monkey. My attention was soon transferred from the primary object of my investigation to the remarkable anatomical features of the gibbon's spine and trunk; in their arrangement the bones and muscles of the gibbon were altogether human, while the same parts in the semnopitheque and macaque, which outwardly looked as if they might be cousins to the gibbon, were altogether different. It was then I realized that the history of many of man's postural adaptations had to be traced back to the evolution of the gibbonish or hylobatian body (Hylobates is the generic name for the gibbons). Nor was there any difficulty in ascertaining that these structural features of the gibbon's body were postural adaptations. In his flight from tree to tree the gibbon's manner of progression differs altogether from that of monkeys. It is true that before start-

ng their flight the resting posture of gibbon ınd monkey is much the same; both sit in a ;emi-erect posture, resting on their ischial :allosities. In progression the gibbon uses ıis long arms as the chief means of support ınd of propulsion; he leaps with his arms; he lower limbs are deftly used as accessory neans of support or as the chief means when unning along horizontal branches. The body s held, in all movements, upright to the)lane of progression. The gibbon is *ortho-;rade* in its gait, whereas his neighbours, the nonkeys, are *pronograde*; as they passed rom branch to branch, or from tree to tree, heir bodies are held parallel to the plane of notion. The semnopitheque was a heavy umper; in a forward leap the impetus came rom the hinder limbs and loins; the hands ınd arms were used to clutch the branch on vhich he lighted, but were never used in the ıand-over-hand method which is habitual in he gibbon—a true trapeze athlete. These arly observations convinced me that if we re to seek for the beginnings of human pos-ure we must first unravel the history of the ;ibbons.

The Evidence Afforded by Gibbons

In point of structure the gibbon occupies central position among the higher form of rimates. It is linked to the three surviving reat anthropoid apes—the gorilla, chim-anzee, and orang; all of these show a reater degree of adaptation than the gibbon o the orthograde posture. We have also ood reason for believing that they are later ı date of evolution. The gibbon, when llowance is made for its postural modifica-ions, stands out as the cousin of old world ıonkeys; all of these are pronograde in their ;ait, but in some the arms are used and eveloped to a much greater degree than in thers; this is particularly true of those forms ı which the tail has become reduced in ength and strength. We shall see that the evelopment of the tail depends on posture nd gait. The gibbon is also cousin to the higher forms of South American monkeys; in some points of structure it is more nearly allied to them than to the monkeys of Asia and of Africa. The higher new world apes, although essentially pronograde in their gait, show a specialization of their hinder limbs, and in many cases a peculiar use of their tails, in grasping and climbing. While in the evolution of the gibbon the upper limbs have been exploited as means of support and progression, the specialization of function in South American monkeys has been concentrated on the lower limbs—they are used for suspension rather than for support. The structural similarity which unites gibbons, old-world monkeys, and new-world monkeys is such that we must regard all three as arising from a common ancestral form, from which has arisen a series of postural types represented in the small anthropoids and monkeys of the old and of the new world. The chief problem in the evolution of the gibbon, as of man, is the discovery of the machinery which Nature employs to mould structural form to postural function; the nature of this machinery we shall consider later. Meantime, so far as concerns the group of primates to which man belongs we may safely say that the greatest structural revolution which marks the history of this group occurred with the evolution of the gibbon. It is to this ancient structural revolution that man owes the chief of his postural modifications.

The Antiquity of the Orthograde Posture

All the evidence at our disposal points to an ancient origin for the small anthropoids of the hylobatian or gibbon type. Fossil remains of them have been found in the Pliocene and Miocene deposits of Europe, and so like are they to the corresponding parts of modern gibbons that we feel certain that in the living gibbon we are dealing with an ancient and conservative type which has come through long geological epochs almost

unchanged. It is highly probable that the orthograde gibbon and its pronograde cousins of the old and new worlds began to be differentiated towards the end of the Eocene period. In the Eocene formations of North America and of Europe are found fossil remains of numerous primates, but all of those so far discovered are tarsioid in form—more generalized in structure than gibbons or monkeys. The common stock from which gibbon and monkey arose will probably prove to be an Eocene tarsioid. That the orthograde hylobatian type had been differentiated from the ancestral pronograde monkey type at an early period is proved by the discovery of the remains of fossil apes in the Oligocene deposits of Egypt, which in point of geological age are intermediate to the older Eocene and more recent Miocene formations. Amongst these Egyptian fossil remains, which were described by Professor Schlosser in 1910, was the left half of a mandible of a small and primitive form of gibbon. Whether or not this early gibbon possessed the orthograde posture we have as yet no certain means of telling, but there is good reason for presuming that it did.

THE TROGLODYTE OR GREAT ANTHROPOID STAGE

The first or hylobatian stage in the evolution of man's posture came during a remote geological epoch, with the appearance of the small type of anthropoid ape now represented by the gibbon. The second stage came with the evolution of the great anthropoid apes; and because the chimpanzee is the most generalized surviving member of this group and in former times was given the generic name of Troglodytes, this stage in the evolution of man's posture may be named the "Troglodytian." All available evidence points to the great anthropoids as having been evolved from a small anthropoid ancestry. In bulk and strength of body man and the chimpanzee are nearly alike, but the male orang, and particularly the male gorilla, outstrip the strongest man in strength and weight of body. With the evolution of the great anthropoids from the small, the weight of the body undergoing then an eight- or twelve-fold increase, adaptations for the orthograde posture and gait were necessarily modified as well as strengthened. In none of the great anthropoids do the arms reach the high degree of specialization in structure and function to be seen in modern gibbons; none of them are pure brachiators as are gibbons. In the orangs, it is true, the arms are much more important and more developed than the legs for arboreal progression; in the gorilla the opposite has happened; the lower limbs are the more specialized. The chimpanzee holds an intermediate position, both limbs being developed to an equal degree, as was probably the case in early anthropoid forms. One other point deserves mention; in the gibbon, as in old-world monkeys, there are ischial callosities to serve as natural rests in the sitting posture; in the great anthropoids these callosities have disappeared. As in man, true rest is obtained by the great anthropoids only when the body is laid prone upon bed or tree scaffold.

Such scanty evidence as we now possess leads us to believe that the troglodytian, or second, phase in the evolution of man's posture, took place about the end of the Oligocene period or the beginning of the Miocene. We know of the fossil remains of at least six species of Dryopithecus, an anthropoid which was neither less nor more primitive than any of the surviving giant anthropoids. The earliest traces of Dryopithecus come from deposits belonging to the middle of the Miocene period; it will probably be found that the great or giant form of anthropoid is pre-Miocene in date of origin.

THE THIRD OR PLANTIGRADE PHASE

We come now to the third phase in the evolution of man's posture—the *plantigrade* stage. The first, or hylobatian, stage came

with the appearance of the gibbons; the second, or troglodytian, with the evolution of the great anthropoids; and the third, the really human stage with which we are now dealing, when the line leading on to man branched off from the great anthropoid stock. The structural changes which occurred in the third stage were confined almost entirely to the lower limbs. The knees and thighs became more extended and strengthened until the lower limbs came to appear as if they were a downward continuation of the trunk. The pelvis or fulcrum of the lower limbs, as also of the spinal column, was modified; the hip and knee joints became adapted to the new posture; the muscles and bones of the leg assumed a human form; and, above all, the foot was transformed. We shall see, however, that underneath all that is so peculiarly human in our lower limbs there still lurk numerous vestiges and arrangements which we can only explain by supposing that at one time all the parts had passed through a troglodytian stage in their evolution. In the third stage only minor alterations occurred in the structure of the trunk. The chief adaptations to fit the thorax and the abdomen to the erect posture had been nearly perfected before the third or plantigrade stage had commenced.

In which geological period the third stage was entered and the plantigrade posture evolved we cannot as yet fix with any degree of certainty. No fossil form has yet been found in which the lower limbs are in process of transformation. It is true that the lower limbs of Neanderthal man show minor anthropoid traits, but it is also true that the femur of Pithecanthropus is a fully developed human form. No one who accepts evolution as a working hypothesis will have any difficulty in regarding the three great anthropoids—the gorilla, the chimpanzee, and the orang—as divergent branches from the common giant stem. Seeing that man shares so many characters in common with these we are compelled, I think, to regard man as an aberrant branch from the troglodytian stock or stem, and it is therefore probable that the plantigrade posture was evolved as soon as the common giant stock began to break up into its various living and fossil forms. We know for certain that this stock was in existence before the middle of the Miocene period, and it is therefore prior to that very remote date, most likely about the beginning of the Miocene or end of the Oligocene—two or three millions of years ago at the lowest estimate—that the plantigrade posture began to be evolved.

THE MODERN THEORY OF MAN'S POSTURE

Thus it will be seen that modern anatomists no longer regard the postural adaptations of the human body as the result of a transformation peculiar to man, as did Lamarck and Darwin. They regard man's gait and posture as the culmination of a series of evolutionary phases which are to be traced in the bodies of orthograde primates throughout the greater part of the Tertiary duration of the earth's history.

THE COMPLEXITY OF THE PROBLEM

The great extension of our knowledge of the constitution and mechanism of the central nerve system, largely the outcome of the discoveries made by Sir Charles Sherrington during the past thirty years, has shown us that the evolution of the orthograde posture was a far more complex and difficult problem than the great pioneers had supposed. We know how complex and delicately adjusted are the nerve centres which carry out the spinal reflexes of even pronograde apes; with the elaboration of the orthograde posture all of these spinal centres must have undergone a structural elaboration as well as a functional adjustment. Further, the orthograde posture, even in its more primitive form, demands a higher degree of coordination of the reflex centres in the spinal

cord—centres or clusters which extend from one end of the cord to the other; consequently the higher centres—the red nucleus and other cell masses of the mid-brain, which regulate the postural tone—and the cerebellum, which has so much to do with the "timing" of the spinal centres, must have undergone a high degree of elaboration and expansion. The elaboration of the centres for automatic control of the orthograde muscular system was accompanied by an expansion of the basal ganglia and cortical centres of the brain. During the evolution of the orthograde posture brain and body had to become modified in unison.

The researches of Dr. Leonard Hill have made us aware of the elaborate mechanism needed to regulate the arterial blood pressure when the posture of the body is changed. In the early pronograde primates the vasomotor postural mechanisms must have been already highly evolved, but it is clear that, with each step towards the plantigrade posture of man, there must have been further specializations in the reflex centres which control the distribution of blood and in the structures which support the weight of the blood mass. Further, we shall see that all the structures concerned in the mechanism of respiration underwent a change in form, function, and control. The evolution of the orthograde posture entailed a structural revolution in all parts and systems of the body, from the crown of the head to the soles of the feet.

THE MACHINERY OF STRUCTURAL EVOLUTION

When we see that a change from the pronograde to the orthograde posture entails a modification of nearly every muscle of the body as well as of corresponding changes in the nerve centres which control them we have to seek an answer to this problem: By what evolutionary machinery does Nature bring about simultaneous and harmonious modifications in a thousand apparently independent units of structure? The explanation offered by Lamarck, and also to a certain extent by Darwin, was that in the animal body there exists a mechanism by which structural modification acquired by one generation as the result of use and habit can be passed on, in ever-increasing degree, from generation to generation. The existence of such a machinery for transmission is not only unproved, but for several reasons is highly improbable. Darwin observed that there was evidence of some controlling factor which correlated the growth of associated structures. The nature of the mechanism which regulates the development and growth of parts and so fits them for performing their function in a new way is becoming apparent bit by bit as we get to know more of the behaviour of animal tissues. Phagocytes are attracted to sources of infection by a chemotactic mechanism. Kappers of Amsterdam has demonstrated that groups of developing nerve cells migrate in swarms and arrange themselves at sites favourable for the reception of the stimuli with which they have to deal; to the mechanism involved he gives the name "neurobiotaxis." Cells removed from the body of an embryo and grown in artificial media exert a regulating influence on each other; in a sutured wound of the intestine epithelium seeks out epithelium, and muscle cells seek out muscle cells in the process of union. The testicle throws into the blood a hormone which stimulates and regulates the growth of a crop of structures. In acromegaly we see a structural transformation effected in all systems of the body. It is along such lines as these that we are to be guided to the adaptational machinery which Nature has employed in bringing about evolutionary changes in posture and in the creation of new types of animals. We are only beginning to realize the elaborate growth machinery which is at work in shaping the body of the embryo; the one thing

we can be certain of is that this machinery is constituted, not on an anatomical, but on a physiological basis. Further, it is not a supernatural machinery but one which, given means, opportunity, and industry, the mind of man can study and determine.



ARTHUR KEITH

Sir Arthur Keith (1866–1955) at the very beginning of his career was interested in those investigative areas which today would be referred to as the Basic Sciences of Orthopaedics. He became Curator of the Hunterian Museum of the Royal College of Surgeons in London and remained so for the greater part of his life. More than anyone he translated morphology and embryology into terms of orthopaedic value.

I studied under Keith's supervision in London in 1928 as part of his graduate training as a young orthopaedic surgeon, as did others at a time preceding the foundation of orthopaedic programs in bone pathology, the prototype subject that became our basic sciences. These classic Hunterian Lectures, of which the present is the first of a series of 5 appearing in the same volume, was of tremendous influence in orienting the orthopaedic viewpoint of contemporary orthopaedic surgeons and their successors.

CLASSIC 40 On the Healing of Wounds in Articular Cartilage

P. REDFERN, M.D., EDINBURGH, MEMBER OF THE ROYAL SOCIETY (1821–1912)

In my former observations, I found that from the 37th to the 49th day after incisions had been made into the articular cartilages of dogs, adhesion had taken place between the cut surfaces to such an extent as to render it easy to make thin sections through both and leave them attached. The uniting substance was composed of a granular mass, containing very imperfect fibres, and a number of corpuscles not to be distinguished from the nuclei of cartilage cells. The cartilage cells lying near the cut surfaces were very much enlarged, rounded or oblong in shape, and filled with corpuscles; in several places they projected into the mass between the cut surfaces, and were therefore in a position to discharge their contents into it whenever the cell-wall should offer too little resistance to their escape. The inter-cellular substance of the same part was somewhat softened and more transparent than ordinary, and presented indistinct traces of fibres. From these appearances, discovered on examination, I concluded that the stimulus of the incision had produced an a[b]normal development of the cells of the part through which it had passed, whilst the inter-cellular substance having become softened, received the contents of the cells after the destruction of their walls; and that this process, so similar in every respect to that by which a fibrous membrane is formed from diseased human articular cartilage, would terminate in a similar way, by forming a dense fibrous mass, with its fibres leading into the substance of the cartilage, and therefore attaching the opposed surfaces firmly to each other. This, however, was not proved, for the fibres observed were very imperfect, and the uniting medium was too soft to remain as a permanent structure; I therefore instituted other experiments, which were as follows:—Three incisions were made across the cartilage of the patella and obliquely from below upwards, in a young dog, and two others were made vertically and from the centre towards the circumference in the cartilage of the trochlear surface of the femur. The patella became dislocated on the inner condyle of the femur, and the dislocation returned instantly after reduction, so that it was allowed to remain. The dog suffered considerably, and could not put his leg to the ground for a fortnight, after which, slight lameness continued for some time, and then almost altogether disappeared, except when any unusual movement was produced. The joint was examined at the end of twenty-four weeks and

five days, and presented the following appearances:—A slightly increased quantity of synovia exists in the joint; the patella rests by the external half of its articular surface on the inner side of the internal condyle of the femur, and the part of the fibrous capsule of the joint which lies upon the trochlear surface of the femur and glides over it, presents a dense, white, and smooth spot, similar in appearance to fibro-cartilage, and of exactly the same size and shape as the trochlea. The edges of the trochlear surface of the femur, and the vertical ridge on the cartilage of the patella, are less prominent than usual, and rounded. The cartilage of the femur appears perfectly healthy, that of the tibia somewhat softer than natural, and the cartilage of the patella is more transparent, and has a small perforation in its centre leading down to the bone. The position of the incisions is difficult to see on the patella, and is only marked by the slightest curvilinear depressions: on the femur, one incision is recognised with the greatest difficulty, and the position of the other cannot be seen with the naked eye.

On microscopical examination, the superficial cells over a considerable extent of the surface of the cartilage of the patella, and especially in the neighbourhood of the central depression, have become much enlarged, many measuring ¹⁄₁₀₀₀th of an inch in diameter; they are nearly spherical, and their contents appear to have divided into three or four masses like nuclei; they are lodged in hyaline substance of greater transparency, and much greater softness than ordinary, so that the cells can be pressed out of it. The appearance formerly described as showing the structure of the superficial layers of the cartilage of the tibia of a dog at a spot in which increased pressure had been made.

In the neighbourhood of the incisions into the cartilage of the patella, and upon the trochlear surface of the femur, though not extending upon the condyloid surfaces, the substance of the superficial layers of the cartilage has become converted into a membrane composed of granules, nuclei, and fibres. The formation of this membrane may readily be traced by an examination of it at the line of junction of the trochlear and condyloid surfaces, where it becomes thin before it ceases to be observed. The contents of the cells first become granular, and the hyaline substance soft and more transparent; the walls of the cells disappear gradually, and scarcely anything but cell-membranes, granules, and molecules lying in a hyaline mass, can be seen; fibres are then formed between the nuclei, and the latter either disappear altogether or elongate into nuclear fibres, and thus a dense fibrous mass is produced. If, during this process, the cells have become larger than natural, they give to the junction of the cartilage and membrane a notched appearance, by bursting and discharging their contents into the latter; but if no enlargement has taken place, the textures run into each other so insensibly that no distinct line of demarcation can be drawn between them.

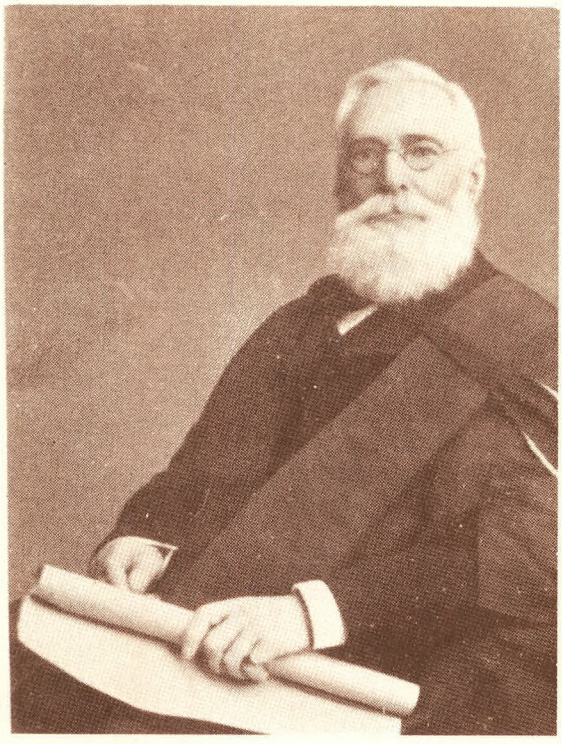
The portions of the texture through which incisions were made present similar appearances in every instance. Not the slightest difficulty is experienced in making sections through both the cut surfaces and the substance by which they are firmly united. Such sections show the cut surfaces to be very uneven and hollowed into small pits of the size of the cartilage cells of these parts. The pits are obviously produced by the half-destroyed cells, the former contents of which are now seen lying on the surface. No evident change has taken place in the texture of the cartilage at a little distance from the cut surfaces, except that here and there the inter-cellular substance presents a fibrous appearance. There is no obvious enlargement of the cells, or crowding of their interior with corpuscles, as is frequently seen to occur under similar circumstances. The substance uniting the cut surfaces consists of a hyaline, granular, and indistinctly striated

mass, in which there are numbers of rounded, oblong, elongating, or irregularly-shaped corpuscles, varying in size from ⅟₅₀₀₀th to ⅟₂₃₀₀th of an inch in diameter, those in the adjacent cartilage measuring more uniformly about ⅟₃₀₀₀th of an inch. The corpuscles are more numerous in the substance connecting the cut surfaces than in the cartilage itself, and the inter-cellular substance of the same part is slightly more transparent than that of the adjacent texture, the appearance of fibres being most distinct in those parts which are directly in contact with the cartilaginous surfaces. In sections obtained from the cartilage of the femoral trochlea the mass between the cut surfaces is less transparent, its fibres are much more perfect, and the corpuscles are smaller and less easily seen. The fibrous and nucleated membrane formed on the surface of the cartilage is continuous with the uniting medium, and differs from it merely in having its fibres parallel to the surface.

It may be here remarked, that the lameness which occurred in this case is by no means to be viewed as the result of the injury to the cartilages; for except when dislocation, or some other accidental occurrence, takes place, incisions in the articular cartilages of the knee-joints of dogs are attended with no lameness or evidence of suffering whatever, after the first few days which are required for the healing of the external wound. Neither is it to be supposed that articular cartilages are in a favourable position for the healing of wounds; for, independently of the continued movement, which is no less detrimental here than in the healing of ordinary wounds, many actions which take place in these textures proceed very slowly, and, therefore, are in greater danger of being interfered with in their progress. In an instance in which I made three incisions into the cartilage of the patella, and two into that of the trochlear surface of the femur, no adhesion had taken place in any of the instances when the parts were examined twenty-nine weeks afterwards, though no inflammation of the joint, dislocation, lameness, or other apparent cause for the want of union had occurred. Yet some of the cut surfaces were in such close contact, before the parts were examined by means of sections, as to lead to the supposition that union had taken place. On the examination of these wounds, no effused matter of any kind appeared on the perfectly smooth cut surfaces; but as the cells near to them in the substance of the cartilage were obviously enlarged and rounded, having in their interior three or four corpuscles into which their nucleus appeared to have divided, or a number of bright granules, there appears reason to believe that union might still have occurred had more time been allowed.

*After the foregoing observations, I no longer entertain the slightest doubt that wounds in articular cartilages are capable of perfect union by the formation of fibrous tissue out of the texture of the cut surfaces.** The essential parts of the process appear to be the softening of the inter-cellular substance of the cartilage, the release of the nuclei of its cells, the formation of white fibrous tissue from the softened inter-cellular substance, and of nuclear fibres, by the elongation of the free nuclei. It does not appear necessary that the cells should become much enlarged or crowded with corpuscles, for the union is still more perfect, and it took place without any enlargement of the cells, or increase in the number of their corpuscular contents; these changes, therefore, though they may contribute materially in some cases to the rapidity of completion of the process under consideration, are clearly not essential in any of its stages.

* Italics by editor.



PETER REDFERN

Peter Redfern (1821-1912) was born in Derbyshire and spent his early career as a student of Goodsir in London and at Edinburgh. In 1860 he became professor of anatomy at Queens University in Belfast where he remained. This present study on the healing of cartilage occupied his early years at Edinburgh and became a classic contribution to the subject.

CLASSIC 41 Healing of Cartilage

SIR JAMES PAGET, BART., M.D., LONDON,
MEMBER OF THE ROYAL SOCIETY (1814–1899)

This last lecture on the process of repair I propose to devote to the consideration of the modes of healing of several different tissues; modes which, although they be all consistent with what has been said of the general rules and methods of the healing process, yet present each some peculiarity that seems worthy of observation.

And first, (though it matters little which I begin with), of the healing of wounds and other injuries of cartilage.

*There are, I believe, no instances in which a lost portion of cartilage has been restored, or a wounded portion repaired, with new and well-formed permanent cartilage, in the human subject.** When a fracture extends into a joint, one may observe that the articular cartilage remains for a long time unchanged, or else has its broken edges a little softened and rounded-off. In one case, I saw no other change than this in six weeks: but at a later period the gap is filled with a tough fibrous tissue; or rather, the gap becomes somewhat wider and shallower, and the space thus formed is so filled-up.

The excellent researches of Dr. Redfern† have ascertained the method of this process in incised wounds of the articular cartilages of dogs. As showing the slowness of the repair, he found in one instance, in which he made three incisions into the cartilage of a patella, and two into that of the trochlear surface of the femur, that no union had taken place in twenty-nine weeks. No unusual cause for the want of union had been apparent, yet a reparative process had but just commenced. In another case, twenty-five weeks and four days after similar incisions, he found them completely and firmly united by fibrous tissue formed out of the substance of the adjacent healthy cartilage. The cut surfaces of the cartilage were very uneven, and were hollowed into small pits, produced by the half-destroyed cartilage-cells, the former contents of which were now lying on the surface. No evident change had taken place in the texture of the cartilage at a little distance from the cut surfaces, except that here and there the intercellular substance presented a fibrous appearance. The

* Italics by editor.

† Anormal Nutrition in Articular Cartilages: Edinburgh, 1850. And, On the Healing of Wounds in Articular Cartilages: in the Monthly Journal of Medical Science, Sept. 1851.

substance uniting the cut surfaces consisted of a hyaline, granular, and indistinctly striated mass, in which were numbers of rounded, oblong, elongating, or irregularly-shaped corpuscles. A nucleated fibrous membrane, formed by the conversion of the superficial layers of the cartilage bordering the wounds, was continuous with their uniting medium. "The essential parts of the process [of union of such incised wounds] appear to be," Dr. Redfern concludes, "the softening of the intercellular substance of the cartilage, the release of the nuclei of its cells, the formation of white fibrous tissue from the softened intercellular substance, and of nuclear fibres by the elongation of the free nuclei."

Such a process has peculiar interest as occurring in a tissue which has no blood-vessels, and in which, therefore, the reparative material is furnished by transformation of its own substance, not by exudation from the blood. In the same view the results of inflammation of articular cartilage will have to be particularly noticed.

Sir James Paget (1814-1899) was a graduate of "St. Bart's" of London, with which he was associated throughout his career. He was one of the pioneers in surgical pathology, a discipline which formed the careers of many of the significant investigators of the 19th and early 20th centuries. He was of sufficient surgical stature, however, to become Sergeant Surgeon to Queen Victoria.

CLASSIC 42 Ueber eine neue Art von Strahlen

(On a New Kind of Rays)

W. C. RÖNTGEN (1845–1923)

(1) A discharge from a large induction coil is passed through a Hittorf's vacuum tube, or through a well-exhausted Crookes' or Lenard's tube. The tube is surrounded by a fairly close-fitting shield of black paper; it is then possible to see, in a completely darkened room, that paper covered on one side with barium platinocyanide lights up with brilliant fluorescence when brought into the neighbourhood of the tube, whether the painted side or the other be turned towards the tube. The fluorescence is still visible at two metres distance. It is easy to show that the origin of the fluorescence lies within the vacuum tube.

(2) It is seen, therefore, that some agent is capable of penetrating black cardboard which is quite opaque to ultra-violet light, sunlight, or arc-light. It is therefore of interest to investigate how far other bodies can be penetrated by the same agent. It is readily shown that all bodies possess this same transparency, but in very varying degrees. For example, paper is very transparent; the fluorescent screen will light up when placed behind a book of a thousand pages; printer's ink offers no marked resistance. Similarly the fluorescence shows behind two packs of cards; a single card does not visibly diminish the brilliancy of the light. So, again, a single thickness of tinfoil hardly casts a shadow on the screen; several have to be superposed to produce a marked effect. Thick blocks of wood are still transparent. Boards of pine two or three centimetres thick absorb only very little. A piece of sheet aluminium, 15 mm. thick, still allowed the X-rays (as I will call the rays, for the sake of brevity) to pass, but greatly reduced the fluorescence. Glass plates of similar thickness behave similarly; lead glass is, however, much more opaque than glass free from lead. Ebonite several centimetres thick is transparent. If the hand be held before the fluorescent screen, the shadow shows the bones darkly, with only faint outlines of the surrounding tissues.

Water and several other fluids are very transparent. Hydrogen is not markedly more permeable than air. Plates of copper, silver, lead, gold, and platinum also allow the rays to pass, but only when the metal is thin. Platinum ·2 mm. thick allows some rays to pass; but only when the metal is thin. Platinum ·2 mm. thick allows some rays to pass; silver and copper are more transparent. Lead 1·5 mm. thick is practically opaque. If a square rod of wood 20 mm. in the side be painted on one face with white lead, it casts little shadow when it is so turned that the painted face is parallel to the X-rays, but a strong shadow if the rays have to pass through the painted side. The salts of the

metals, either solid or in solution, behave generally as the metals themselves.

(3) The preceding experiments lead to the conclusion that the density of the bodies is the property whose variation mainly affects their permeability. At least no other property seems so marked in this connection. But that the density alone does not determine the transparency is shown by an experiment wherein plates of similar thickness of Iceland spar, glass, aluminium, and quartz were employed as screens. Then the Iceland spar showed itself much less transparent than the other bodies, though of approximately the same density. I have not remarked any strong fluorescence of Iceland spar compared with glass (see below, No. 4).

(4) Increasing thickness increases the hindrance offered to the rays by all bodies. A picture has been impressed on a photographic plate of a number of superposed layers of tinfoil, like steps, presenting thus a regularly increasing thickness. This is to be submitted to photometric processes when a suitable instrument is available.

(5) Pieces of platinum, lead, zinc, and aluminium foil were so arranged as to produce the same weakening of the effect. The annexed table shows the relative thickness and density of the equivalent sheets of metal.

	Thickness.	Relative thickness.	Density
Platinum	·018 mm.	1	21·5
Lead	·015 mm.	3	11·3
Zinc	·100 mm.	6	7·1
Aluminium ...	3·500 mm.	200	2·6

From these values it is clear that in no case can we obtain the transparency of a body from the product of its density and thickness. The transparency increases much more rapidly than the product decreases.

(6) The fluorescence of barium platinocyanide is not the only noticeable action of the X-rays. It is to be observed that other bodies, uranium glass, Iceland spar, rock-salt, &c.

Of special interest in this connection is the fact that photographic dry plates are sensitive to the X-rays. It is thus possible to exhibit the phenomena so as to exclude the danger of error. I have thus confirmed many observations originally made by eye observation with the fluorescent screen. Here the power of the X-rays to pass through wood or cardboard becomes useful. The photographic plate can be exposed to the action without removal of the shutter of the dark slide or other protecting case, so that the experiment need not be conducted in darkness. Manifestly, unexposed plates must not be left in their box near the vacuum tube.

It seems now questionable whether the impression on the plate is a direct effect of the X-rays, or a secondary result induced by the fluorescence of the material of the plate. Films can receive the impression as well as ordinary dry plates.

I have not been able to show experimentally that the X-rays give rise to any calorific effects. These, however, may be assumed, for the phenomena of fluorescence show that the X-rays are capable of transformation. It is also certain that all the X-rays falling on a body do not leave it as such.

The retina of the eye is quite insensitive to these rays: the eye placed close to the apparatus sees nothing. It is clear from the experiments that this is not due to want of permeability on the part of the structures of the eye.

(7) After my experiments on the transparency of increasing thicknesses of different media, I proceeded to investigate whether the X-rays could be deflected by a prism. Investigations with water and carbon bisulphide in mica prisms of 30° showed no deviation either on the photographic or the fluorescent plate. For comparison, light rays were allowed to fall on the prism as the apparatus was set up for the experiment. They were deviated 10 mm. and 20 mm. respectively in the case of the two prisms.

With prisms of ebonite and aluminium, I have obtained images on the photographic plate, which point to a possible deviation. It is, however, uncertain, and at most would point to a refractive index 1·05. No deviation can be observed by means of the fluorescent screen. Investigations with the heavier metals have not as yet led to any result, because of their small transparency and the consequent enfeebling of the transmitted rays.

On account of the importance of the question it is desirable to try in other ways whether the X-rays are susceptible of refraction. Finely powdered bodies allow in thick layers but little of the incident light to pass through, in consequence of refraction and reflection. In the case of the X-rays, however, such layers of powder are for equal masses of substance equally transparent with the coherent solid itself. Hence we cannot conclude any regular reflection or refraction of the X-rays. The research was conducted by the aid of finely-powdered rock-salt, fine electrolytic silver powder, and zinc dust already many times employed in chemical work. In all these cases the result, whether by the fluorescent screen or the photographic method, indicated no difference in transparency between the powder and the coherent solid.

It is, hence, obvious that lenses cannot be looked upon as capable of concentrating the X-rays ; in effect, both an ebonite and a glass lens of large size prove to be without action. The shadow photograph of a round rod is darker in the middle than at the edge ; the image of a cylinder filled with a body more transparent than its walls exhibits the middle brighter than the edge.

(8) The preceding experiments, and others which I pass over, point to the rays being incapable of regular reflection. It is, however, well to detail an observation which at first sight seemed to lead to an opposite conclusion.

I exposed a plate, protected by a black paper sheath, to the X-rays, so that the glass side lay next to the vacuum tube. The sensitive film was partly covered with star-shaped pieces of platinum, lead, zinc, and aluminium. On the developed negative the star-shaped impression showed dark under platinum, lead, and, more markedly, under zinc ; the aluminium gave no image. It seems, therefore, that these three metals can reflect the X-rays ; as, however, another explanation is possible, I repeated the experiment with this only difference, that a film of thin aluminium foil was interposed between the sensitive film and the metal stars. Such an aluminium plate is opaque to ultra-violet rays, but transparent to X-rays. In the result the images appeared as before, this pointing still to the existence of reflection at metal surfaces.

If one considers this observation in connection with others, namely, on the transparency of powders, and on the state of the surface not being effective in altering the passage of the X-rays through a body, it leads to the probable conclusion that regular reflection does not exist, but that bodies behave to the X-rays as turbid media to light.

Since I have obtained no evidence of refraction at the surface of different media, it seems probable that the X-rays move with the same velocity in all bodies, and in a medium which penetrates everything, and in which the molecules of bodies are embedded. The molecules obstruct the X-rays, the more effectively as the density of the body concerned is greater.

(9) It seemed possible that the geometrical arrangement of the molecules might affect the action of a body upon the X-rays, so that, for example, Iceland spar might exhibit different phenomena according to the relation of the surface of the plate to the axis of the crystal. Experiments with quartz and Iceland spar on this point lead to a negative result.

(10) It is known that Lenard, in his investigations on kathode rays, has shown that they belong to the ether, and can pass through all bodies. Concerning the X-rays the same may be said.

In his latest work, Lenard has investigated the absorption coefficients of various bodies for the kathode rays, including air at atmospheric pressure, which gives 4·10, 3·40, 3·10 for 1 cm., according to the degree of exhaustion of the gas in discharge tube. To judge from the nature of the discharge, I have worked at about the same pressure, but occasionally at greater or smaller pressures. I find, using a Weber's photometer, that the intensity of the fluorescent light varies nearly as the inverse square of the distance between screen and discharge tube. This result is obtained from three very consistent sets of observations at distances of 100 and 200 mm. Hence air absorbs the X-rays much less than the kathode rays. This result is in complete agreement with the previously described result, that the fluorescence of the screen can be still observed at 2 metres from the vacuum tube. In general, other bodies behave like air ; they are more transparent for the X-rays than for the kathode rays.

(11) A further distinction, and a noteworthy one, results from the action of a magnet. I have not succeeded in observing any deviation of the X-rays even in very strong magnetic fields.

The deviation of kathode rays by the magnet is one of their peculiar characteristics ; it has been observed by Hertz and Lenard, that several kinds of kathode rays exist, which differ by their power of exciting phosphorescence, their susceptibility of absorption, and their deviation by the magnet ; but a notable deviation has been observed in all cases which have yet been investigated, and I think that such deviation affords a characteristic not to be set aside lightly.

(12) As the result of many researches, it appears that the place of most brilliant phosphorescence of the walls of the discharge-tube is the chief seat whence the X-rays originate and spread in all directions ; that is, the X-rays proceed from the front where the kathode rays strike the glass. If one deviates the kathode rays within the tube by means of a magnet, it is seen that the X-rays proceed from a new point, *i.e.* again from the end of the kathode rays.

Also for this reason the X-rays, which are not deflected by a magnet, cannot be regarded as kathode rays which have passed through the glass, for that passage cannot, according to Lenard, be the cause of the different deflection of the rays. Hence I conclude that the X-rays are not identical with the kathode rays, but are produced from the kathode rays at the glass surface of the tube.

(13) The rays are generated not only in glass. I have obtained them in an apparatus closed by an aluminium plate 2 mm. thick. I purpose later to investigate the behaviour of other substances.

(14) The justification of the term "rays," applied to the phenomena, lies partly in the regular shadow pictures produced by the interposition of a more or less permeable body between the source and a photographic plate or fluorescent screen.

I have observed and photographed many such shadow pictures. Thus, I have an outline of part of a door covered with lead paint ; the image was produced by placing the discharge-tube on one side of the door, and the sensitive plate on the other. I have also a shadow of the bones of the hand . . . of a wire wound upon a bobbin, of a set of weights in a box, of a compass card and needle completely enclosed in a metal case . . . of a piece of metal where the X-rays show the want of homogeneity, and of other things.

For the rectilinear propagation of the rays, I have a pin-hole photograph of the discharge apparatus covered with black paper. It is faint but unmistakable.

(15) I have sought for interference effects of the X-rays, but possibly, in consequence of their small intensity, without result.

(16) Researches to investigate whether electrostatic forces act on the X-rays are begun but not yet concluded.

(17) If one asks, what then are these X-rays ; since they are not kathode rays, one might suppose, from their power of exciting fluorescence and chemical action, them to be due to ultra-violet light. In opposition to this view a weighty set of considerations presents itself. If X-rays be indeed ultra-violet light, then that light must possess the following properties.

(*a*) It is not refracted in passing from air into water, carbon bisulphide, aluminium, rock-salt, glass or zinc.

(*b*) It is incapable of regular reflection at the surfaces of the above bodies.

(*c*) It cannot be polarised by any ordinary polarising media.

(*d*) The absorption by various bodies must depend chiefly on their density.

That is to say, these ultra-violet rays must behave quite differently from the visible, infra-red, and hitherto known ultra-violet rays.

These things appear so unlikely that I have sought for another hypothesis.

A kind of relationship between the new rays and light rays appears to exist ; at least the formation of shadows, fluorescence, and the production of chemical action point in this direction. Now it has been known for a long time, that besides the transverse vibrations which account for the phenomena of light, it is possible that longitudinal vibrations should exist in the ether, and, according to the view of some physicists, must exist. It is granted that their existence has not yet been made clear, and their properties are not experimentally demonstrated. Should not the new rays be ascribed to longitudinal waves in the ether?

I must confess that I have in the course of this research made myself more and more familiar with this thought, and venture to put the opinion forward, while I am quite conscious that the hypothesis advanced still requires a more solid foundation.

PROFESSOR RÖNTGEN'S DISCOVERY

The newspaper reports of Prof. Röntgen' experiments have, during the past few days excited considerable interest. The discover does not appear, however, to be entirel novel, as it was noted by Hertz that metalli films are transparent to the kathode ray from a Crookes or Hittorf tube, and i Lenard's researches, published about tw years ago, it is distinctly pointed out tha such rays will produce photographic impres sions. Indeed, Lenard, employing a tube witl an aluminium window, through which th kathode rays passed out with comparativ ease, obtained photographic shadow image almost identical with those of Röntgen through pieces of cardboard and aluminiun interposed between the window and th photographic plate.

Prof. Röntgen has, however, shown tha this aluminium window is unnecessary, a some portion of the kathode radiations tha are photographically active will pass throug the glass walls of the tube. Further, he ha extended the results obtained by Lenard in manner that has impressed the popular imagi nation, while, perhaps most important of all he has discovered the exceedingly curiou fact that bone is so much less transparent t these radiations than flesh and muscle, that i a living human hand be interposed between Crookes tube and a photographic plate, shadow photograph can be obtained whic shows all the outlines and joints of the bone most distinctly.

Working upon the lines indicated in th telegrams from Vienna, recently published i the daily papers, I have, with the assistanc of Mr. J. C. M. Stanton, repeated many o Prof. Röntgen's experiments with entire suc cess. According to one of our first experi ments, an ordinary gelatinous bromide dr photographic plate was placed in an ordinar camera back. The wooden shutter of th back was kept closed, and upon it wer

placed miscellaneous articles such as coins, pieces of wood, carbon, ebonite, vulcanised fibre, aluminium, &c., all being quite opaque to ordinary light. Above was supported a Crookes tube, which was excited for some minutes. On development, shadows of all the articles placed on the slide were clearly visible, some being more opaque than others. Further experiments were tried with thin plates of aluminium or of black vulcanised fibre interposed between the objects to be photographed and the sensitive surface, this thin plate being used in place of the wood of the camera back. In this manner sharper shadow pictures were obtained. While most thick metal sheets appear to be entirely opaque to the radiations, aluminium appears to be relatively transparent. Ebonite, vulcanised fibre, carbon, wood, cardboard, leather and slate are all very transparent, while, on the other hand, glass is exceedingly opaque. Thin metal foils are moderately opaque, but not altogether so.

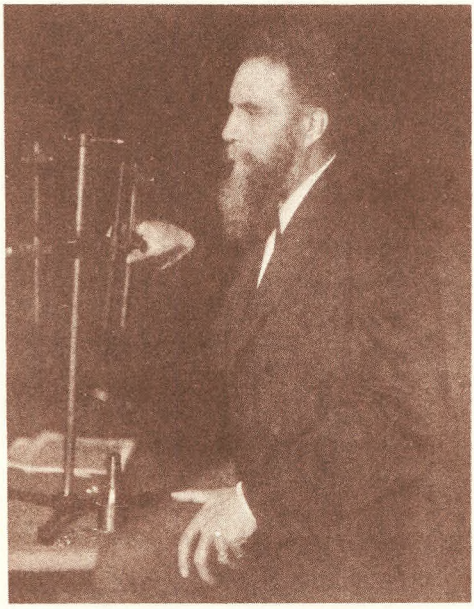
As tending to the view that the radiations are more akin to ultra-violet than to infra-red light, it may be mentioned that a solution of alum in water is distinctly more transparent to them than a solution of iodine in bisulphide of carbon.

So far as our own experiments go, it appears that, at any rate without very long exposures, a sufficiently active excitation of the Crookes tube is not obtained by direct connection to an ordinary Rhumkorff induction coil, even of a large size. So-called high frequency currents, however, appear to give good results, and our own experiments have been made with the tube excited by current obtained from the secondary circuit of a Tesla oil coil, through the primary of which were continuously discharged twelve half-gallon Leyden jars, charged by an alternating current of about 20,000 volts pressure, produced by a transformer with a spark-gap across its high-pressure terminals.

For obtaining shadow photographs of inanimate objects, and for testing the relative transparency of different substances, the particular form of Crookes tube employed does not appear to greatly signify, though some forms are, we find, better than others. When, however, the human hand is to be photographed, and it is important to obtain sharp shadows of the bones, the particular form of tube used and its position relative to the hand and sensitive plate appear to be of great importance. So far, owing to the frequent destruction of the tubes, due to overheating of the terminals, we have not been able to ascertain exactly the best form and arrangement for this purpose, except that it appears desirable that the electrodes in the tube should consist of flat and not curved plates, and that these plates should be of small dimensions . . . a living human hand . . . was exposed for twenty minutes through an aluminium sheet ·0075 in thickness, the Crookes tube, which was one of the kind containing some white phosphorescent material (probably sulphide of barium), being held vertically upside down, with its lowest point about two inches above the centre of the hand.

By substituting a thin sheet of black vulcanised fibre for the aluminium plate, we have since been able to reduce the exposure required to four minutes. Indeed with the aluminium plate, the twenty minutes' exposure appears to have been longer than was necessary. Further, having regard to the great opacity of glass, it seems probable that where ordinary Crookes tubes are employed, a large proportion of the active radiations must be absorbed by the glass of the tube itself. If this is so, by the employment of a tube partly constructed of aluminium, as used by Lenard, the necessary length of exposure could be much reduced.

A. A. C. Swinton.



WILLIAM CONRAD RÖNTGEN

In 1895 William Conrad Röntgen (1845-1923) first reported *on a new kind of rays* before the Sitzungsberichter der Wurzburger Physik-medic Gesellschaft; on December 28, 1895, while professor of physics at Wurzburg, he called the new rays "x-rays." However, on the motion from the floor by Kölliker, who immediately recognized their importance, the Society named them Röntgen rays.

Röntgen was awarded the Nobel Prize in Medicine in 1901 for this work. The significance of his discovery was so quickly recognized that a translation of his paper into English was published a month later in Nature, a British journal with wider circulation in world medicine than the German journal in which it originally appeared. Along with Stanton's translation I have included the notes of Swinton, his associate, which give a background to the events surrounding Röntgen's discovery.

CLASSIC 43 Osteotomy of the Spine for Correction of Flexion Deformity in Rheumatoid Arthritis

M. N. SMITH-PETERSEN, M.D., CARROLL B. LARSON, M.D., AND OTTO E. AUFRANC, M.D.

"Osteotomy of the Spine" is a slightly misleading title for this paper, but it is an intriguing one, effective in stimulating interest and curiosity. The operative procedure is confined to the laminae and articular facets and does not involve the vertebral bodies.

Summary of Recent Progress in Surgery of Rheumatoid Arthritis. In 1941 the authors were granted the assignment of "Operative Procedures for the Prevention and Correction of Deformities in Rheumatoid Arthritis," at the Massachusetts General Hospital. This assignment allowed us to evaluate acromioplasty, excision of the radial head, and excision of the distal end of the ulna for the relief of pain and restoration of function to the joints of the upper extremity.[1] The technique of arthroplasty of the hip has been improved, so that more nearly perfect mechanical joints can be shaped. Progress is also being made in mold arthroplasty of the knee.

Optimum Time for Surgical Procedures in Rheumatoid Arthritis. One problem has been constantly before us, and that is the question of the optimum time for surgical treatment. Up to the present time, the generally accepted opinion has been that surgery must wait until the active stage of the disease has passed. This waiting period is a period of gradually diminishing activities, commonly terminating in recumbency in the position of minimum pain. The results of diminished or absent function are atrophy of muscle and bone (loss of elasticity of ligaments, fascia, and intermuscular septa) and development of joint deformities. Surgery performed under these conditions is technically difficult; restoration of motion is slow; and the functional end result less satisfactory than when surgery is undertaken at a relatively early stage, while the disease is still active.

Analysis of Development of Flexion Deformity and Its Surgical Correction. Recumbency in the position of minimum pain commonly results in a flexion deformity of the spine sufficiently marked to interfere with the function of the lower extremities in standing and walking, and to make the sitting position one of strain and discomfort. Manipulation, followed by support, will improve many of these patients; it will not be of benefit after bony ankylosis of the articular facets and calcification of the longitudinal ligaments have occurred. Patients with ankylosis of both hips not infrequently present this latter ex-

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treme condition of the spine. After arthroplasties, the flexion deformity of the spine interferes to such an extent with function of the lower extremities that the problem of correction becomes most important. Analyzing the obstacles to correction, we came to the conclusion that the ankylosed facets, surrounded by overgrowth of bone, offered more resistance than any of the other spinal structures. Any surgical procedure for correction of the flexion deformity must, therefore, be aimed at the facets, articular processes, and adjacent laminae; osteotomy of these structures, with excision of sufficient bone, should allow corrective leverage to be transmitted to the intervertebral discs and longitudinal ligaments, overcoming whatever resistance these may present.

Preceding the first operation, a diagram was made and the operative steps were outlined. It is rare that a surgeon is able to carry out a preconceived plan of operation, but in this case that was true; furthermore, the operation is even now essentially the same. Only six cases have been done; further experience may, and probably will, bring about improvement in the operative technique.

OPERATIVE TECHNIQUE

The lumbar region is more favorable than the thoracic, since the latter commonly presents ankylosed costovertebral joints rendering correction difficult, if not impossible. Thoracic osteotomy has been done in only one case; it resulted in subjective improvement, but there was no objective evidence of it.

Selection of the lumbar level or levels at which the osteotomy is to be performed depends on the roentgenographic findings; the less marked the ossification, the better the chance of correction.

Operative Steps. Through an incision in the mid-line, at least three lumbar spinous processes are exposed. Even if the osteotomy is performed at one level only, the spinous process above and below that level must be completely exposed and excised in order to allow adequate retraction.

The second step consists of the incision and reflection of supraspinous and interspinous ligaments, followed by the subperiosteal reflection of muscle attachments from the spinous processes and laminae.

The spinous processes are then osteotomized into lamellae with a thin osteotome, and are excised at their bases. This allows further reflection of the periosteum from the superior and inferior articular processes, exposing the intervertebral notch as well as the articular facets. The reflection of the periosteum must be accompanied by division of the muscular attachments to the ligamentum flavum.

By means of a periosteum elevator, the ligamentum flavum is detached from the inferior margin of the lamina and inferior articular process. The elevator is then advanced anterior to the lamina and inferior articular process until it appears in the lateral intervertebral notch just above the articular facet; it serves as a guide to the direction of the osteotomy through the superior articular process of the vertebra below and the inferior articular process of the vertebra above. The osteotomy is done in an oblique plane, at an angle of approximately 45 degrees with the frontal plane. The osteotomes should be narrow and thin-bladed; both straight and curved osteotomes are required. Gouges of the same type are sometimes useful. A rongeur with narrow jaws is indispensable. The osteotomy is performed at one, two, or three levels, depending upon the extent of new-bone formation in relation to the facets and intervertebral discs.

Upon completion of the osteotomy or osteotomies, leverage in the direction of extension is applied by raising the head and foot of the operating table very slowly. The gradual narrowing and final obliteration of the oblique spaces between the laminae and between the remnants of the articular processes marks the "high-spot" of the operation. The obliquity of the osteotomy ensures locking and prevents any serious displacement.

By means of delicate osteotomes, bone flaps are raised from the laminae adjacent to the osteotomy, and the bone lamellae obtained from the spinous processes are inserted

by means of a bone-graft carrier. These grafts bridge the gap between the laminae, and consequently hasten bony fusion in the corrected position.

In closing the wound, close apposition of the split interspinous and supraspinous ligaments is important. If the approach is developed with proper regard for structures and structural planes, the closure and nature's repair of the wound are facilitated.

Postoperative Care. A plaster shell is applied and kept on for four to six weeks, followed by a plaster jacket or back brace, to be worn continuously for a year or longer. Since complete correction is never obtained, it is important to guard against recurring deformity by having the patient wear the brace part of the day for two or three years postoperatively. It is hardly necessary to emphasize the importance of exercises for control of posture, as well as for maintaining chest expansion.

Aspects of Operative Technique Demanding Emphasis

1. The operative procedure must not be belittled,—there are many points in the technique that we have found difficult.

2. In developing the approach, it is more important to follow structural planes and preserve hemostasis than to save a few minutes in operating time. The osteotomy is in itself difficult, and demands a dry field.

3. The spinous processes must be excised before an attempt is made to expose the articular processes and intervertebral notch.

4. The interspinous ligament and the ligamentum flavum have been found ossified, sometimes partially, sometimes completely. In excising the ossified ligamentum flavum, one should keep in mind that the dura is apt to be adherent to it and is, therefore, easily punctured. A leak of spinal fluid is in itself of relatively little consequence, but it does add another problem to the operative technique.

5. In introducing the elevator for the purpose of reflecting the periosteum from the anterior surface of the lamina, care must be exercised in order to avoid injury to the dura and spinal nerves. The inflammatory process which has resulted in the articular destruction is accompanied by periarticular adhesions and inelastic structures, not easily reflected.

6. The bone instruments should be of a delicate type,—they are intended to cut, not crush.

7. The possibility of overcorrection must be kept in mind. If the thoracic spine presents marked flexion, there is apt to be compensatory extension deformity of the cervical spine with motion in the occipitocervical joints only. In the presence of such deformities, overcorrection in the lumbar region makes it difficult for the patient to see his plate on the dining room table and to read without holding the book on a level with his head.

CONCLUSIONS

1. Surgical intervention in rheumatoid arthritis should be undertaken early, before secondary deformities develop.

2. Flexion deformity of the spine frequently results from delayed surgical treatment of the hips.

3. Such flexion deformity may be sufficiently severe to demand surgical correction.

4. Osteotomy of the spine, performed in a small series of six cases, has yielded satisfactory results.

DISCUSSION

Dr. George E. Bennett, Baltimore, Maryland: Many years ago I had the honor of opening the discussion of a paper by Dr. Smith-Petersen—his first paper on the introduction of the Smith-Petersen nail. That was a subject I could talk on with perfect freedom, because I had had a great deal of experience with the operative reduction of fractures of the neck of the femur. Later, I had the honor and privilege of discussing his paper on the use of the vitallium cup for arthroplasty of the hip. That was also a subject about which I could talk from experience. Today I am confronted with opening the discussion on an operation on which I have had absolutely no experience. I can only say that this is an operation designed by a man who

is one of the master-surgeons of his generation. I can see that it has its place. I know none of the older men are going to do this operation, unless they do a little work on the cadaver. As Dr. Smith-Petersen said, this operation should be reserved for the cases in which all conservative treatment has failed. I think again Dr. Smith-Petersen has presented an operation developed by a genuine master-surgeon. Unless you are a master-surgeon, do not try it!

Dr. H. R. McCarroll, St. Louis, Missouri: This is an operative procedure I have never done, I have never seen, and, until about one month ago, I had never heard of. Any discussion by me must, therefore, be entirely theoretical.

First, there can be no objection to any procedure, regardless of how technically difficult it may be, which offers the unfortunate patient with a flexion deformity of the spine from Marie-Strümpell disease some hope of being able to look the world in the face once more. There are three points, however, which should, I think, be taken into consideration:

(1) The question as to whether or not these deformities should be fairly complete before surgery is done. If they are still in the formative stage, the deformity may recur. This in turn prompts the question of whether or not enough motion remains in the intervertebral spaces to allow correction of the deformity, if bone aready bridges the interspaces along the anterior longitudinal ligament;

(2) The prospect of a surgical correction for the deformity should not prevent us from making every attempt to prevent the flexion deformity from developing. During the early stages of the disease, adequate conservative measures will accomplish this in some patients;

(3) This operation is not one to be undertaken by an amateur. Many of us have attempted exploration of a spine for a possible disc lesion after a previous spinal fusion. The technical difficulties encountered in the two operations are essentially the same. Such an exploration is one of the most difficult of al orthopaedic operations and should never be considered lightly.

Dr. M. N. Smith-Petersen, Boston, Massachusetts (closing): I have been very fortunate in having Dr. Bennett discuss all my first presentations of what I have considered new procedures. He discussed one procedure which he did not mention,—namely, that of acetabuloplasty. In his discussion he warned me that this procedure was not going to turn out as well as I expected; he was right. Evaluating the results of this operation, five years after I operated on the first case, I found that only 50 per cent of the cases were satisfactory to the patient and to the surgeon. Since the advent of mold arthroplasty, we rarely do acetabuloplasties.

I want to thank Dr. Bennett for his encouraging discussion.

Dr. McCarroll asked three questions: The first was about the deformity being fixed before surgery is done. The operation is not undertaken until conservative measures have failed; it is performed in the lumbar region at levels showing a minimum of bony bridging. Such bony bridging may be expected to yield after osteotomies of the articular facets.

The second point that Dr. McCarroll raised is that of prevention of flexion deformity. This point can not be overemphasized, but, in spite of conscientious efforts in this direction, flexion deformities will occur every so often.

Finally, Dr. McCarroll points out the technical difficulties of the operation. I have emphasized this point in my paper, and Dr. Bennett has also referred to it. The operation is a difficult one and should never be undertaken lightly.

I want to thank Dr. McCarroll for his thoughtful discussion.

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CLASSIC 44 Diagnostic Puncture of the Intervertebral Disks in Sciatica

KNUT LINDBLOM

In early stages the degeneration of a lumbar disk is often followed by a radial rupture of the annulus fibrosus, that is a channel through which the central masses of the disk herniate and cause a protrusion of the corresponding part of the disk surface [Figs. 1-2].* In the lower lumbar region the usual direction of a radial rupture is postero-lateral or posterior. The neighbouring roots and nerves are compressed to a very great extent. These facts were established by anatomical studies on disks, injected with red lead through anterior punctures (*Lindblom* 1941 and 1944). The red lead filled the central cavities of the nucleus pulposus (*Luschka*) and passed through the radial ruptures to the surface of the disks, spreading concentrically under the outmost layer of the annulus or outside the annulus along nerves and other structures.

Since the red lead leaked through the disk ruptures in the anatomic specimens another contrast medium injected in living human should also demonstrate the presence of radial ruptures and disk protrusions. The original intention was to continue the anatomical studies on clinical material, but reports of disk lesions caused by lumbar punctures (*Pease,* and others) made me hesitate. In 1941 *Lindgren* demonstrated a case of normal disk injected with parabrodil, but on account of the above mentioned lesions, I warned against the method. Later *Hirsch* found that disk punctures during operation caused no immediate prolapses through the puncture canal and no consecutive troubles. On the bases of these observations, I resumed my original intention of performing diagnostic disk punctures.

INDICATIONS

So far the indication for a diagnostic disk puncture is long-standing sciatica, which was not improved by conservative treatment and which had been myelographed by abrodil without definite localization of the disk protrusion.

The radial ruptures of the disks cause nerve compressions in the region of the intervertebral foramina, where the homonymous nerve crosses the disk. These lateral compressions are very common in anatomical material (*Lindblum*) and also seem to be a usual cause of sciatica in clinical material (personal communication by *Hirsch*). In cases of short root sheathes also disk protrusions into the spinal canal may escape detection through myelography; the disk prolapse is too lateral in relation to the extension of the dural sac even if the medium is abrodil, which fills the root sheathes very completely.

TECHNIQUE

In outlines, the procedure of the diagnostic disk puncture is the following: Under control

* Since the original illustrations have not been included, references to the figures have been retained for clarity but are enclosed in brackets.

of screening and roentgenography a tiny needle is inserted into the nucleus of the disk. A little amount of a watersoluble contrast medium is injected and the spreading of the medium is studied on roentgenograms.

The patient is placed in a prone position with pads under his stomach. A centimeter indicator scale is fixed to the back along the row of the spinal processes. In a lateral view the vertical depth from the skin to the disk nucleus is measured. By the aid of an a.p. view the insertion point on the skin is determined. The puncture is performed by a double needle, the inner one with a diameter of 0.5 mm. The outer needle is inserted to the posterior longitudinal ligament. The inner needle is forced through the ligament into the disk to its centre. The puncture is controlled by screening in antero-posterior direction; the insertion of the needle is vertical in the direction of the rays. As the needle passes the posterior longitudinal ligament a slight resistance is felt, and the patient notes a back pain as a moderate lumbago.

The opaque medium is a mixture of 2 cc of 35 percent parabrodil or diodrast and 0.5 cc of 2 percent novocain. An amount of 0.5-2 cc is used. The injection is followed by low back pain, and in cases of ruptured disk a sciatic pain may occur. If the punctured disk is the cause of the symptoms of lumbago and sciatica, the pains caused by the injection will remind the patient of his usual complaints. Thus he may note that the injection lumbago is at the same level or at a higher or lower one. If his usual sciatic pains become worse by the injection this means that the punctured disk is the ruptured one responsible for the root or nerve compression.

Material and roentgenographical appearance of injected disks.

Until now 13 patients were examined by disk punctures. The number of injected disks was 15: the fourth disk in 5 cases, the fifth in 10 cases.

Only in one case was the punctured disk normal or almost normal. Radial ruptures towards the spinal canal were present in 8 disks. Postero-lateral ruptures towards the intervertebral foramina occurred in 3 disks. The remaining 3 disks showed a spreading of the contrast medium in the whole disk as a sign of general degeneration without remnants of the original rupture and without spreading of the contrast outside the disk.

[Radial ruptures are illustrated in Figs. 3-6. Most easily interpreted is the rupture in Figs. 4 a and b. From the puncture canal (p) the opaque solution has filled an oval cavity somewhat to the right near the disk centre. From this cavity the solution runs backwards to an irregular cavity at the posterior side of the disk, that is into the disk prolapse. In Figs. 5 a and b the rupture runs to the left into the intervertebral foramen, where the disk prolapse was found. Figs. 3 a and b illustrate a posterior rupture in the midline with the contrast spreading on the dorsal surface of the sacral corpus under the posterior longitudinal ligament; in this case ruptures are seen also in anterior direction.]

It is known, from the anatomical studies mentioned above, that the cavities in a ruptured disk may communicate with the epidural and perineural spaces and that a high pressure by injection may establish an artificial communication with the adjacent veins epidurally and in the vertebral bodies. [The epidural and perineural spreading of the opaque solution is demonstrated in the cases illustrated in Figs. 6 a-d, 7 and 8. In Fig. 8 the solution surrounds the lateral side of the fifth nerve, coming from the injected fourth disk and escaping through a dorso-lateral rupture towards the intervertebral foramen. The other cases had ruptures of the fifth disk into the spinal canal, and the solution surrounds the first sacral nerve epidurally. The epidural deposit of solution may be mottled as demonstrated in Fig. 9.]

[In cases of general degeneration of the disk the opaque solution spreads in the whole disk as illustrated in Figs. 10, and 11 a and b. In the latter case the solution also ran outside the disk in a dorso-lateral direction; the operation revealed a lateral disk prolapse in

the intervertebral foramen under the fifth nerve, and the patient was free from symptoms immediately after operation.]

The value of diagnostic disk puncture.

Until now we dispose of too little material to warrant general conclusions on the value of the diagnostic disk puncture. However, as related above the symptoms of pains give a definite hint as to whether the punctured disk is the right one or not. In a few cases of advanced degeneration with wide-spread ruptures in different directions the interpretation of the roentgenograms may be difficult, but on the whole, of all methods the diagnostic disk puncture gave the most exact diagnosis and the agreement with the operation findings was complete.

The diagnostic disk punctures were not followed by any late complaints of the patient or other complications. In the first cases the outer needle was inserted only to the ligamentum flavum and the inner needle was too flexible to retain direction; thus it was difficult to reach the disk centre. In two cases no injection could be made for the same reason. At the insertion of the needle through the dural sac two patients experienced shooting pains from root puncture; but after a slight change of direction the needle bypast the roots without causing pains.

SUMMARY

Diagnostic disk puncture with injection of opaque medium demonstrates disk ruptures and protusions and tells if the patients symptoms originate from the punctured disk. The method seems to be of great practical value.

RÉSUMÉ

La ponction diagnostique du disque intervertébral suivie d'une injection de substance opaque, met en évidence les ruptures et protrusions du disque. Elle précise, egalement, si le disque en question est bien celui qui cause les symptomes du patient. La méthode semble être d'un vif intérêt pratique.

LIST OF AUTHORS

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KNUT LINDBLOM

Knut Lindblom, working in the famous Karolinska Institute of Stockholm in the late 1940's directed his attention to the physiologic aspects of the nucleus pulposus. Several reports appeared in radiologic journals on the subject, but this report in 1948 in the *Acta Orthopaedic Scandinavica* introduced the technic of reaching the nucleus pulposus *in vivo.* Building upon Lindblom's original procedures, Lyman Smith and his associates and the contributors to this symposium developed the concept of chemonucleolysis.

CLASSIC 45

The State of Calcium in the Fluids of the Body

1. The Conditions Affecting the Ionization of Calcium

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Modern interest in the state of calcium in the fluids of the body dates from the work of Rona and Takahashi, in 1913.[1] By means of dialysis experiments with serum they distinguished diffusible from non-diffusible calcium, and attributed the non-diffusible form to a combination with protein. By comparison with the conditions governing the solubility of calcium in saline solutions containing bicarbonate they also concluded that the diffusible calcium in serum represents a metastable supersaturated solution of calcium bicarbonate. Their concept of non-diffusible calcium as bound to protein is now almost universally accepted. The state of the diffusible calcium in the fluids of the body has, however, remained an open problem.

The very large amount of literature on this subject has recently been reviewed by Klinke,[2] Peters and Van Slyke,[3] and by Thomson and Collip,[4] making an extensive review unnecessary here. All of these reviewers incline toward acceptance of the hypothesis, advanced by Greenwald,[5] that the diffusible calcium in the fluids of the body is partly ionized, and partly bound to some citrate-like substance, as yet unidentified. On the other hand, Greenberg and Greenberg,[6] who have recently reviewed the evidence concerning this hypothetical bound but diffusible calcium, have concluded that there is no direct evidence that it exists. The hypothesis, therefore, has rested chiefly upon the argument that the alternative of supersaturation of the fluids of the body with respect to calcium carbonate and calcium phosphate (not bicarbonate, as Rona and Takahashi assumed) not only seems in itself highly improbable, but is also difficult or impossible to reconcile with the very attractive concept of a simple chemical equilibrium between plasma and bone.

With acceptance of two, or possibly three, forms of calcium in the protein-containing fluids of the body, the idea of an equilibrium between these forms has made but little headway, nor has it been possible to approach this problem with the methods heretofore available except under the assumption that all of the diffusible calcium is ionized. Marrack and Thacker,[7] on the basis of evidence favoring this assumption, have related diffusible and non-diffusible calcium by an empirical formula which is compatible with a mass law relationship. Greenberg and Gunther,[8] making the same assumption, have correlated the diffusible and non-diffusible forms by means of an adsorption isotherm. They point out, however, that this is not necessarily evidence that the binding of calcium

by protein is an adsorption phenomenon, as a mass law relationship might also apply. Thomson and Collip[4] suggest the probability of an equilibrium, but bring forward no quantitative evidence.

Obviously the difficulty in reaching definite conclusions as to the *state* of calcium in the fluids of the body, and as to any *equilibrium* which may exist between the various forms, has been due to the fact that no satisfactory method for the direct observation of Ca^{++} concentrations has existed. Consequently the problem has necessarily been attacked chiefly by indirect methods. Attempts to make direct measurements of Ca^{++} concentrations by electrometric methods have not been lacking, but these methods have shown little or no dependability in biological fluids. The results of Neuhausen and Marshall,[9] who used a calcium-amalgam electrode, have been most quoted, largely because they seemed to confirm the views of those who held to the belief that Ca^{++} concentrations in the fluids of the body are limited by the solubility of calcium carbonate.

A new approach to the problem has been made possible by the introduction by the authors[10] of a biological method for the direct estimation of Ca^{++} concentrations, by use of the isolated heart of the frog as an indicator. This method, while not ideal for the examination of serum, is workable, and has a reasonable degree of accuracy. It has the disadvantage that it cannot be used for observations at the temperature of the mammalian body, and that the degree to which observations made at 25 C represent the conditions at 38 C, particularly in protein-containing fluids, is as yet not accurately known. Use of the method has, however, yielded results which throw considerable light upon the problem of the state of calcium in the fluids of the body, and the present paper is based chiefly upon these results. This paper deals primarily with the factors concerned in the ionization of calcium in the fluids of the body. Presentation and discussion of findings bearing upon the physiology and pathology of the behavior of calcium in the organism have been reserved for subsequent communications.

METHODS

Total calcium was determined by the method of Kramer and Tisdall,[11] as modified by Clark and Collip.[12] Total nitrogen was determined by the Kjeldahl method. Total protein was calculated from total less non-protein nitrogen, a factor of 6.3 being used to convert gm. of nitrogen to gm. of protein. In the case of serum from normal individuals, an arbitrary correction of 30 mg. per 100 cc. has been made for non-protein nitrogen.

Direct observations of Ca^{++} concentrations were made by the method described by the authors[10] with the isolated heart of the frog as a biological indicator. All observations, unless otherwise noted, were made at room temperature, ordinarily 22–25 C, and no temperature correction has been made (see the discussion of the effect of temperature).

Calculations involving protein-containing fluids have been based upon the water content of these fluids. Water has not been determined, but has been calculated, in the case of the fluids of the body, from the formula, water (in gm. per 100 cc.) = 99.0 − 0.75 P (P = gm. of protein per 100 cc.). This formula assumes that on the average 1 per cent of the volume of the fluids of the body is occupied by solids other than protein, and adopts the value of 0.75 for the specific volume of the serum proteins, as found by Svedberg and Sjögren.[13] Use of the slightly different formulæ in the literature[14,15] would not affect the result of calculations appreciably. In the case of solutions of purified proteins in saline solutions, the formula used is water = 99.6 − 0.75 P.

Symbols—In addition to the usual chemical symbols, the following are employed in this paper.

[ ] = concentration, moles per kilo of water
$Prot^-$ = dissociated base-combining groups of protein, expressed as equivalents or milli-equivalents, divided by 2
CaProt = calcium bound to protein (or base-combining groups of protein, bound by calcium)
p = negative logarithm

Ionization of Calcium in Protein-Free Fluids—A large number of observations have been made upon human cerebrospinal fluid, as the most easily available approximately protein-free fluid. The method used has been applied to these fluids with little or no difficulty, and with no discordant results. In nearly every case the observed Ca^{++} concentration has been very near, but slightly below, the total calcium concentration. Table 1 records the results of ten consecutive carefully controlled observations, in which total calcium concentrations were determined independently by two different observers. The samples of cerebrospinal fluid were obtained from patients suffering with various disorders of the central nervous system, by drainage of the cerebrospinal canal in preparation for encephalography.

These observations provide evidence against the assumption that Ca^{++} concentration is limited by the usual conceptions concerning the solubility of calcium carbonate and calcium phosphate. The observed Ca^{++} concentrations are about double those which could be calculated from the solubility product of calcium carbonate, and approach instead the values for total calcium, which in a protein-free fluid are the same as for diffusible calcium. The discrepancy between total calcium and Ca^{++} remains to be accounted for. The difference is generally within the limit of accuracy of the method, but is nearly always in the same direction. The possibility of a constant error of this magnitude in the Ca^{++} observations has not been excluded. There is, however, good reason for believing that the discrepancy is real. Human cerebrospinal fluid has been found[16] to contain about 0.2 mM per liter of citrate. This amount of citrate is sufficient to bind an amount of calcium of the order of magnitude of the difference found between total and ionized calcium.[17] It appears, therefore, that a bound, diffusible, form of calcium may exist in the cerebrospinal fluid, but, at least in human material, in much smaller proportions than many had previously supposed.

The conclusion drawn from these observations is that calcium in human cerebrospinal fluid is ionized approximately as it is in artifically prepared solutions, containing the same proportions of inorganic constituents, and of citrate, as are found in the cerebrospinal fluid. This conclusion is fur-

TABLE 1. Total Calcium and Observed Ca^{++} Concentrations (in mM per Liter) in Human Cerebrospinal Fluid

Sample No.	Total Ca			Ca^{++}	Difference
	Observer 1	Observer 2	Mean	Observed	
1	1.06	1.12	1.090	1.00	−0.090
2	1.20	1.24	1.220	1.15	−0.070
3	1.11	1.22	1.165	1.05	−0.115
4	1.21	1.12	1.165	1.20	+0.035
5	1.02	1.23	1.125	1.00	−0.125
6	1.03	1.16	1.095	1.00	−0.095
7	1.22	1.23	1.225	1.20	−0.025
8	1.11	1.10	1.105	1.10	−0.005
9	1.05	1.00	1.025	1.00	−0.025
10	1.00	1.25	1.125	0.95	−0.157
Mean	1.101	1.167	1.134	1.065	−0.069

TABLE 2. Effect of Added Citrate upon Ca^{++} Concentrations in Human Cerebrospinal Fluid

Sample No.	Total Ca	Total Mg	Citrate Added	Ca^{++}		
				Calculated	Observed	Difference
1	1.08	1.00			1.00	
	1.08	1.00	0.5	0.85	0.80	−0.05
	1.08	1.00	1.0	0.66	0.65	−0.01
2*	1.06	(1.00)			1.00	
	1.06	(1.00)	1.0	0.66	0.75	+0.09
3	1.36	1.03			1.25	
	1.36	1.03	0.5	1.05	1.05	
	1.36	1.03	1.0	0.86	0.875	+0.015
	1.36	1.03	1.5	0.69	0.70	+0.01

pK_{CaCit^-} 3.22; pK_{MgCit^-} 3.22.
The results are expressed in mM per liter.
* Magnesium concentration assumed.

ther supported by the observation that when citrate is added to cerebrospinal fluid the effect upon observed Ca^{++} concentrations is the same as in artificially prepared solutions (Table 2). Changes in Ca^{++} concentration in cerebrospinal fluid on the addition of citrate cannot be calculated directly from the ionization constant of calcium citrate, owing to the fact that in the presence of magnesium the relationships become more complex. The calculated Ca^{++} figures in Table 2 are obtained by equations previously published, involving simultaneously the dissociation constants of calcium citrate and magnesium citrate.[17]

Further support for this conclusion is derived from the observation that when cerebrospinal fluid is diluted with saline solutions of approximately the same inorganic composition, but without calcium, the observed Ca^{++} concentrations are changed in approximately direct proportion to the dilution of total calcium (Table 3).

Ionization of Calcium in Protein-Containing Fluids—Examination of protein-containing fluids of human origin, including serum and ascitic, pleural, and subcutaneous edema fluids, has yielded the information that the observed Ca^{++} concentrations in these fluids, in individuals without disorders of calcium metabolism, are in a range the extremes of which may be put provisionally at 1.10 and 1.40 mM per kilo of H_2O (4.4 to 5.6 mg. per 100 gm. of water) (Fig. 2 and Table 7). By giving equal weight to observed and calculated values the small series of observations on undiluted normal serum included in Fig. 2 gives an mean Ca^{++} concentration of 1.25 ± standard deviation 0.09 mM per kilo of H_2O. The range is slightly higher than that of cerebrospinal fluid, and again is more than double the concentration which could be calculated from the solubility of calcium carbonate.

When the protein-containing fluids of the body are diluted with saline solutions of approximately the same inorganic composition (per unit of water), but without calcium, the observed values for Ca^{++} fall, but not in proportion to the dilution of total calcium (Table 4, Column 5). This effect is readily reversible.

This suggests an equilibrium between calcium and protein. From the data the relationship

$$(1)\ \frac{[\text{Total Ca}] - [Ca^{++}]}{[Ca^{++}]} = k \times \text{total protein}$$

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TABLE 3. Observed Ca^{++} Concentrations (in mM per Liter) in Human Cerebrospinal Fluid Undiluted and Diluted with an Equal Volume of Saline Solution

Sample No.	Total Ca	Ca^{++} observed	
		Undiluted	Diluted
1	1.22	1.20	0.575
2	1.10	1.10	0.525
3	1.02	1.00	0.50
4	1.11	0.95	0.50
5	1.35	1.20	0.65
6	1.37	1.25	0.60
Mean	1.19	1.11	0.56

holds approximately true (Table 4, Column 8). This corresponds to the relationship found by Marrack and Thacker[7] between total calcium, diffusible calcium, and total protein.

Since Equation 1 suggests a mass law relationship, the equation

$$(2) \qquad \frac{[Ca^{++}] \times [Prot^{=}]}{[CaProt]} = K$$

has been tested. This is a typical mass law equation for the dissociation of calcium proteinate, assuming that the protein molecule behaves as though it were composed of a series of negatively charged divalent ions. In logarithmic form this equation assumes the form

$$(3) \quad pCa^{++} + pProt^{=} - pCaProt = pK_{CaProt}$$

Equations 2 and 3 require further assumptions and definitions. It is assumed, as a first approximation, that [total Ca] − [Ca^{++}] = [CaProt], and that [total protein] − [CaProt] = [$Prot^{=}$]. The latter assumption requires that total protein and CaProt be expressed in comparable terms. The assumption that the base-combining groups of protein behave toward calcium as though they were divalent ions was at first adopted in order to fit the data obtained by observation. If it were assumed that the base-combining groups of protein behave toward calcium as though they were monovalent ions, then the mass law equation would be

$$(4) \qquad \frac{[Ca^{++}] \times [Prot^{-}]^2}{[CaProt_2]} = K$$

This equation does not fit the data (Table 4, Column 10).

From the conclusions of the authors and their collaborators[17] as to the probable structural formula for calcium citrate, it appears that calcium may, under appropriate conditions, be bound between pairs of carboxyl groups, and that the calcium so bound is in equilibrium with the Ca^{++} in solution. On the basis of the study of the calcium-citrate relationship, of the relationship between calcium and protein, as found empirically, and of a study of a series of dicarboxylic acids, to be published later, we are proceeding under the hypothesis that calcium is bound by protein between spatially neighboring

TABLE 4. Derivation of Mass Law Equation from Representative Dilution Experiment (Normal Human Serum)*

Dilution (1) (per cent serum)	Total protein (2) (gm. per 100 cc.)	(3) (mM per kg. H_2O)	Total Ca (4) (mM per kg. H_2O)	Ca^{++} Observed (5) (mM per kg. H_2O)	CaProt (6) (mM per kg. H_2O)	$Prot^{=}$ (7) (mM per kg. H_2O)	Equation 1 $\frac{[\text{Total Ca}] - [Ca^{++}]}{[Ca^{++}] \times \text{total Prot}} = k$ (8)	Equation 2 $\frac{[Ca^{++}] \times [Prot^{=}]}{[CaProt]} = K$ (9)	Equation 4 $\frac{[Ca^{++}] \times [Prot^{-}]^2}{[CaProt_2]} = K$ (10)
100	7.45	9.69	3.07	1.35	1.72	7.97	0.171	$10^{-2.21}$	$10^{-3.71}$
75	5.54	7.10	2.27	1.15	1.12	5.98	0.175	$10^{-2.21}$	$10^{-3.83}$
50	3.72	4.70	1.49	0.90	0.59	4.11	0.176	$10^{-2.20}$	$10^{-3.99}$
25	1.86	2.31	0.74	0.55	0.19	2.12	0.186	$10^{-2.21}$	$10^{-4.28}$

* Temperature 25°; pH 7.35; f_{Prot} 0.243.

pairs of carboxyl groups in the protein molecule.

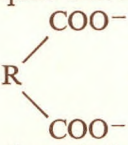
On the basis of this hypothesis the mass law Equations 2 and 3 require that Prot$^{=}$ be expressed in terms of  groups available at the pH of the solution. The nearest approach we have to such an expression is obtained from titration of proteins with base, although as will be seen later, the results of such titrations may not accurately express the base-combining power of proteins. For serum proteins these titrations have been made by Van Slyke, Hastings, Hiller, and Sendroy,[18] and we have used their factors for converting gm. of protein to base-combining groups, in terms of milli-equivalents. In the case of total serum proteins, at pH 7.35, we have used the combined factor of 0.243, as calculated by them, assuming an average albumin to globulin ratio of 1.8. Wherever total protein and Prot$^{=}$ are expressed in terms of mM, the figure has been obtained by dividing the figure for milli-equivalents by 2, in accordance with the hypothesis that protein behaves toward calcium as if it were composed of a series of negatively charged divalent ions.

Table 4 illustrates a representative experiment designed to test the validity of Equations 2 and 3 and of the above assumptions.

pK_{CaProt} As Determined upon Protein-Containing Fluids—The type of experiment illustrated in Table 4 does not, taken by itself, establish the calcium–protein relationship expressed in Equation 3. Dilution of serum results in dilution not only of its protein content, but also of the content of any other substances in the serum capable of binding calcium. In view, however, of the sharp contrast between the effects of dilution of cerebrospinal fluid and of serum, upon observed Ca^{++} concentrations, it seems *a priori* probable that the dilution of the protein content is at least chiefly responsible for the observed effects of dilution upon the ionization of calcium in serum.

Resolution of the questions thus raised depends, in part, upon comparison of the behavior of serum with that of solutions of purified serum proteins. In order to establish a basis for such a comparison, and to test the validity of Equation 3 as an approximation of the conditions present in protein-containing fluids, further observations upon whole and diluted normal human serum (including diluted serum with the addition of calcium) have been carried out. The distribution of values for pK_{CaProt} thus obtained is summarized in Table 5.

Table 5 reveals a fair degree of constancy for pK_{CaProt} as determined upon serum in varying dilutions. A slight inconsistency is seen, in that with increasing dilution the values for pK_{CaProt} tend to become lower. This tendency can be corrected by raising [Prot$^{=}$] in Equation 2 to the power of 1.1, but in the absence of any theoretical justification for this procedure the data in Table 5 have been regarded as indicating that Equation 3 represents a satisfactory first approximation of the conditions found in serum. From the observations upon serum in Table 5, the mean value of 2.22 ± standard deviation 0.07 for pK_{CaProt} in Equation 3, corresponding to a value of $10^{-2.22 \pm 0.07}$ for K in Equation 2, has been adopted for all calculations involving the protein-containing fluids of the body.

Calculation of Calcium Ion Concentrations from Total Calcium and Total Protein—By substituting ([total Ca] − [Ca^{++}]) for [CaProt] and ([total Prot] − [total Ca] + [Ca^{++}]) for [Prot$^{=}$], Equation 2 takes the form

$$(5) \qquad \frac{[Ca^{++}] \times ([\text{total Prot}] - [\text{total Ca}] + [Ca^{++}])}{[\text{Total Ca}] - [Ca^{++}]} = K$$

If we solve for $[Ca^{++}]$

(6)

$$[Ca^{++}] = \frac{[\text{total Ca}] - [\text{total Prot}] - K + \sqrt{4K\,[\text{total Ca}] + ([\text{total Prot}] - [\text{total Ca}] + K)}}{2}$$

Solution of Equation 6 is simplified by the use of a nomogram. Fig. 1 is a Cartesian nomogram, in which the value for K is $10^{-2.22}$. The nomogram assumes pH 7.35, temperature 25 C, and albumin to globulin ratio 1.8. While based on concentrations of base-combining groups of protein per kilo of H_2O, it is constructed, for convenience in use, in terms of gm. of protein per 100 cc. For this reason the iso-Ca^{++} lines are slightly curved.

Such a nomogram, in terms of base-combining groups of protein per kilo of H_2O, in which the iso-Ca^{++} lines are straight, is most easily constructed with the aid of the general regression equation

(7) $$[\text{Total Ca}] = \frac{[Ca^{++}] \times [\text{total Prot}]}{[Ca^{++}] + K} + [Ca^{++}]$$

which is obtained by solving Equation 5 for [total Ca], and from which the slope of iso-Ca^{++} lines is readily calculated.

From Equation 7 there follows, since $[\text{CaProt}] = [\text{total Ca}] - [Ca^{++}]$,

(8) $$[\text{CaProt}] = \frac{[Ca^{++}] \times [\text{total Prot}]}{[Ca^{++}] + K}$$

from which calcium bound to protein may be calculated at any given Ca^{++} and protein concentrations.

Calculated Ca^{++} concentrations in protein-containing fluids; as referred to in this paper, have been calculated from Equation 6, generally by means of the nomogram. The degree of correlation between observed and calculated values, in the case of whole and diluted normal human serum, is illustrated in Fig. 2, which is based upon calculations from the same observations reported in Table 5.

TABLE 5. Distribution of Values Found for pK_{CaProt}, and Mean pK_{CaProt}, Normal Human Serum, Whole and Diluted, Serum Globulin, and Serum Albumin

	1.90–1.94	1.95–1.99	2.00–2.04	2.05–2.09	2.10–2.14	2.15–2.19	2.20–2.24	2.25–2.29	2.30–2.34	2.35–2.39	2.40–2.44	Totals	Mean pK_{CaProt}* ±S.D.	
All serum		1			3	12	13	11	10			50	2.22	0.07
Undiluted serum							3	3	3			9	2.27	0.04
75% serum					1	1	2	3	3			10	2.24	0.07
50% serum						4	3	4	3			14	2.23	0.04
25% serum			1		2	7	5	1	1			17	2.18	0.08
Serum globulin					1	7	7	11	3	2	1	32	2.24	0.08
Serum albumin	8	4	2	8	3	2	3					30	2.03	0.11

* Obtained by averaging the values for K in Equation 2.

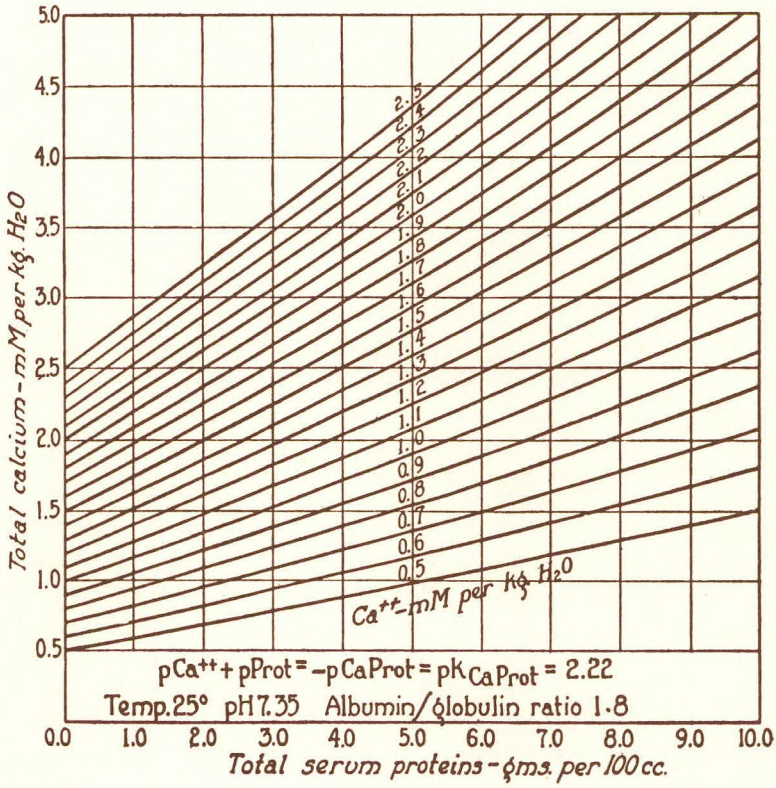


FIG. 1. Cartesian nomogram for calculation of Ca^{++} concentrations from total calcium and total serum protein.

The average deviation between calculated and observed values for Ca^{++} concentrations increases with increasing protein concentrations, and is at its height in undiluted serum. The deviations in whole and diluted serum, in the series of observations illustrated in Fig. 2, are shown in Table 6.

The question naturally arises as to the relative accuracy of observed and calculated Ca^{++} concentrations in serum, in individual cases. While no final answer can be given, some light can be thrown on this question. Examination of Fig. 2 and Table 6 will indicate that the poorest correlation is evident in the case of the nine observations on undiluted serum, and that the tendency is toward low observed, as compared with calculated, values. The calculations in these cases were based upon the same analytical data as those for the diluted sera, in which the correspondence between observed and calculated values is much closer. We incline to the belief that the difficulties already described[10] as inherent in the use of the frog heart method for observations upon undiluted serum tend to give low values by direct observation, and that consequently the calculated values are probably of greater accuracy in individual cases, provided that the necessary analyses are accurately carried out and that no unrecognized variables are present.

A small series of observations in patients without evident calcium dyscrasia, is here reported, to illustrate the applicability of the combined methods of calculation and observation of Ca^{++} concentrations in biological fluids, under conditions of varying protein content (Table 7). The occasional discrepancy between observed and calculated Ca^{++} concentrations is again evident.

From the data as reported it would appear that the conditions governing the ionization of calcium in human protein-containing fluids

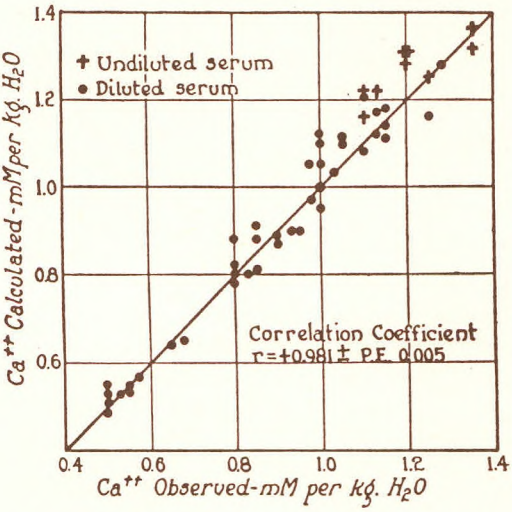


FIG. 2. Observed and calculated Ca^{++} concentrations in normal human serum, whole and diluted.

may be described, as a first approximation, by the simple mass law Equation 2. This conclusion involves acceptance of a concept of continuous supersaturation of the fluids of the body with respect to calcium carbonate and calcium phosphate. This concept is not new, but has been advanced or made use of by Rona and Takahashi,[1] Marrack and Thacker,[7] Greenberg and Gunther,[8] Holt, La Mer, and Chown,[19] and others.

The authors and their collaborators[17] have shown that in the presence of citrate a solution originally supersaturated with respect to $CaCO_3$ fails to come to equilibrium with the solid phase for at least a considerable length of time. This phenomenon of delay in reaching equilibrium from a supersaturated state, which is well known from the qualitative standpoint, is clearly of biological importance, and is being systematically and quantitatively investigated, particularly with reference to the salts of calcium and the influence of other substances, present in biological fluids, which delay their precipitation from supersaturated solutions.

pK_{CaProt} As Determined upon Solutions of Purified Proteins—On account of the difficulty in obtaining stable and strictly comparable preparations of serum proteins, casein (Pfanstiehl, highest purity) was utilized to establish the relationships involved. The casein was dissolved in a solution containing the same concentration of inorganic constituents (per unit of water) as that of the standard solutions of reference, but with NaOH substituted for NaCl in a quantity sufficient to dissolve the casein and to bring the solution to pH 7.35. Since the casein was not calcium-free, it was analyzed for its calcium content, and the result was included in the total calcium figure. The concentration of casein in the solutions was checked by analysis for total nitrogen. It was found that the same relationship existed as in the case of serum, and Table 8 records the results of a representative experiment. The values for total protein in terms of base-combining groups in the case of casein have been obtained by using a factor of 0.600 for total base-combining groups at pH 7.35,[20] and dividing by 2.

TABLE 6. Comparison of Observed and Calculated Ca^{++} Concentrations (in mM per Kilo H_2O) in Whole and Diluted Normal Human Serum, Including Diluted Serum with Added Calcium*

Dilution (% serum)	No. of Observations	Average Ca^{++}			Deviation	
		Calculated	Observed	Difference	Maximum	Average
100	9	1.27	1.21	−0.06	−0.12	±0.07
75	10	1.11	1.07	−0.04	−0.12	±0.06
50	14	0.93	0.92	−0.01	−0.08	±0.04
25	17	0.74	0.75	+0.01	+0.05	±0 02

* The same data as in Fig. 2.

TABLE 7. Comparison of Calculated and Observed Ca^{++} Concentrations in Individuals without Evident Disturbance in Calcium Metabolism

Patient	Fluid	Total protein (gm. per 100 cc.)	Total Ca (mM per kg. H_2O)	Ca^{++} Calculated (mM per kg. H O)	Ca^{++} Observed (mM per kg. H_2O)	Ca^{++} Difference (mM per kg. H_2O)	Diagnosis
La	Serum	4.00	2.31	1.37	1.30	−0.07	Multiple infections, severe anemia
Se	Serum	5.11	2.16	1.13	1.20	+0.07	Amyloid nephrosis
Sm	Serum	5.21	2.32	1.20	1.20		Glomerulonephritis
Si	Serum	6.67	2.68	1.22	1.20	−0.02	Arteriosclerosis, diabetes, gangrene
Co	Serum	7.58	3.11	1.32	1.10	−0.22	Arteriosclerosis, diabetes, gangrene
So	Serum	7.23	2.86	1.25	1.30	+0.05	Primary hypertension
No	Serum	4.71	2.60	1.44	1.30	−0.14	Glomerulonephritis
Go	Serum	3.60	2.40	1.49	1.30	−0.19	Glomerulonephritis, nephrotic type
	Serum	3.97	2.67	1.60	1.50	−0.10	Glomerulonephritis, nephrotic type
Pa	Serum	4.02	2.36	1.40	1.30	−0.10	Glomerulonephritis, mixed type
	Serum	4.70	2.72	1.50	1.35	−0.15	Glomerulonephritis, mixed type
	Ascitic fluid	0.32	1.70	1.60	1.40	−0.20	Glomerulonephritis, mixed type
	Pleural fluid	0.19	1.48	1.45	1.40	−0.05	Glomerulonephritis, mixed type
	Edema fluid	0.15	1.58	1.55	1.40	−0.15	Glomerulonephritis, mixed type
Wa	Serum	4.00	1.95	1.15	1.25	+0.10	Nephrosis
	Pleural fluid	1.80	1.63	1.25	1.25		Nephrosis
	Ascitic fluid	2.13	1.65	1.20	1.25	+0.05	Nephrosis
An	Edema fluid	0.33	1.50	1.43	1.35	−0.08	Nephrosis

TABLE 8. Determination of pK_{CaProt} in Casein Solutions

Solution No.	Total protein (gm. per 100 cc.)	Total protein (mM per kg. H_2O)	Total Ca (mM per kg. H_2O)	Ca^{++} Calculated (mM per kg. H_2O)	Ca^{++} Observed (mM per kg. H_2O)	Ca^{++} Difference (mM per kg. H_2O)	Calculated from observed Ca^{++}: CaProt (mM per kg. H_2O)	Calculated from observed Ca^{++}: $Prot^{=}$ (mM per kg. H_2O)	pK_{CaProt}
1	5.0	15.66	4.17	1.05	1.05		3.16	12.64	2.38
2	5.0	15.66	3.55	0.87	0.90	+0.03	2.68	13.21	2.36
3	5.0	15.66	2.71	0.64	0.65	+0.01	2.09	13.71	2.37
4	3.75	11.61	3.41	1.06	1.10	+0.04	2.33	9.35	2.35
5	3.75	11.61	2.89	0.88	0.93	+0.05	1.98	9.70	2.32
6	3.75	11.61	2.38	0.70	0.70		1.69	9.99	2.38
7	2.5	7.68	2.76	1.13	1.10	−0.03	1.67	6.03	2.40
8	2.5	7.68	2.25	0.90	0.93	+0.03	1.33	6.37	2.35
9	2.5	7.68	1.74	0.67	0.65	−0.02	1.09	6.61	2.41
10	1.25	3.81	1.62	0.93	0.90	−0.03	0.72	3.08	2.41
11	1.25	3.81	1.37	0.77	0.75	−0.02	0.62	3.18	2.41
12	1.25	3.81	1.11	0.62	0.60	−0.02	0.51	3.29	2.41
Average deviation		±0.023					Mean pK_{CaProt}		2.38
							S.D.		±0.02

pH 7.35; temperature 22°C; f_{Prot} 0.600 (Pertzoff and Carpenter[20]; Ca^{++} calculated from pK_{CaProt} 2.38.

The results of Weir and Hastings, who have determined pK_{CaProt} in the case of casein, as well as of the serum proteins, by means of an equilibration method, will be reported in a separate paper.[21]

Serum albumin and serum globulin have also been examined. These proteins were fractionated from serum by precipitation with an equal volume of saturated ammonium sulfate and purified by electrodialysis at the isoelectric point. Serum albumin was dried and weighed before redissolving, the concentration being confirmed by analysis for total nitrogen. Serum globulin was not dried, the concentration being determined by analysis for total nitrogen. The procedure as to the pH and inorganic composition of the solutions was the same as in the case of casein. The available base-combining groups were calculated by use of the factors found by Van Slyke, Hastings, Hiller, and Sendroy.[18] Table 9 shows the results of representative observations on serum globulin. Since the experiments on serum albumin were similar, the extended data are not reported, but the values found for pK_{CaProt} are shown in Table 5.

Table 5 indicates a mean value of 2.24 ± standard deviation 0.08 for serum globulin (beef and horse) and of 2.03 ± standard deviation 0.11 for serum albumin (beef and horse). Satisfactory agreement between the results on serum and on purified serum globulin by the frog heart method is apparent. In the case of serum albumin the discrepancy is too great to be attributed to observational error. It should be noted that the preparations of serum albumin examined had been subjected to drying, which was not the case with serum globulin, and also that certain preparations of serum albumin so treated had very slight base-binding and calcium-binding capacities. Only results obtained from observations upon preparations exhibiting approximately the buffer values usually found have been included in Table 5.

If the figures for purified serum globulin and serum albumin, as determined by the frog heart method, be accepted at their face value, it is possible to calculate the amount of calcium bound in serum, under average normal conditions, by each of the serum proteins. With Ca^{++} concentration known, unaccounted for calcium is then calculated by difference. A typical calculation, with total protein 7 per cent, albumin to globulin ratio 1.8, gives

TABLE 9. Determination of pK_{CaProt} in Serum Globulin (Horse) Solutions

Solution No.	Total protein (gm. per 100 cc.)	Total protein (mM per kg. H_2O)	Total Ca (mM per l.)	Total Ca (mM per kg. H_2O)	Ca^{++} Calculated (mM per kg. H_2O)	Ca^{++} Observed (mM per kg. H_2O)	Ca^{++} Difference (mM per kg. H_2O)	Calculated from observed Ca^{++}: CaProt (mM per kg. H_2O)	Calculated from observed Ca^{++}: $Prot^{-}$ (mM per kg. H_2O)	pK_{CaProt}
1	6.97	7.06	1.90	2.04	1.02	1.10	+0.08	0.94	6.12	2.15
2	6.97	7.06	1.60	1.71	0.85	0.85		0.86	6.20	2.21
3	6.97	7.06	1.40	1.50	0.73	0.70	−0.03	0.80	6.26	2.26
4	6.97	7.06	1.20	1.29	0.63	0.60	−0.03	0.69	6.37	2.26
5	5.23	5.16	1.60	1.67	0.96	0.95	−0.01	0.72	4.44	2.23
6	5.23	5.16	1.30	1.36	0.77	0.80	+0.03	0.56	4.60	2.18
7	5.23	5.16	1.10	1.15	0.65	0.60	−0.05	0.55	4.61	2.30
8	3.48	3.39	1.40	1.44	0.97	0.95	−0.02	0.49	2.90	2.25
9	3.48	3.39	1.20	1.24	0.83	0.85	+0.02	0.39	3.00	2.19
10	3.48	3.39	0.90	0.93	0.61	0.60	−0.01	0.33	3.06	2.26
Average deviation							±0.03			

pH 7.35; temperature 22°C; f_{Prot} 0.189; Ca^{++} calculated from pK_{CaProt} 2.22.

	mM per kg. H_2O
Total Ca	2.90
Ca^{++}	1.29
Ca bound to globulin	0.465
Ca bound to albumin	0.805
Ca unaccounted for	0.34

Since the values obtained for pK_{CaProt} in the case of purified serum proteins may in all probability be accepted as indicating at least the *minimum* calcium-binding power of these proteins under natural conditions, the above figure of 0.34 mM per kilo of H_2O should represent the *maximum* concentration of calcium not accounted for by the calcium–protein relationship represented by Equation 2. On account of the treatment to which the proteins were subjected during purification and on account of the tendency, particularly of serum albumin, to lose its calcium-binding power during this process, there is considerable doubt as to whether the value of 2.03 for pK_{CaProt} in the case of serum albumin represents the full calcium-binding power of this protein under natural conditions.

Additional Variables Affecting Ionization of Calcium in Protein-Containing Fluids—It has been recognized throughout the above that Equation 2 is to be regarded as a first approximation only, and that certain variables, known to influence the ionization of calcium in protein-containing fluids, have been ignored. It would appear that the effect of these variables, in the aggregate, cannot be large in proportion to the protein effect, but they may be examined separately.

Ionization of Calcium in Presence of Protein and Magnesium—We have previously shown[17] that the addition of magnesium to solutions containing calcium and citrate increases the concentration of Ca^{++}, owing to the fact that magnesium combines with part of the citrate present. A similar effect in the case of mixtures of calcium, magnesium, and protein is to be expected, but we have not been able to detect such an effect by use of the frog heart method.

The data of Greene and Power[22] indicate a ratio of diffusible to non-diffusible magnesium, in the presence of protein, approximately equal to the ratio of diffusible to non-diffusible calcium, making it appear that magnesium and calcium combine with protein in approximately the same proportions. On the other hand, Watchorn and McCance[23] and Greenberg[24] have found that about 80 per cent of the magnesium in serum is diffusible. Using the data of Greene and Power as an indication of the maximum combining power of magnesium with protein, and assuming equal values for pK_{CaProt} and pK_{MgProt}, we can calculate the maximum error introduced into the calculation of Ca^{++} concentrations by neglecting the amount of protein bound to magnesium, and hence unavailable for the equilibrium with calcium. Such a calculation, under average normal conditions, indicates a difference of +0.06 mM per kilo of H_2O for the calculated Ca^{++} concentration when the possible effect of magnesium is taken into account. Since this difference is too small to be detected with accuracy by the frog heart method, and since in any case this effect of magnesium upon the ionization of calcium tends to be neutralized by the small amount of citrate present in human serum (see the following section), it may be neglected.

Ionization of Calcium in Presence of Citrate and Protein—We have previously shown[17] that in the presence of citrate the following relationship holds:

$$(9) \quad [Ca^{++}] = \frac{[CaCit^-]}{[Cit^=]} \times 10^{-3.22}$$

From Equation 2:

$$(10) \quad [Ca^{++}] = \frac{[CaProt]}{[Prot^=]} \times 10^{-2.22}$$

For mixtures of calcium, citrate, and protein

$$(11) \quad [\text{Total Ca}] = [Ca^{++}] + [CaCit^-] + [CaProt]$$

and the values satisfying Equation 11 must also satisfy Equations 9 and 10.

Table 10 shows the results of a test of this relationship. Calculated Ca^{++} concentra-

TABLE 10. Calculated and Observed Ca^{++} Concentrations in Mixtures of Calcium, Citrate, and Casein

Solution No.	Total Ca	Total citrate	Total protein	$CaCit^-$ calculated	CaProt calculated	Ca^{++}		
						Calculated	Observed	Difference
1	4.2		18.45		3.18	1.02	1.05	+0.03
2	4.2	1.05	18.45	0.60	2.75	0.85	0.85	
3	4.2	2.10	18.45	1.14	2.35	0.71	0.65	−0.06
4	4.2	3.15	18.45	1.57	2.03	0.60	0.55	−0.05
5	2.77		8.98		1.66	1.11	1.20	+0.09
6	2.77	0.51	8.98	0.29	1.50	0.98	1.00	+0.02
7	2.77	1.03	8.98	0.60	1.32	0.85	0.85	
8	2.77	1.54	8.98	0.83	1.19	0.75	0.75	

pK_{CaCit^-} 3.22; pK_{CaProt} 2.31.
The results are expressed in mM per kilo of H_2O.

tions are obtained (nomographically) from Equations 9, 10, and 11.

The fact that the values for $[Ca^{++}]$ found by direct observation by the frog heart method satisfy simultaneously Equations 9, 10, and 11, provides additional evidence in support of the validity of the frog heart method as being specific for Ca^{++}, since these equations could not be satisfied if the heart were sensitive to either $CaCit^-$ or CaProt, or both.

The concentration of 0.12 mM per liter of citrate reported in normal human plasma[25] is sufficient to introduce a small error into the calculation of Ca^{++} concentrations from Equation 6. As pointed out above, however, this error is of the same order of magnitude as, and in the opposite direction from, the error introduced by neglecting the influence of magnesium. Consequently, the effects of magnesium and of citrate, in the concentrations reported in normal human serum, tend to neutralize each other with respect to their influence upon the ionization of calcium, and both may be disregarded.

The relationship described in Equations 9, 10, and 11 makes possible an interpretation of the results of Shelling and Maslow.[26] They found that the total calcium of the serum of rabbits, to which high concentrations (as much as 72 mM per liter) of citrate were added, either *in vivo* or *in vitro*, became nearly 100 per cent ultrafiltrable, as compared to the 45 to 47 per cent in the serum of normal rabbits. Inspection of Equations 9, 10, and 11 will show that under these conditions nearly all of the calcium present is in the form of the complex ion $CaCit^-$, and consequently diffusible.

Ionization of Calcium in Presence of Magnesium, Protein, and Citrate—From theoretical considerations set forth in a previous paper[17] and assuming equal values for pK_{CaProt} and pK_{MgProt}, equations including four independent variables influencing the ionization of calcium in the fluids of the body (*viz.*, total calcium, total magnesium, total protein, and total citrate) may be added to Equation 11.

$$(12)\qquad [\text{Total Mg}] = [Mg^{++}] + [MgCit^-] + [MgProt]$$

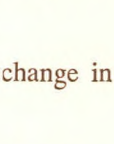
$$(13)\qquad [\text{Total Prot}] = [Prot^=] + [CaProt] + [MgProt]$$

$$(14)\qquad [\text{Total citrate}] = [Cit^=] + [CaCit^-] + [MgCit^-]$$

$$(15)\qquad [Ca^{++}] = \frac{[\text{total Ca}]}{[\text{total Ca}] + [\text{total Mg}]} \times \frac{[CaProt] + [MgProt]}{[Prot^=]} \times 10^{-2.22}$$

$$(16)\qquad [Ca^{++}] = \frac{[\text{total Ca}]}{[\text{total Ca}] + [\text{total Mg}]} \times \frac{[CaCit^-] + [MgCit^-]}{[Cit^=]} \times 10^{-3.22}$$

As shown above, the combined influence of magnesium and citrate upon the ionization of calcium in human material is negligible and may be disregarded. On the other hand, Equation 6 has failed to predict observed Ca^{++} values in the case of serum from the rabbit. The serum from the rabbit is high in total calcium (3 to 4 mM per liter) has long been known. Updegraff, Greenberg, and Clark[27] have shown that the diffusible calcium is also high (average 2 to 2.25 mM per liter). Kuyper and Mattill[28] have shown that the serum of the rabbit contains quantitatively significant amounts (0.35 to 0.65 mM per liter) of citrate. Our observations (Table 11) indicate that the Ca^{++} concentrations in the rabbit are only slightly higher than in the case of man. If it be assumed that the calcium-binding capacity of the serum proteins of the rabbit is the same as for those of man, the findings can be examined for evidence of a diffusible form of calcium, bound to citrate. Table 11 includes a number of observations on rabbit serum. The values for CaProt are calculated from Equation 2 and Ca*X* (calcium unaccounted for by Equation 2) is obtained by subtracting (Ca^{++} + CaProt) from total calcium. The values for the concentrations of citrate necessary to account for Ca*X* are calculated by assuming a total magnesium concentration of 1.0 mM per liter, and satisfy Equations 11 to 16. They are larger than the citrate concentrations found by Kuyper and Mattill, using the Thunberg method,[25] but are sufficiently near to indicate that the high total and diffusible calcium of the serum of the rabbit is at least largely due to the presence of a calcium citrate compound. Since these calculations are based upon the assumption of equal values for pK_{CaProt} and pK_{MgProt}, a slight correction will be required if the combining power of magnesium with protein is found to be less than that of calcium. This will result in slightly lower calculated values for citrate.

Effect of pH upon Ionization of Calcium in Serum—If it be assumed that the only effect of pH upon the ionization of calcium in protein-containing fluids is due to the change in available  groups, and

that the figures obtained from titration of protein with base provide an accurate measurement of this change, then $\Delta Ca^{++}/\Delta pH$ may be calculated, under the usual conditions, as follows:

Assuming protein 7.0 per cent, albumin to globulin ratio 1.8, total Ca 2.9 mM per kilo of H_2O, and with the factors of Van Slyke, Hastings, Hiller, and Sendroy[18]

TABLE 11. Representative Observations on Serum of Rabbits, and Calculation of Amounts of Citrate Necessary to Account for Calcium Not Accounted For by Equation 2 (CaX)

Sample No.	Total protein (gm. per 100 cc.)	Total Ca (mM per kg. H_2O)	Ca^{++} observed (mM per kg. H_2O)	CaProt calculated (mM per kg. H_2O)	Ca*X* calculated (mM per kg. H_2O)	*X* calculated as citrate (mM per kg. H_2O)
1	6.26	4.19	1.30	1.42	1.47	2.3
2	5.83	4.36	1.60	1.57	1.19	1.8
3	6.39	4.13	1.40	1.55	1.18	2.0
4	6.92	4.11	1.60	1.88	0.63	0.9
5	6.62	4.11	1.40	1.62	1.09	1.9
6	5.60	3.87	1.50	1.43	0.94	1.5
7	5.34	3.68	1.40	1.27	1.01	1.7

Mg (assumed) 1.0 mM per kilo of H_2O; pK_{CaProt} 2.22; pK_{CaCit^-} 3.22.

	At pH 7.35	*At pH 7.60*
Total protein		
mM per kilo H_2O	9.08	10.15
Calculated Ca^{++}		
mM per kilo H_2O	1.29	1.20

from which

$$(17) \quad \frac{\Delta Ca^{++}}{\Delta pH} = \frac{-0.09}{+0.25} = -0.36$$

We have been unable to demonstrate a change in Ca^{++} concentration of this magnitude with change in pH. This may be due, in part at least, to the fact that the calculated change in Ca^{++} concentration over a narrow pH range is too small to be detected accurately by the frog heart method, but certain considerations also raise some question as to the validity of the calculation.

While the only expression we have for the base-combining groups of protein is derived from the titration of protein with base, and while in relating the combination of calcium and protein to these groups we have made use of titration figures as an expression of total base-combining groups at the pH of the solution, it is by no means certain that we are theoretically justified in doing so. The isoelectric point is not necessarily a point at which proteins have neither free acid- nor base-combining groups, but rather may be the pH at which these groups neutralize each other. Consequently there may be a zone in which both acid- and base-combining groups are present, and titration with base, in this zone, would give a figure for base-combining groups minus acid-combining groups.

Northrop and Kunitz[29] have shown that both zinc and calcium combine with gelatin at the isoelectric point, and that only at pH 2.0 or below is calcium completely uncombined. Similarly Loeb[30] has shown that serum proteins can be rendered calcium-free, by dialysis against hydrochloric acid, only at pH 2.5 or below. The difficulty or impossibility of freeing serum proteins from calcium by electrodialysis at the isoelectric points of the proteins is well known. It is apparently incorrect to assume, as one does in using figures obtained from titrating protein with base, that calcium may not combine with protein at the isoelectric point.

The titration curves for serum proteins obtained by Van Slyke, Hastings, Hiller, and Sendroy, which may be regarded as representing base- minus acid-combining power, as a function of pH, have slopes which are probably much steeper than would be the slopes of similar curves if they represented only base-combining capacity. If this view is sound, then our use of the titration curves for expressing protein concentrations in terms of base-combining groups is theoretically unsound. From the practical standpoint, at a relatively constant pH, the question is unimportant, since any correction in expression of base-combining groups would simply result in a new value for K and hence for pK_{CaProt}. It becomes important, however, in dealing with changes in calcium-binding capacity with changes in pH. Our failure to find changes in Ca^{++} concentrations of the magnitude predicted from our calculations from the data of Van Slyke, Hastings, Hiller, and Sendroy may perhaps be due to these factors, for which we have at present no quantitative expression.

The data of Greenberg and Schmidt[31] are also of interest in this connection. They treated casein with the hydroxides of Ca, Mg, Sr, and Ba in varying amounts, and by determination of transport numbers calculated the amount of cation bound by protein. The data cover a pH range from 6.8 to 10.7 and in the higher pH ranges the values for bound cations appear to become approximately constant. The data are therefore reconcilable with the conclusions in this paper only on the assumption that the negatively charged groups of casein made available above pH 8.0 are of relatively little importance in the binding of the cations under consideration.

In view of the above considerations, our conclusions as to the quantitative relationships between calcium and protein must be limited to the relatively narrow pH range in which we have worked and the question of the relation of changes in pH to changes in

the capacity of protein to bind calcium must remain open for the present.

Effect of Temperature upon Ionization of Calcium in Serum—The frog heart method is not available for observations above 30 C and ordinarily loses its sensitiveness in the higher ranges of Ca^{++} concentrations at temperatures above 25 C. It has, therefore, not been possible to arrive by this method at the effect upon the ionization of calcium of changes in temperature between 25–38 C.

At 15 C observed Ca^{++} concentrations on serum have been found to be about 0.15 mM per kilo of H_2O higher than at 25 C. In this range

$$(18) \quad \frac{\Delta Ca^{++}}{\Delta t} = \frac{-0.15}{10.0} = -0.015$$

If this relationship were extrapolated to 38 C, Ca^{++} concentrations at 38 C in normal serum would be calculated as approximately 0.2 mM per kilo of H_2O lower than those observed at 25 C. We have not, however, been able to confirm the validity of this extrapolation. From indirect evidence it would appear that the effect of change of temperature, between 25–38 C, upon the ionization of calcium in the presence of protein is slight. Pertzoff and Carpenter[20] have found a difference between the titration curves of casein with base at 22 C and at 38 C, but the difference is too slight to introduce any significant correction in calculated Ca^{++} values. Weir and Hastings[21] have found values for pK_{CaProt} at 38 C, by an equilibration method, which are higher than those found by the frog heart method in the case of the serum proteins, and lower in the case of casein. In view of the conflicting evidence, and in the absence of any basis for introducing a temperature correction into our calculations, our Ca^{++} concentrations are reported as of 22–25 C, with the tentative conclusion that the temperature correction between 25–38 C is probably small.

Effect of Change in Albumin-Globulin Ratio upon Ionization of Calcium—All calculations of Ca^{++} concentrations in serum in this paper are based on an average albumin to globulin ratio of 1.8, a factor of 0.243 being used to transform total protein to base-combining groups. The factor at pH 7.35 for serum albumin is 0.273 and for serum globulin is 0.189. Consequently the use of a single factor based on an average albumin to globulin ratio introduces an error into the calculation of Ca^{++} concentrations.

If we assume that the values for pK_{CaProt} as above reported for serum albumin and serum globulin accurately represent the calcium-binding power of these proteins under natural conditions, then the calculated effect of a change in the albumin to globulin ratio upon the ionization of calcium would be very small, since the greater number of base-combining groups per gm. of protein, in the case of albumin, would be offset by a lower value for pK_{CaProt}.

If, on the other hand, in order to calculate the maximum effect possible, we assume that the correct values for pK_{CaProt} for serum albumin and for serum globulin are approximately equal, the error introduced by the use of a factor representing an average albumin to globulin ratio is again not large. Within the range of albumin to globulin ratios from 1.2 to 2.4, the maximum error introduced by using the average factor is less than 0.03 mM of Ca^{++} per kilo of H_2O and is consequently negligible. Assuming a low total protein concentration (4.0 per cent) and an albumin to globulin ratio of 0.6, representing a condition found in nephrosis, the error due to the use of the factor 0.243 is about 0.07 mM of Ca^{++} per kilo of H_2O. At still lower albumin to globulin ratios the error is further increased.

While separate analysis for albumin and globulin may be theoretically desirable, the error due to use of total protein figures, with the assumption of an average albumin to globulin ratio, is small, and may be neglected, except in cases with very low values for the albumin to globulin ratio.

Ionization of Calcium in Presence of Phosphate and in Protein-Phosphate Mixtures—The problem of the interrelations of calcium and phosphate, especially in the formation of bone, is of great biological interest. No attempt is here made to review or to clarify this problem, except in so far as it directly concerns the state of calcium in the fluids of the body.

Grollman[32] has shown that, while the inorganic phosphates of serum are normally completely diffusible, when calcium is added to serum, a portion of the phosphate becomes non-diffusible. Laskowski[33] in similar experiments obtained the same results, and showed, in addition, that the Ca × P product in the dialysate remained constant. This evidence points to the formation of a non-diffusible calcium–phosphorus complex under the conditions of these experiments, but on the other hand Laskowski was unable to obtain comparable results when phosphate was added to serum, the calcium concentration in the dialysate being unchanged or only slightly diminished. Brull[34] and Greenberg[24] have carried out similar experiments, and the latter has adopted the hypothesis that the phenomenon of reduction in ultrafiltrable phosphate induced by the addition of calcium to serum is the result of the formation of a colloidal material composed of calcium, phosphate, and probably carbonate, which is stabilized and prevented from precipitating by the protective action of the serum proteins.

A second, diffusible form of a calcium–phosphorus complex has also been postulated. Benjamin and Hess[35] and Benjamin[36] have brought forward evidence which has led them to the conclusions that about two-thirds of the diffusible calcium present in normal human serum is in the form of a calcium–phosphorus complex, adsorbable by barium sulfate, and that a similar complex is present in "artificial ultrafiltrates" containing calcium, bicarbonate, and phosphate.

We have repeatedly demonstrated that the addition of phosphate up to concentrations of 2.0 mM per liter to our standard solutions of reference has no appreciable effect upon the amplitude of contraction of the ventricle of the isolated heart of the frog. A similar finding by Günther and Heubner,[37] who assumed the presence of an un-ionized calcium–phosphate complex, was interpreted by them to mean that the frog's heart is sensitive to the total calcium present in solution, rather than to Ca^{++} alone. Since we have shown that calcium combined with citrate or protein, as well as with a series of carboxylic acids, either in the form of a complex ion or in an un-ionized form, exerts no appreciable effect upon the frog's heart, there appears to be no good reason for believing that calcium combined with phosphate would prove to be an exception to this case. Moreover, the equilibrium experiments of Sendroy and Hastings[38] afford no evidence of the formation of a calcium–phosphate complex similar to the combination of calcium with citrate. Our findings and interpretations in the case of artificially prepared solutions, and of cerebrospinal fluid, and of serum containing normal concentrations of phosphate, are therefore at variance with the conclusions of Benjamin and Hess.

Formation of a calcium–phosphorus complex, either diffusible or non-diffusible, in appreciable amounts, on the addition of phosphate, should result in appreciable changes in Ca^{++} concentration. In order to investigate the possibility of such a complex being formed in mixtures of calcium, protein, and phosphate we have added an isotonic phosphate mixture at pH 7.35, in concentrations up to 10 mM per liter, to solutions of casein, and have observed the effect upon apparent Ca^{++} concentrations by the frog heart method. As controls we have used simple saline solutions, to which corresponding amounts of phosphate were added. The results are included in Table 12. The higher concentrations of phosphate added are sufficient to cause precipitation of calcium phosphate in the controls. The effect upon observed apparent Ca^{++} concentrations in the controls may be due to such precipitation,

to the formation of a calcium–phosphorus complex, or to the effect of increased ionic strength. The protein solutions show no effect of the addition of phosphate up to a concentration of 5 mM per liter, and consequently no evidence of the formation of a calcium–phosphorus complex under these conditions.

From these results, which confirm those of Dolhaine[39] on serum, using a similar method, it appears that in the presence of proteins such concentrations of inorganic phosphate as are encountered in human plasma, even under pathological conditions, are not combined with sufficient calcium to affect the Ca^{++} concentration appreciably.

Correlation of Total Protein with Total Calcium in Serum of Numbers of Individuals —Salvesen and Linder[40] showed some years ago that the level of total calcium in the serum, in the absence of any recognizable disturbance in calcium metabolism, was directly correlated with the concentration of total protein. Since that time their work has been in general abundantly confirmed. A number of authors,[14,41–45] of whom some have made use of Salvesen and Linder's data, have expressed this correlation in the form of the empirical regression equation

(19) Total Ca = m total protein + b

where m and b are constants.

Reference to Equation 7, derived from the mass law Equation 2, suggests at once that this empirical equation is a special case of the more general mass law equation, with the Ca^{++} concentration constant. This would imply that the meaning of the empirical correlation is that the Ca^{++} concentration under usual circumstances is held, by means of physiological regulation, within a narrow range, which is consistent with the findings reported in this paper. It would then follow that the intercept with the Ca axis, expressed by the constant b, is the mean Ca^{++} concentration for the material studied, and that the slope of the correlation curve, represented by the constant m, is determined by the relationship $[Ca^{++}]/([Ca^{++}] + K)$.

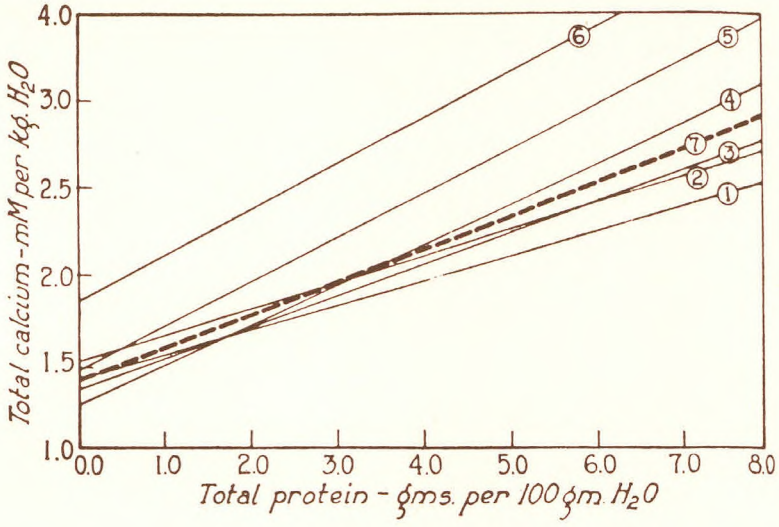
TABLE 12. Effect of Phosphate on Apparent Ca^{++} Concentrations in Saline Solutions and in Solutions of Casein*

Casein (gm. per 100 cc.)	Total calcium (mM per l.)	Total phosphate (mM per l.)	Apparent Ca^{++} observed (mM per kg. H^2O)
	0.7		0.7
	0.7	2.0	0.675
	0.7	5.0	0.625
	0.7	10.0	0.525
5.0	2.7		0.6
5.0	2.7	2.0	0.6
5.0	2.7	5.0	0.6
5.0	2.7	10.0	0.55

*The Ca^{++} concentrations in these observations are designated as "apparent" for the reason that the condition of equal ionic strength in known and unknown solutions, necessary for accurate observations, was not observed in the solutions to which phosphate was added.

From these interpretations, calculation of the mean values for K, and consequently for pK_{CaProt}, from the empirical regression equations as reported, is a simple matter. Figure 3 illustrates the correlations found, together with the mean Ca^{++} concentrations and values for pK calculated from the equations. All correlations have been reduced to terms of concentrations per unit of water, unless already in this form. In so doing, the intercept with the Ca axis has been left unchanged, and the correction in the slope applied arbitrarily at 6 per cent protein. The average of the data represented by Lines 1 to 5 is shown in the broken line (Line 7). This was obtained by taking the means of the intercepts and of the slopes. Line 6 was not included in the average because it seemed improbable that the data from the experiments upon which it was based were comparable to the others.

Figure 3 affords confirmation of the validity of the concepts advanced in this paper, and shows reasonable agreement with the quantitative results reported. These data are of special interest in that they represent *in vivo* conditions at the temperature of the body, and that no membrane equilibrium is involved in the data or the calculations, except to the extent that some of the correlations



Line No.	Authors	Material	Equation	Mean Ca^{++} (mM per kg. H_2O)	Mean pK_{CaProt}
1	Hastings, Murray, Sendroy[41]	Misc. human*	$Ca = 0.14\ Prot + 1.4$	1.4	1.97
2	Peters and Eiserson[42]	Misc. human*	$Ca = 0.153\ Prot + 1.5$	1.5	1.98
3	Miller[45]	Misc. human	$Ca = 0.178\ Prot + 1.35$	1.35	2.10
4	Greenwald[44]	Misc. human	$Ca = 0.232\ Prot + 1.25$	1.25	2.28
5	Darrow and Cary[43]	Dog*	$Ca = 0.250\ Prot + 1.45$	1.45	2.25
6	Darrow, Hopper, Cary[14]	Dog‡	$Ca = 0.256\ Prot + 1.86$	1.86	2.15
7	Mean, Lines[1–5]		$Ca = 0.188\ Prot + 1.40$	1.40	2.12

* Including data of Salvesen and Linder.[40]
† Nutritional hypoproteinemia.
‡ Plasmapheresis.

FIG. 3. Correlation of total calcium in serum with total protein, and calculation of mean Ca^{++} concentration and pK_{CaProt}.

included observations upon both serum and transudates.

Diffusible and Non-Diffusible Calcium—It would appear probable that diffusible calcium is nearly all ionized, as is the case with cerebrospinal fluid, and that the difference between diffusible and non-diffusible calcium, in protein-containing fluids, represents chiefly calcium bound to protein. Consequently it should be possible to derive the mass law equation from dialysis or ultrafiltration data and thereby to confirm the quantitative rela-

TABLE 13. Calculation of pK_{CaProt} from Dialysis Experiment with Serum Globulin*

Sample No.	Total protein (gm. per 100 cc.)	Total protein (mM per kg. H_2O)	Total Ca: Inside (mM per l.)	Total Ca: Inside (mM per kg. H_2O)	Total Ca: Outside (mM per l.)	Donnan $1/r^2$	Calculated: Ca^{++} (mM per kg. H_2O)	Calculated: CaProt (mM per kg. H_2O)	Calculated: $Prot^{=}$ (mM per kg. H_2O)	pK_{CaProt}
1	7.9	7.97	2.20	2.35	1.40	1.055	1.48	0.87	7.10	1.92
2	7.9	7.97	4.10	4.38	2.95	1.055	3.11	1.27	6.70	1.79
3	7.9	7.97	5.30	5.66	3.80	1.055	4.01	1.65	6.32	1.81
1	5.7	5.65	2.12	2.23	1.58	1.04	1.64	0.59	5.06	1.85
2	5.7	5.65	3.05	3.20	2.37	1.04	2.46	0.74	4.91	1.79
3	5.7	5.65	4.00	4.20	3.08	1.04	3.20	1.00	4.65	1.83
4	5.7	5.65	5.20	5.46	4.10	1.04	4.26	1.20	4.45	1.80
1	2.7	2.62	1.95	2.00	1.52	1.02	1.55	0.45	2.17	(2.13)†
2	2.7	2.62	3.55	3.64	3.18	1.02	3.24	0.40	2.22	1.75
3	2.7	2.62	4.70	4.82	4.08	1.02	4.16	0.66	1.96	1.91
1	1.2	1.15	1.45	1.47	1.23	1.01	1.24	0.23	0.92	(2.31)†
2	1.2	1.15	3.28	3.32	3.08	1.01	3.11	0.21	0.94	1.86
3	1.2	1.15	4.43	4.49	4.13	1.01	4.17	0.32	0.83	1.97

Mean pK_{CaProt} 1.84

Temperature 22°C; pH 7.4 ± 0.10; f_{Prot} 0.189.
* Data of Loeb[49] p. 456, Table 2.
† Excluded from mean as improbable.

tionships between calcium and protein above described. Data suitable for such calculations are abundant in the literature.

All diffusion experiments involve membrane equilibria, with non-diffusible protein on one side of the membrane. Consequently the Donnan effect must be taken into account in considering the concentration of calcium in the diffusate as a measure of the diffusible calcium and of the Ca^{++} concentration in the protein-containing fluid. The literature concerning the applicability of the Donnan theory to serum need not be reviewed here. Greenberg and Greenberg[46] have shown that ultrafiltration and compensation dialysis, the two methods most commonly used, both appear to be based on the same principle of the Donnan membrane distribution. On the basis of available theory the distribution of Ca^{++} should be as represented by Equation 20

$$(20) \qquad \frac{[Ca^{++}]\,p}{[Ca^{++}]\,d} = \frac{1}{r^2} = \left(\frac{[Na^{+}]\,p}{[Na^{+}]\,d}\right)^2 = \left(\frac{[Cl^{-}]\,d}{[Cl^{-}]\,p}\right)^2 = \left(\frac{[HCO_3^{-}]\,d}{[HCO_3^{-}]\,p}\right)^2$$

in which p indicates the protein-containing fluid and d the diffusate. Greenberg and Gunther,[8] from the data of Loeb and Nichols,[47] have estimated $1/r^2$ from the Cl^- ratios at about 1.05 at 7 per cent protein, and this corresponds with estimates from the data of Greene and Power,[22] although the theoretical value as calculated by Van Slyke, Wu, and McLean[48] should be approximately 1.10. From the theoretical considerations in the latter paper it also appears that the value of $1/r^2$ is an approximately linear function of the total protein present, at constant pH.

Under the assumption that the Donnan correction is valid in the case of Ca^{++}, and using the correction as calculated from the Cl^- ratio, we have made calculations of pK_{CaProt} from data in the literature. Table 13 includes such calculations from the data of Loeb[49] on serum globulin. Since these data

include observations in which both total protein and total calcium were varied, they provide a range sufficient for a test of the mass law relationship.

The data and calculations in Table 13 provide additional evidence in favor of the mass law relationship described in this paper. It will be noted, however, that the values for pK_{CaProt}, while internally consistent, are lower than those found by the frog heart method and that the discrepancy is too great to be accounted for on the basis of experimental error. If this were an isolated observation, the discrepancy might be attributed to partial denaturation of the protein used by Loeb, but from reference to Table 14, in which additional calculations made by the same method are reported, it will appear that lower values for pK_{CaProt} are characteristic of diffusion methods, in spite of considerable variation as between different methods and different observers.

As will be seen in the following section, the findings by diffusion methods may in part be reconciled with those by the frog heart method, by assuming a small amount of bound but diffusible calcium in the fluids studied by both methods. This cannot, however, be offered in explanation of all of the variations recorded in Table 14.

TABLE 14. Calculation of pK_{CaProt} from Diffusion Experiments

Authors	Method and material	Temperature C.	No. of observations	pK_{CaProt} Maximum	pK_{CaProt} Mean	pK_{CaProt} Minimum	Remarks
Marrack and Thacker[7]	Dialysis, purified horse serum proteins	37	12	2.21	2.02	1.91	
	Same; mixed proteins only	37	7	2.06	2.01	1.91	
	Same; serum albumin only	37	5	2.21	2.03	1.94	
Loeb[49]	Dialysis, purified human serum globulin (Table XIII)	22	11	1.97	1.84	1.75	Excluding 2 values (2.13, 2.31) as improbable
	Same; miscellaneous human serum, Ca varied	22	19	2.05	1.86	1.70	Excluding 2 values (1.32, 1.54) as improbable
Greenberg and Gunther[8] (data of Loeb and Nichols[47])	Dialysis, miscellaneous human serum, protein constant, Ca varied	22	17	2.24	2.01	1.83	pK decreases with increase in calcium, suggesting equilibrium not reached
Hertz[50]	Ultrafiltration, dog serum	22	19	2.38	2.10	1.78	
	Same; normal dogs only	22	11	2.25	2.13	1.98	
	After parathormone only	22	5	2.38	2.14	1.78	
	After parathyroidectomy	22	3	2.01	1.93	1.84	
Bendien and Snapper[51]	Ultrafiltration, miscellaneous human serum	22	9	2.44	2.17	2.00	
Herbert[52]	Dialysis, miscellaneous human serum	22	26	2.24	2.06	1.76	Excluding 1 value (2.55) as improbable
	Same; tetany only	22	2	2.15	2.07	2.00	
Greene and Power[22]	Vividuffusion, heparinized dogs	38	14	2.16	1.95	1.66	

Evidence for a Bound but Diffusible Calcium in Fluids of Body—Reference has been made to the probability of small amounts of a bound but diffusible form of calcium in the fluids of the body. It seems desirable to recapitulate the evidence derived from this paper in favor of such a form of calcium, and to attempt some estimate of its concentration.

That such a form of calcium is present in human fluids in small amounts (0.15 mM per kilo of H_2O or less) can scarcely be doubted, since the amount of citrate found in these fluids is now known to combine with an amount of calcium of this order of magnitude. This conclusion is supported by the indirect evidence reported above in the case of cerebrospinal fluid, and by the fact that the quantitative results obtained from serum by the frog heart method can be reconciled with the average of the results obtained by correlation of total calcium and total protein (Fig. 3) by the assumption that not more than 0.15 mM per kilo of H_2O of calcium is bound to some substance other than protein.

There still remains the possibility, however, of somewhat larger concentrations of a third form of calcium. It has been seen above that if the observations upon purified serum proteins are taken at their face value an unaccounted for fraction of calcium, not necessarily diffusible, amounting to approximately 0.34 mM per kilo of H_2O must be postulated, and that this is probably to be considered the maximum amount possible in view of our findings. Similarly, although the results of Bendien and Snapper and of Hertz (Table 14), by ultrafiltration methods, can be reconciled quantitatively with the results obtained by the frog heart method by assuming a correction of 0.15 mM per kilo of H_2O or less for bound but diffusible calcium, a larger correction would be necessary in the case of the observations included in Table 14 and obtained by means of dialysis methods. Since the evidence in favor of amounts of a bound but diffusible form of calcium in excess of 0.15 mM per kilo of H_2O is all indirect, and is capable of being otherwise explained, it would appear unnecessary to postulate such amounts, although the possibility of their presence in serum has not as yet been excluded.

SUMMARY

1. In human cerebrospinal fluid, which may be regarded as the prototype of the protein-free fluids of the body, ionization of the calcium present corresponds closely to that in an artifically prepared solution of similar composition. There is, therefore, no reason to postulate a bound but diffusible form of calcium in amounts larger than can be accounted for on the basis of the small amount of citrate present in such fluids.

2. In protein-containing fluids (serum, ascitic fluid, pleural fluid, edema fluid) of human origin, the ionization of calcium is determined primarily by an equilibrium between calcium and protein, which may be described, as a first approximation, by the mass law equation

$$\frac{[Ca^{++}] \times [Prot^{=}]}{[CaProt]} = K = 10^{-2.22 \pm s.d.0.07}$$

(temperature 25C, pH 7.35)

or in logarithmic form $pCa^{++} + pProt^{=} - pCaProt = pK_{CaProt} = 2.22 \pm$ standard deviation 0.07.

3. Calcium ion concentrations in human material may be calculated from the mass law equation, with a degree of accuracy which is probably as great as that of direct observation by the frog heart method. No gross deviations from this relationship have as yet been discovered in human material.

4. A value of 2.24 ± standard deviation 0.08 for pK_{CaProt} has been found in the case of purified serum globulin (beef and horse) and of 2.03 ± standard deviation 0.11 in the case of purified serum albumin (beef and horse).

5. A value of 2.38 ± standard deviation 0.03 for pK_{CaProt} has been found in the case of purified casein.

6. No evidence of the presence of a calcium–phosphorus complex in the fluids of the body has been found.

7. In the fluids of the body the calcium ion concentrations, under normal conditions and conditions of hypercalcemia, are such as to indicate a condition of supersaturation with respect to calcium carbonate and calcium phosphate.

8. The effects of temperature, pH, magnesium, citrate, and albumin to globulin ratio upon the ionization of calcium in the fluids of the body have been considered. Except in the case of citrate, the concentration of which in the fluids of the rabbit, and possibly of some other herbivorous animals, may be sufficiently high to exert a quantitatively significant effect, the effects of these variables are small in comparison with the effect of protein.

9. The fluids of the human body, including both protein-free and protein-containing fluids, contain a small but appreciable amount of a bound but diffusible form of calcium. This amount cannot at present be accurately determined, but is estimated to be of the order of magnitude of 0.15 mM per kilo of H_2O or less.

CONCLUSIONS

It appears from the above that the ionization of calcium in the fluids of the body is determined chiefly by the protein content of the fluids, and that the relationship between calcium and protein can, as a first approximation, be described by a simple mass law equation, yielding the ionization constant of calcium proteinate. From the standpoint of the ionization of calcium in protein-containing fluids, therefore, these fluids may be most simply thought of as solutions of calcium proteinate, which ionizes as a weak electrolyte into calcium and protein ions, with a residue of the un-ionized compound. With total calcium and total protein known, calcium ions may be readily calculated.

This statement, presented as a first approximation, is an over-simplification of the conditions which actually exist in the fluids of the body. Other variables, including pH, temperature, albumin to globulin ratio, magnesium, and citrate, are known to influence the ionization of calcium in these fluids, but the individual and combined effects of these variables are small. They are of slight practical importance, as compared with the calcium–protein relationship, except that in the case of the rabbit, and possibly also in some other herbivorous animals, the citrate concentration is sufficiently high to exert a quantitatively significant effect.

This concept of the state of calcium in the fluids of the body is essentially that advanced by Rona and Takahashi in 1913, and involves the concept of continuous supersaturation of these fluids with respect to calcium carbonate and calcium phosphate. It has been seen that the apparent improbability of this concept has delayed general acceptance of the views above advanced, and that its adoption introduces difficulties into the hypothesis of a simple chemical equilibrium between plasma and bone.

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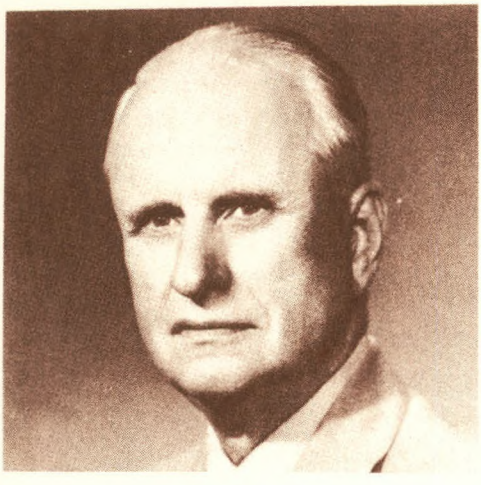

FRANKLIN C. MCLEAN

Franklin C. McLean (1899–1968) was the doyen of calcium and bone researchers in the United States and the world during the period from 1947 to 1967. He was Professor of Medicine, Dean of the Medical School at the University of Chicago and the full-time innovator of academic medicine in America during the 1930's. The coauthor, A. B. Hastings, emeritus Professor of Physiological Chemistry at Harvard University, is now living at La Jolla, Calif.

CLASSIC 46 Observations on Forty-Five Cases of Flat-Foot with Particular Reference to Etiology and Treatment

ROYAL WHITMAN (1857-1946)

I am inclined to think that the frequency of troubles caused by overstraining the arch of the foot is not appreciated, and that the condition is not generally recognized, because nearly every patient whom I have treated for this affection, many of whom presented the typical appearances of flat-foot, sometimes to an extreme degree, were taking, or had taken for long periods, internal remedies on the supposition that the symptoms were caused by rheumatism. Some observations on the etiology of the affection, with a more detailed account of its treatment than can be found in surgical or orthopedic works, may prove of interest to those who may be called upon to treat it.

The gross appearances and symptoms in acquired flat-foot have been sufficiently well described by various writers. In a typical case they are as follows: The arch of the foot is lowered; or completely broken down, so that the entire sole rests upon the floor; on the inside of the foot the slight normal outward curve from the heel to the head of the first metatarsal is replaced by a bulging inwards, most prominent below and in front of the internal malleolus. The foot seems broader than usual, and the internal malleolus is abnormally prominent; when the patient stands the entire foot seems displaced outwards on the leg, this being especially marked when looking at it from behind; the tissues on the inside of the arch and ankle seem thickened and congested; prominent veins and increased moisture of the foot are often noticed; in walking the feet are turned out more than usual, and a short awkward step is sometimes observed (see plates 1 and 2); the subjective symptoms are various, the most constant being pain especially after long standing or walking, most often about the inside of the ankle, sometimes shooting up the inside of the leg, or in the outside of the ankle, the ball of the foot, the heel, or middle of the sole; as patients express it, the foot seems heavy, and to have lost its spring; a symptom which I have not seen described is often complained of, a stiffness in the foot; for example, after sitting for any length of time, or on rising in the morning, the feet seem stiff and unmanageable when attempting to walk, the sensation lasting several minutes.

On manipulation—pressure over the astragalo-scaphoid articulation is painful—forcibly turning the fore-foot out or in, causes pain here, sometimes also just in front of the external and internal malleoli; forced flexion or extension of the mediotarsal joint is often attended with pain. These symptoms may, and most often do,come on

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slowly, and are of long duration, aggravated by overwork, relieved by rest; but they may appear suddenly, as in cases where there has been a gradual breaking down of the arch, a slight unnoticed injury may result in great pain, accompanied by redness and swelling; really, a sprain occurring in a weakened foot.

It must be remembered that in old flat feet the displaced bones constantly rubbing on each other, pressing on their overstretched ligaments, may induce a low grade inflammation, as shown at autopsies by eroded cartilages, ligaments and porosities of the bones. Such cases might easily be mistaken for chronic rheumatism, if the deformity were slight, especially if, as sometimes happens, but one foot were affected in a person subject to rheumatic inflammation in other joints. The symptoms, too, do not at all correspond with the degree of deformity. Many persons with complete flat-foot have no trouble, while others who are practically disabled by it show but a slight flattening of the arch.

Many flat feet can, by manipulation, be nearly or quite replaced in their normal position, others only partially.

In order to understand the etiology of the affection, and the reasons for the treatment which will be recommended may be made clear, it will be necessary to describe some of the anatomical peculiarities of the foot.

The astragalus, when the foot rests upon the ground, is usually held firmly between the tibia and fibula, permitting almost no movement except as a hinge-joint, the lateral movements taking place in the joint between it and the os calcis, to which it is attached principally by the interosseous ligament. When the foot bears weight the tendency is to abduction, that is, a slight flattening out of the arch, a turning out of the toes, and a tilting of the os calcis over towards the inner side, its anterior extremity slightly inwards and downwards, while the point of the heel turns slightly outwards.

There is a slight rotation of the astragalus forwards, downwards, and inwards, so that its anterior extremity, or head, articulating with the scaphoid, becomes more prominent: also a broadening and slight lengthening of the foot. These movements, which normally take place to an appreciable extent, are exaggerated in a foot whose muscles are weakened and ligaments stretched from overwork; thus the anterior extremity of the os calcis falls inwards and downwards, the bone tilts over so that its external tubercle is raised to a considerable angle with the floor. This change would affect the level of the astragalus in its relation to the leg bones, were it not for the fact that its increased rotation allows its outer margin to sink down into the interosseous fossa, pressing, before it the interosseous ligament, a movement which depresses its external and raises its internal border. The head of the astragalus, in its exaggerated rotation, presses inwards on the internal lateral, and inwards and downwards on the calcaneoscaphoid ligaments, while its axis which should be in a line with the second toe, may point inside the great toe. The distance between the internal malleolus and the sustentaculum tali is increased, and the external malleolus comes in close proximity to the os calcis, pressing on the external ligaments. At the same time the flattening and abduction of the foot strain, to a certain extent, all its minor ligaments. After a time the displacement may become permanent. Then may follow changes in muscles, ligaments, cartilages and bones.[2]

In order to ascertain the amount of rotation of the astragalus, and the expansion of

[2] Vide Autopsies.

Symington. Journal of Anat. and Phys., Oct., 1884.

Stokes. Annals of Surgery, Oct., 1885.

Humphrey. Lancet, March 20, 1886.

Hueter. Grundriss der Chirurgie, 2 Hälfte, 1882.

Von Meyer. Ursache und Mechanismus der Entstehung des erworbenen Plattfusses, 1883.

Children

	Normal						*Flat*					
	Age	*A*	*B*	*C*	*D*	*E*	*Age*	*A*	*B*	*C*	*D*	*E*
1	8	184	54	56	71	75	7	184	55	59	62	70
2	10	190	54	59	72	76	12	209	57	63	67	76
3	11	190	63	69	79	88	8	210	59	61	70	78
4	11	194	62	64	74	78	9	215	61	64	76	81
5	12	197	65	69	79	86	12	222	61	64	78	85
6	9	200	51	61	72	76	13	222	72	75	75	82
7	11	203	57	63	70	73						
8	13	210	61	66	75	82						
9	13	210	62	67	75	82						
10	13	228	62	69	83	86						
Avge.		200.6	59.7	64.3	75	80.2	Avge.	210.3	60.8	64.3	71.3	78.6
							Women					
1	36	203	57	61	83	89	60	229	70	72	89	99
2	18	209	62	67	89	97	45	229	70	76	77	85
3	38	209	61	64	78	89	25	235	67	71	91	97
4	38	209	51	62	89	95	50	241	69	71	100	113
5	38	209	61	62	84	91	24	241	64	69	89	94
6	36	216	76	80	92	105	29	254	69	71	99	115
7	20	222	64	69	85	94						
8	50	229	67	73	99	107						
9	30	248	69	70	92	95						
10	34	248	71	75	92	95						
Avge.		220.2	64.4	68.3	88.3	95.7	Avge.	238.1	68.1	71.5	89.8	100.5
							Men					
1	30	235	69	70	92	94	28	254	75	81	101	104
2	30	241	69	75	88	94	25	261	82	85	105	107
3	35	241	67	70	94	97	18	264	81	91	93	94
4	32	244	61	70	91	94	50	266	83	87	103	107
5	30	248	69	70	92	95	45	267	78	83	99	102
6	28	254	69	71	88	94	20	268	83	84	94	102
7	33	257	75	76	92	100	18	268	72	78	102	110
8	21	260	78	83	97	105	17	268	78	83	95	107
9	33	262	71	76	97	100	25	279	80	82	95	101
10	30	262	71	75	95	100	40	292	73	76	98	109
Avge.		250.4	69.9	73.6	92.6	97.3	Avge.	268.7	78.5	83	98.5	104.3

the heads of the metatarsals under weight, a series of comparative measurements, of normal and flat feet, in children and adult males and females, were made, with the following results:

A, Length of foot.

B, Distance between the external malleolus and the head of the astragalus, the foot resting easily on the floor at a right angle with the leg.

C, The same measurement when the foot sustains the entire weight of the body.

D, Distance between the head of the first and fifth metatarsals.

E, Same measurement under weight.

Measurement in Millimetres.

These measurements would seem to show that the flat-foot is longer than the normal; that the distance between the external malleolus and the head of the astragalus is greater, showing a certain amount of permanent rotation and displacement of this bone; that the fore-foot in flat cases is broader, and the expansion of the metatarsals is greater than in normal cases.

The area of rotation of the astragalus in women and children was restricted in the flat cases, because of the certain amount of permanent rotation which already existed, while in men it was increased. This variation may be explained by the fact that there are two classes of flat-foot, the most exaggerated types being met with in men, as might be expected, from their more laborious occupations.

(1) In well-marked cases, characterized by extreme laxity of ligaments, with very great deformity, as shown in Figures 1 and 2.

Recapitulation

Children	
Length of foot in normal cases	200.6
Length of foot in flat cases	210.3
Distance from external malleolus to head of astragalus, normal	59.7
Distance from external malleolus to head of astragalus, flat	60.8
Rotation of astragalus in normal cases	4.6
Rotation of astragalus in flat cases	3.5
Expansion of head of metatarsals in normal cases	5.2
Expansion of head of metatarsals in flat cases	7.3
Women	
Length of foot in normal cases	220.2
Length of foot in flat cases	238.1
Distance from external malleolus to head of astragalus, normal	64.4
Distance from external malleolus to head of astragalus, flat	68.1
Rotation of astragalus in normal cases	3.9
Rotation of astragalus in flat cases	3.5
Expansion of heads of metatarsals in normal	7.4
Expansion of heads of metatarsals in flat	9.7
Men	
Length of foot in normal cases	250.4
Length of foot in flat cases	268.7
Distance from external malleolus to head of astragalus, normal	69.9
Distance from external malleolus to head of astragalus, flat	78.6
Rotation of astragalus in normal cases	3.7
Rotation of astragalus in flat cases	4.5
Expansion of metatarsals in normal cases	4.7
Expansion of metatarsals in flat cases	5.8

Yet the symptoms are usually slight, and often no discomfort, other than the very apparent deformity, is experienced. The foot in young subjects can by manipulation be almost entirely replaced to its normal shape. In this class, the area of rotation of the astragalus is increased. As an example, Case No. 3 of the flat feet in men may be cited. Here measurement b. is 81 mm., compared with a normal of 69.9, the rotation of the astragalus 10 mm., compared with a normal of 3.7. The fore-foot in this case was so everted as to be almost useless in walking, the waist of the foot under weight measuring 91 mm., and the heads of the metatarsals 94 mm., compared with the normal of 73.6 and 97.3. Lesser grades of this type are usually classed as weak ankles.

(2) The cloddy type, characterized by flatness of the sole, with much less deformity. The foot seems thick and unyielding. The shape can be but slightly changed by manipulation. The pain is often severe, with tenderness of the joint on pressure and congestion of the foot. In this class, the rotation of the astragalus is restricted. It may be that the greater severity of symptoms in this class is due to more unyielding ligaments, which, allowing a certain amount of displacement, then hold the bones closely against each other in their abnormal positions, so that the effect of pressure in inflammation and other changes may be more apparent.

The early recognition of the affection is of considerable importance to the future comfort of the patient, and it may be stated that pain in the feet, aggravated by standing or walking, with pain on pressure over the astragalo-scaphoid joint, or pain on motion at the medio-tarsal joint, are symptoms much more likely to be caused by an over-strained arch, even though no deformity exists, than

by ill-fitting boots or subacute rheumatism, and that "sprained ankles" are often in reality sprained feet.

As to the etiology of acquired flat-foot, various theories have been advanced.

THE MUSCULAR THEORY

(1) Paralysis or atrophy of the tibialis anticus.[3]

(2) Paralysis of the peroneus longus.[4]

It is interesting to note that Sayre, finding in his cases the changes in the tibialis anticus, did not discover the affection of the peroneus longus, while Duchenne not only found no weakening of the tibialis anticus but says: "I have demonstrated that every flat-foot of which the etiology or genesis is in muscular action, is produced by preponderance of the tonic force of the tibialis anticus, which, as will later be demonstrated, destroys the plantar arch" (p. 457).

Mr. Golding-Bird, in fifty cases of flat foot, found no atrophy or paralysis of the tibialis anticus.[5]

In the forty-five cases examined by me, no paralysis was found, or muscular changes that might not better be classed as results than causes; for example, in some cases where there is a considerable displacement of the astragalus to the inside, as in Figure 1, it is difficult or impossible for the patient to flex the foot in an adducted position, as is the ordinary action of the tibialis anticus; this might be thought due to atrophy of that muscle, but it may be more easily explained by this displacement of the astragalus, which necessitates a wide movement of the fore-foot about its head: if the displacement be so great as to render this impossible, the foot must be flexed and abducted as though it were moved by the long extensor of the toes. I have noticed, too, in some of these cases, when attempting manually to flex and abduct the foot, that there seemed to be an abnormal resistance in the calf muscle, which had been acting so long with its tendon displaced outwardly in its relation to the foot.

[3] Sayre. Orthopedic Surgery, p. 62.
[4] Duchenne. Physiologie des Movements.
[5] Guy's Hosp. Reports, Vol. xli, 1883.

LAX LIGAMENTS

By some, flat-foot has been ascribed to lax ligaments. As to this, it may be said that some persons have strong muscles, and others weak ones. So, too, there is a great difference in ligaments. One has only to examine a certain number of normal joints to convince himself of this. It seems reasonable that a person whose muscles are weak and whose joints are loose, will, under favoring conditions, develop flat-foot, while another with strong muscles and closer joints would not. It does not follow, however, that a primary relaxation of ligaments is the ordinary cause of this affection. It is impossible to say how much hereditary influences have to do with the causation of flat-foot. No. 1, of "flat feet in men," a case of extreme deformity, informed me that he was one of eight brothers, all of whom had feet as flat as his own. No. 3, already cited, the most extreme case of all, said he had inherited the affection from his father, yet he had three brothers with perfect feet. The occupation, in which he had been engaged for five years, bell-boy in a hotel, a most trying one for the feet, may have been in his case a more important factor than inheritance.

I am not now speaking of the negro type of foot, long, flat, with projecting heels, but of cases that would be considered typical illustrations of the deformity. In one family I found three generations of flat feet. The child, however, showed marked evidence of rachitis, an affection in which it is usually present.

HIGH HEELS

Mayo-Collier[6] contends that the wearing of high heels is the cause of flat feet, quoting Little: "a slight degree of atonic valgus is common in girls, especially in those of the upper and middle classes." "Why not in the less fortunate and badly-nourished females of the lower classes? Because the high heels are less prevalent with them." My experience leads me to consider "atonic" flat-foot as especially the affection of servant-girls, often badly nourished, and obliged to be almost constantly on their feet. This class do not wear especially high heels; they do wear ill-fitting boots, with narrow soles, which compress and deform the toes, and rest their feet with cloth boots and slippers, which give no support to the arch; and in this class the tired feeling and dull ache in the feet, so characteristic of an over-strained arch, is very common.

Again, raising the heel in one of these cases does not increase the deformity. On the contrary, if the bare foot be placed squarely on the floor, and the body be inclined forward so that more weight is brought on the "waist" of the foot, it will be increased.

CONGENITAL OSSEOUS MALFORMATION

It has been suggested, because flat-foot occurs in robust persons, and because changes in the bone have been found, too great to be accounted for by mechanical causes, that an original osseous malformation would best explain the origin of the affection.[7] The affection does, it is true, occur in robust persons, but if one of these patients be questioned, it will be found that he dates his symptoms from some strain or from some peculiarity in his occupation. As an illustration, a healthy, well-developed young man was sent to me last week, presenting a very considerable flattening of the arch of one foot, accompanied by pain, swelling, and muscular spasm. I found that his occupation as a bookbinder compelled him to stand all day on the affected foot, while he worked a treadle with the other. Again, I should not admit that the bone deformities, as described in the published autopsies, were too great for explanation on mechanical grounds. They are no greater than those found in other bones under similar conditions.

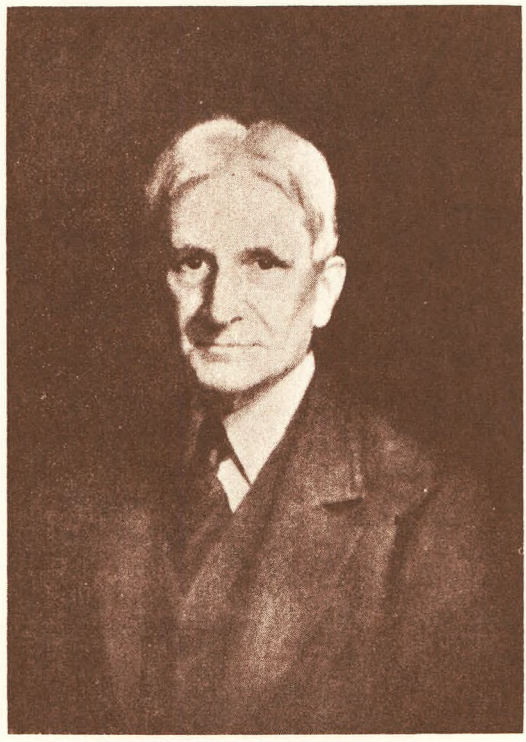
Lastly, the number of autopsies on flat-foot is too small to support any peculiar and improbable theory as a general explanation of the affection. It may be that these different theories have resulted from a failure to recognize the varying types of the affection. One observer sees cases or makes a dissection of a foot showing great relaxation of ligaments, and concludes that all cases result from lax ligaments. Another meeting acute cases where, as in acute affection of other joints, muscular spasm and contraction are prominent features, considers muscular spasm, contraction, atrophy or paralysis as exciting causes. While another accounts high heels responsible for the symptoms which he notices.

THE OVERWORK THEORY

It seems to me that the most reasonable explanation of its cause is that of a disproportion between the weight the foot is called upon to bear and the ability of its muscles and ligaments to sustain it, a simple breaking down from overwork.

[6] Flat-Foot, by M. P. Mayo-Collier. Lancet, September 4, 1886.

[7] Stokes. Annals of Surgery, Oct., 1885.



ROYAL WHITMAN

Royal Whitman (1857–1946) born in Vermont, began his orthopaedic career in Boston. Later established in New York City, he succeeded Virgil Gibney as Chief at the Hospital for Ruptured and Crippled (now the Hospital for Special Surgery). One of his earliest contributions to orthopaedic surgery was the first serious study of painful feet of the static or functional type as opposed to the pathologic clubfoot or polio foot. The present reprint is that of his earliest and classic study. The chapter on static foot disease in his incomparable textbook of later years remains the most readable and informative source of clinical teaching on the subject. May I add that this opinion is objective and not merely the prejudice of his last House Surgeon.

E.M.B.

CLASSIC 47 A Treatise on Gout

ALFRED BARING GARROD (1819–1907)

Having given a slight sketch of the different ideas of the proximate cause or nature of gout, which have been entertained both in ancient and modern times by physicians whose opinions are most worthy of esteem, and having had occasion to point out the fallacies of many of them, it now behoves me to expound the views which, from a long and attentive consideration of the varied phenomena of the disease, I have myself arrived at, and this task I will endeavour to perform in as succinct a manner as possible.

In the Medico-Chirurgical Transactions for 1848, I ventured to advance the following guarded opinion, derived from several observations on the condition of the blood and urine in gout, rheumatism, and albuminuria. "The results of these experiments on the condition of the blood and urine, prove that uric acid is not a product of the action of the kidneys, as frequently supposed, but is merely excreted from the system by these organs. They also appear to indicate that the excreting function of the kidneys with regard to the solid portion of the urine, is not a simple one, but that urea and uric acid are separately eliminated; also that one of these functions may be impaired or destroyed, the other remaining entire. It appears also probable that, as in albuminuria, the *urea-excreting* function being chiefly impaired, we find a vicarious discharge of urea in dropsical effusions; so, in gout, the *uric-acid-excreting* function being defective, chalk-like deposits are produced by a similar vicarious discharge of urate of soda.

"Gout would thus appear, at least partly, to depend on a loss of power (temporary or permanent) in the uric-acid-excreting function of the kidneys; the premonitory symptoms, and those also which constitute the paroxysm, arising from an excess of this acid in the blood, and the effort to expel the *materies morbi* from the system. Any undue formation of this compound would favour the occurrence of the disease, and hence the connection between gout, gravel, and calculus, hence also the influence of high living, wine, porter, want of exercise, and other like causes, in inducing it.

"This hypothesis also explains two facts, which have been regarded as militating against the humoral pathology of the affection, namely, its hereditary nature, and its frequent occurrence in low states of the system; for we can understand that the peculiarity of the kidney, with reference to the excretion of uric acid may be transmitted, and likewise, that when the function in question is permanently injured, it will not require an excessive formation of this acid to cause its accumulation in the blood."

These views were made public twenty-seven years since, and subsequent clinical observations have fully confirmed their accuracy; although in themselves insufficient

to explain all the phenomena of gout, still, by their aid, in conjunction with other more recent investigations, I shall hope to be able to give a rational exposition of the disease.

In order to render my views concise and explicit, I shall present them to the reader in a series of propositions:

First, in true gout, uric acid, in the form of urate of soda, is invariably present in the blood in abnormal quantities, both prior to and at the period of the seizure, and is essential to its production; but this acid may occasionally exist, at least for a time, in the circulating fluid without the development of inflammatory symptoms, as in cases of lead poisoning. Its mere presence, therefore, does not explain the occurrence of the gouty paroxysm.

Secondly, the investigations detailed in the chapter on the Morbid Anatomy of Gout, prove incontestably that true gouty inflammation is *always* accompanied with a deposition of urate of soda in the inflamed part.

Thirdly, the deposit is crystalline and interstitial, and when once the cartilages and ligamentous structures become infiltrated, remains for a lengthened time, often throughout life.

Fourthly, the deposited urate of soda may be looked upon as the cause, and not the effect, of the gouty inflammation.

Fifthly, the inflammation which occurs in the gouty paroxysm tends to the destruction of the urate of soda in the blood of the inflamed part, and consequently of the system generally.

Sixthly, the kidneys are implicated in gout, probably in its early, and certainly in its chronic stages; and the renal affection, possibly only functional at first, subsequently becomes structural; the urinary secretion is also altered in composition.

Seventhly, the impure state of the blood, arising principally from the presence of urate of soda, is the probable cause of the disturbance which precedes the gouty seizure, and of many of the anomalous symptoms to which sufferers from gout are liable.

Eighthly, the causes which predispose to gout, independently of those connected with individual peculiarity, are either such as produce an increased formation of uric acid in the system, or lead to its retention in the blood.

Ninthly, the causes exciting a gouty fit are those which induce a less alkaline condition of the blood; or which greatly augment for the time, the formation of uric acid; or such as temporarily check the eliminating power of the kidneys.

Tenthly, in no disease but true gout is there a deposition of urate of soda in the inflamed tissues.

With regard to the fact enumerated in the *first* of these propositions, namely, that the blood in gout always contains an abnormal quantity of uric acid during the attacks, sufficient evidence has been already afforded, inasmuch as it has been shown in Chapter IV., that in forty-seven patients suffering from the disease the blood contained much uric acid, and subsequently to the formation of the table, an examination of the blood of at least a hundred other patients has demonstrated the same truth. This this impregnation occurs prior to an attacks, is well illustrated in the annexed cases of lead paralysis, in which the patients experienced the first fit of gout when in the hospital.

Case I., Feb. 15, 1859.—J. B., aged 41, an artist, engaged in painting both in water and oil colours. About ten years since felt some symptoms arising from the absorption of lead, first in the form of colic and obstinate constipation, and afterwards in the wrists. These symptoms were relieved, and he resumed his usual occupation. About three years ago he completely lost power over both his wrists, and had a severe attack of colic; he then came for the first time under my care, and by treatment was so far restored as to be enabled again to pursue his avocations. Six weeks ago, he had a return of the wrist-drop and colic, which have continued up to the present time. There

s now an entire loss of power in both wrists, also considerable wasting of the extensor muscles of the fore-arms, and of the flexor muscles of the right thumb; severe twisting pain around the umbilicus, and constipated bowels, loss of appetite, and weak pulse. A very distinct blue line is seen on the free edge of the gums, both of the upper and lower jaw.

A small amount of blood, obtained on his admision into the hospital, exhibited the following characters:

Clot firm, and slightly buffed; serum, yellow, transparent and alkaline. Sp. gr. 1027 at 60° Fahr. By the thread experiment there was evidence of its containing abundance of uric acid.

Urine pale, free from deposits, and yielding scarcely a trace of uric acid when acidulated.

During his stay in the hospital this patient experienced a decided attack of gout, first in the metatarso-phalangeal joint of the left great toe, and afterwards in the corresponding joint of the right foot.

Case II., 1866.—Similar to the above: the man, a worker in lead, came into the hospital suffering from wrist-drop; a trial bleeding showed the presence of a large amount of uric acid in the serum. I gave a clinical lecture on his case, pointing out the similarity of his blood to that of a gouty subject; within a few weeks a decided fit of gout in the great toe ensued, although the patient had never experienced anything of the kind before.

That in certain instances the blood may contain an abnormal amount of uric acid without the occurrence of gouty inflammation, has been clearly demonstrated in some cases of lead-poisoning, and others will be alluded to subsequently.

In the Chapters on the Morbid Anatomy of Gout, I believe sufficient evidence will be found to convince any pathologist of the truth of the *second* proposition; for not only has proof been afforded that a deposition of urate of soda occurs in the chronic forms of the disease, but even that the slightest amount of gouty inflammation is accompanied with a similar deposit. Its presence has been discovered in a case in which only one small joint had been affected, as also in a knee-joint, known to have been but once inflamed, and that very slightly; and lastly in a case where only one attack of gout had ever occurred. This fact I wish to impress forcibly on the minds of my readers, because in the *constancy* of such deposition, lies the clue which has long been wanting: the occurrence of the deposit is perfectly pathognomonic, and at once separates gout from every other disease which at first sight may appear allied to it.

To my *third* proposition, little further need be added, as I have already stated that in very numerous instances I have found the cartilaginous and ligamentous deposits distinctly crystalline, and undoubtedly interstitial, and with respect to their long persistence when once deposited, I can bring forward strong evidence. In Case 15, Chapter VI., where only the ball of one great toe had been implicated, two years had elapsed, still the deposit was discovered; at least an equal time had elapsed in Case 13, where the knee had been but once and very slightly inflamed, yet distinct evidence of the mischief remained; in Case 16, in which only one attack of gout had occurred there was proof that after an interval of thirteen years the cartilages and ligaments still remained infiltrated with the urate of soda. In the majority of cases the deposits probably remain during life, increasing more and more with each succeeding fit.

It is of the highest importance to establish the truth of the *fourth* proposition, namely, that the deposited urate of soda must be regarded rather as the cause than the effect of the gouty inflammation, inasmuch as it bears closely upon the pathology of the disease. There are several reasons which militate strongly against the supposition that the deposit is the effect of the inflammation; for instance, when tissues little liable to take on inflammatory action become infiltrated, but slight vascular disturbance is produced; this is especially the case with the fibro-cartilage of the ear; and, although we now and then meet with patients aware of the formation

of these little nodules, who experience, in fact, a gouty fit in the ear, yet in the majority of cases attention has never been directed to the part, so slight has been the inflammation caused by the effusion, and several patients have assured me that they had noticed the existence of deposits on the cartilages of their ears some months before the first attack of articular gout occurred.

Another reason, strongly militating against the same supposition, is contained in the *fifth* proposition, to be now considered, namely, that the inflammation of gout tends to the destruction of the urate of soda in the blood of the part. The proof of this is to be seen, first, in the fact that the serum effused by the application of a blister to the inflamed skin does not exhibit evidence of containing uric acid, while the blood of the patient and the blister serum from a non-inflamed part readily show its presence; and secondly, in the peculiar manner and situations in which these depositions occur, selecting, as they do, structures possessed of slight vascularity, as cartilage, fibro-cartilage, ligament and tendon, and the surface of synovial membranes, and, even in these tissues, keeping to such portions of them as are furthest removed from the influence of blood-vessels. Thus the deposit in articular cartilage, although completely interstitial, first takes place at the free surface, and very gradually travels inwards towards the bone. The only marked exceptions I have seen to this rule have occurred in the patella, in which occasionally nodules of urate of soda are observed at some distance from the articulating surface; but we must remember that the patella is a sesamoid bone, and by no means vascular in its structure; this may probably account for the fact that Cruveilhier discovered deposits which he considered to consist of urate of soda, even within the bone itself.

We have likewise seen that on the surface of bones much altered by gout, especially the condyles of the femur, the deposit avoids contiguity with the vascular fringes of the synovial membrane; a fact first pointed out by Dr. W. Budd, and seen in the delineation of the knee-joint, in Plate III, Fig. 3.

Lastly, the results of certain physiological experiments in which uric acid has been injected into the blood, as also the readiness with which it is decomposed out of the system, confirm the idea that contact with blood-vessels, more especially when in a state of inflammation, has a tendency to cause the destruction of uric acid.

It would thus appear that the gouty fit is, to some extent, a salutary process, ridding the system of much uric acid which may have been accumulating for a considerable time; but we must likewise remember that it is always attended with a certain amount of local mischief, which may or may not prove a source of subsequent inconvenience.

The truth of the *sixth* proposition has been fully demonstrated in Chapter VII., where it has been shown that with very few exceptions, in subjects who had in any degree suffered from gout, the kidneys were altered by the deposition of urate of soda, both at the ends of the pyramids and in the direction of the tubuli uriniferi; that in many instances these organs were contracted, and in almost all, an appreciable change had ensued in the cortical structure. It has been imagined long since that the kidneys are affected in gout, and Moragni had an idea that we should find a clue to the disease in the condition of these organs.

The effect of gout in altering the renal secretion has likewise been fully proved; the uric acid excretory function is defective, and the urine often contains of small amount of albumen. The imperfection in the eliminating power of the kidneys sometimes appears to be the chief, if not the only cause of the impurity of the blood; and to show that an augmented formation of uric acid is not necessarily accompanied with an excess of

it in the blood, we need but refer to the case of birds such as the turkey, fowl and pigeon, whose blood I have examined several times and always found it free from any abnormal amount of uric acid.

The observations of Zalesky, showing that uric acid, probably as urate of ammonia, is actually formed by the kidneys, would rather strengthen my views of the connection between the condition of the renal function and the development of gout. If we assume the truth of his observations, then we must suppose that in healthy animals the urate of ammonia, as soon as it is formed, is quickly eliminated with the urine; but that in certain diseased conditions of the human subject it is retained in the renal cells and gradually becomes absorbed into the blood, where it is converted into urate of soda. We find a good analogy in the case of the liver. When there is nothing to obstruct the exit of bile from the biliary tubes, no appreciable amount of the colouring matter is found in the blood; but when from any cause the free elimination of the bile is checked, then the blood becomes speedily impregnated with it, and jaundice is produced.

There is an interesting clinical fact which I have sometimes observed which is explicable only on this view, the fact, namely, that in certain cases of advanced gout, where extensive deposits have taken place throughout the body, the patient lives on for many years, and often without any subsequent development of gouty symptoms; the urine at the same time being quite devoid of any appreciable amount of uric acid. An example of this is seen in a case in Chapter III., page 72. If uric acid were formed in the system and merely excreted by the kidneys, then, as these organs lose their functions, uric acid should go on accumulating more and more in the blood; but if, on the contrary, the kidneys are themselves the producers of this body, then, as the formative function is diminished, there would be a lessening of the acid.

The *seventh* proposition is difficult to prove, although almost every physician is accustomed to recognise a close relation between particular symptoms and the presence of certain morbid matters in the blood. We have absolute proof, derived both from physiological and pathological observation, that when the urinary secretion is completely stopped, most serious and even fatal symptoms ensue; and it is therefore reasonable to suppose, that if one or more of its constituents be retained in the blood, certain morbid phenomena would result therefrom. Some of these symptoms in the case of gout may arise simply from the presence of the special impurity, others possibly from an attempt at its deposition, and the consequent reaction. I should be inclined to regard the dyspeptic symptoms which usually precede the gouty fit as due to the former, and many of the anomalous and irregular forms of the disease which we shall hereafter more fully consider, as dependent rather upon the latter cause.

The discussion of the *eighth* proposition is of much interest and considerable importance, for if we can prove the truth of the statement that the predisposing causes are of different kinds, the one leading to the increased *formation* of the morbid matter, the other to its *retention* in the blood, we at once have a clue to the varieties of the disease, popularly known as the rich, and the poor man's gout. As it has been shown that the inflammation is invariably accompanied by the deposition of urate of soda, which may be regarded as its cause, it is evident that any circumstance which favours an accumulation of this salt in the system, and thereby paves the way for its infiltration into the articular tissues, becomes a predisposing cause, whether this arises from its augmented formation and the consequent overtaxing of the renal organs, or whether

the excreting power of the kidneys be simply impeded in their normal function. It appears probable, that in the majority of cases of gout both causes are in operation; but on the other hand it is easy to conceive that either, if active, might lead to the production of the disease. In the former case the affection would be typical of the *rich*, in the latter, of the *poor* man's gout.

In the *ninth* proposition we have assumed that the infiltration of urate of soda into the tissues may take place in two ways, either by its great accumulation in the blood, or by that fluid being rendered less capable of holding it in solution; the former condition may be caused by a temporary increase in the formation of uric acid, as by aggravated dyspepsia from partaking of very indigestible articles of diet; or by a sudden loss of the uric-acid-excreting power of the kidneys from mental shocks, severe accidents, and so forth, all of which we know to be very potent in exciting a fit of gout; the latter condition is likely to be induced by partaking of acid liquors, as particular kinds of wine, hard beer, and pickles; or by the suppressed action of the skin causing defective elimination of acid perspiration, and the consequent diminution of the alkalinity of the blood.

The serum, in which the urate of soda is dissolved, is alkaline, and this reaction is caused in part by phosphate of soda, in part by alkaline bicarbonates. In no case of disease—and in my opportunities have been numerous—have I found this fluid acid, and it is probable that such a state would be incompatible with life; but there is often a marked alteration in the degree of its alkalinity, and in many cases of chronic gout it has shown a near approach to neutrality. Any diminution in the alkaline state of the serum lessens its power of holding urate of soda in solution, and facilitates its deposition, especially in tissues whose reaction is naturally less alkaline than the blood. To illustrate this experimentally, we may take a watery solution of the common phosphate of soda, and dissolve uric acid in it, but only to such an extent as to ensure the fluid remaining alkaline; the subsequent addition of a small quantity of a weak acid will cause the precipitation of urate of soda; but if the fluid is rendered acid, then uric acid will be deposited in a crystalline state.

By the adoption of these views we are enabled to explain why differences exist in the classes of exciting causes; for we have found that some of them are of the same nature as those which predispose to gout, but that others, however long their action is continued, are powerless as predisposing agents. We now see the reason of these differences; those agencies which, when in active operation, lead to a rapidly augmented formation of uric acid and the production of a fit, must necessarily, if in slower action, predispose to the affection; whereas agencies which simply diminish the alkalinity of the serum, and render the urate less soluble, cannot of themselves in any way produce the disease; thus cold, which so often excites a fit of gout, never induces the gouty habit.

We have lastly to discuss the *tenth* proposition, namely, that in no other disease but true gout is there a deposition of urate of soda in the inflamed tissues. In at least a dozen fatal cases of genuine rheumatic fever, I have examined the joints known to have been affected. Some of them, which had recently been inflamed, exhibited increased vascularity, turbidity of the synovial fluid, opacity of the cartilage, and other marks of inflammatory action; but in no one case have I seen the slightest trace of a deposit of urate of soda. Again, in numerous cases of rheumatoid or chronic rheumatic arthritis, observed both by myself and others, although the cartilages have always shown signs of much injury, from the effects of ulceration, and have often been covered with

a deposit of bone earth, yet no uric acid deposit has been found. I may here state that it has been asserted that urate of soda is sometimes present in joints which had not been affected with gout during life, and one such case is related by Barwell, who exhibited a diseased knee-joint, supposed to be in this condition, before the Pathological Society; but on careful examination I found that the deposited matters, which had replaced to some extent the absorbed cartilage, consisted of phosphate and carbonate of lime, without a trace of uric acid. The late Beevor, of Manchester, assured me that he had taken a large tumour from the scalp of a young woman, having no tendency to gout, and that it had been analysed and found to consist of urate of soda. Fortunately the tumour had been preserved in spirit, and a slice was given to me, but I failed to detect the least trace of uric acid in it. It have examined the great toe joints in at least forty cases with no known gouty history, and in only two instances was uric acid discovered, and in both these in one foot only, and limited to a single spot in the cup of the first phalanx. One of these individuals was a cabman, aged forty-eight, he had granular kidneys, and had died from an injury; the other was a man aged forty-three, who died from delirium tremens; in both cases the spot was similarly situated, as represented in the annexed woodcut. I have no doubt that many persons experience extremely slight attacks of gout before the development of the affection in an acute form, and several of my patients have assured me that for years before their first severe attack in the great toe, they have felt slight periodical twinges. I am of opinion that when such twinges occur, deposition has already taken place.

Having enumerated and considered these propositions, we will now endeavour, by their aid, to explain certain peculiarities which are met with in the progress of gout, many of which have proved of great difficulty to pathologists. With regard to the phenomena of the fit, it is essential that there should be a prior impurity of the blood due to the presence of urate of soda, and this may be induced by the action of any of the predisposing causes of the disease; it is probable that this condition of itself is sufficient to give rise to the premonitory symptoms which are chiefly manifested in the functional derangement of the digestive and circulating organs. To excite a gouty paroxysm, however, requires the additional operation of other agencies, namely, of those by which the urate of soda is either suddenly augmented or rendered less soluble, and its crystallisation promoted in the ligamentous and cartilaginous structures of the joints. The intensity of the pain which usually accompanies a gouty fit depends upon the rigidity of the parts, or the state of tension within the joint, for it is only when the inflammation is inter-articular that it is so peculiarly intense; when confined to the structures around the joints, the pain does not appear to be more severe than in many other inflammatory diseases.

One peculiarity of gouty inflammation is the occurrence of œdema, and the subsequent desquamation of the cuticle; these symptoms are of some importance, as they are so frequent in gouty, so rare in rheumatic inflammation. An explanation has been before hinted at, namely that the œdema depends on the presence of urea in the blood, and we have seen that this is frequently the case, and we likewise know that in albuminuria, where the elimination of urea is greatly impeded, œdema is a prominent symptom; and in scarlatina, where the kidneys are so liable to be affected by the poison, desquamation of the skin is a characteristic attendant. I cannot help thinking that the above may be the true explanation; but in order to prove it beyond doubt, certain clinical and chemical observations are

required which have not yet been satisfactorily made. The occurrence of chalkstones of gouty tophi, which has so long been a stumbling-block to those who denied the existence of an altered blood, is now easily explained; *every paroxysm of gout is attended with a deposit.*

Sir Henry Holland remarks that a difficulty in the history of gout, and one not easily reconcilable with the view of the disease being dependent on a *materies morbi*, is the fact that frequently some joint is attacked with gouty pain and swelling, without any well marked symptoms to give warning of its approach; for it is necessary to explain how the matter, capable by accumulation of producing an attack, should have been dormant up to the time of the seizure, and why, latent thus long, it should suddenly show itself in the production of acute disease. These questions he confesses could not be answered at the time he wrote.

According to our view their solution is a very easy task, for we have shown that the mere accumulation of the urate is quite unequal to the production of inflammation, and that its actual deposition in tissue is essential, an occurrence which usually requires a peculiar exciting cause; and hence in many cases there may be no well marked symptoms to give warning of the approach of a fit, and hence also the poison may lie dormant for a considerable time; but when crystallisation of the salt takes place in any tissue, inflammation is suddenly lit up by its presence and a paroxysm of gout ensues.

Questions in the history of gout of much greater difficulty to solve, are the following:—

Why does gouty inflammation in its earlier attacks peculiarly select the ball of the great toe? and why, in the subsequent progress of the malady, are the affected joints more numerous?

To answer the first of these questions has been the attempt of many physicians; Sydenham says "the feet are the genuine seat of the peccant matter, which may without doubt fix itself on other parts; but in that case it is plain that either the progress of the distemper is inverted, or the patient's strength, from repeated attacks, is gradually impaired."

Boerhaave has an aphorism to this effect, that the part which gout first and regularly attacks is always the foot, and chiefly those tissues which the fluids have most difficulty in passing through, as the periosteum, tendons, nerves, membranes, and ligaments, and such as are most remote from the heart, and most pressed upon and injured. His commentator, Van Swieten, adds, that considering the difficulty with which the liquids pass through these parts, it is not very difficult to understand why gout is generally observed to commence in them, as they suffer great pressure from having to sustain the weight of the whole body, and being far removed from the heart are subjected to the action of cold and moisture, and the blood brought to them by the arteries, when returning through the veins, has the force of gravitation to overcome. The feet are also peculiarly liable to be hurt in walking, leaping, sudden falls, and accidents.

I believe there is much truth in these remarks of Boerhaave and Van Swieten, although the state of pathology at that period did not allow them to advance further in explanation of the subject.

There are many circumstances which cause the great toe to be selected for the first deposition of gouty matter; it contains, for example, in abundance, the tissues particularly prone to be affected, namely, those either of little vascularity, or nourished altogether independent of blood-vessels; it is likewise very remote from the heart, and in it the force of the circulation is at its minimum; in addition to this, the metatarso-phalangeal joint is one which is liable to

TABLE 1.

Case	*Sex*	*Age*	*Condition of Metatarso-phalangeal joint of great toe*
1.	Female	67	Right, healthy. Left, slight ulceration in cartilage of cup with a small yellow spot (fat).
2.	Female	53	Right, faint ulceration in cartilage of cup. Left, fainter.
3.	Female	62	Right, trace of ulceration in cartilage of cup. Left, scarcely a trace.
4.	Female	64	Right, faint ulceration. Left, faint ulceration.
5.	Female	24	Right, healthy. Left, healthy.
6.	Female	61	Right, very slight ulceration of cartilage of cup. Left, one quarter of articular surfaces denuded completely of cartilage.
7.	Female	64	Right, healthy. Left, small but deep denudation of cartilages of cup.
8.	Male	33	Right, faint ulceration of cartilage of cup. Left, healthy.
9.	Male	46	Right, some ulceration of cartilage of cup. Left, ulceration more marked.
10.	Male	48	Right, healthy. Left, healthy.
11.	Male	29	Right, healthy. Left, healthy.
12.	Male	54	Right, cup and head ulcerated to the same extent. Left, the same.
13.	Male	38	Right, healthy. Left, healthy.
14.	Male	42	Right, small spot of ulceration at outer edge of cup. Left, commencing ulceration.
15.	Male	52	Right, oval ulceration in cartilage of cup, and small ulceration of head of bone opposite that in cup. Left, slight ulceration in cup.
16.	Male	34	Right, very faint ulceration of cartilage of cup. Left, slight ulceration of cartilage of cup.
17.	Male	47	Right, extensive and well marked ulceration of cup. Left, slight ulceration of cartilage of cup.
18.	Male	31	Right, very faint ulceration of cartilage of cup. Left, slight ulceration in cartilage.
19.	Male	26	Right, healthy. Left, healthy.
20.	Male	34	Right, healthy. Left, healthy.

injury from having to support the weight of the body, and from being subjected to sudden shocks, as from false steps.

In connection with this point I may mention that in the examination of this joint in many individuals who have never experienced symptoms of gout, I have commonly found distinct evidence of injury on the surface of the cartilage, both of the head of the metatarsal bone and of the cup-like

cavity of the phalanx, when these appearances were not present either in the corresponding joints of the other toes, or in any of the phalangeal articulations.

Many years since I endeavoured to obtain definite results on this point, by observing the condition of the great toe joints in twenty post-mortem examinations of subjects known not to have had gout; in six cases only were both joints found absolutely healthy; one toe was healthy in three cases; but in the remaining eleven cases both toes were affected with ulceration of the cartilage to a greater or less extent. The following tabular arrangement shows the principal points of interest [Table 1].

Lastly, we know that certain poisons are, as it were, attracted to particular parts, and the external phenomena displayed by their action are usually symmetrical. This is exemplified in many cutaneous affections. The same power of selection is shown in the action of many drugs; thus digitalis acts on the heart, opium on the cerebrum, and strychnia on the spinal cord.

With regard to the second question, why numerous joints are implicated in advanced gout, the following appears to be the probable explanation. When the disease becomes engrafted into the system, the amount of urate soda in the blood is augmented, and requires more surfaces upon which to deposit itself, and hence other joints in addition to the great toe are selected; moreover, the cartilages and ligaments of the joints first attacked after a time become completely incrusted, so much so indeed that the ball of the great toe is in many cases anchylosed, and converted into a solid case of urate of soda, and no further deposit can take place in it.

It is interesting to observe the regularity with which, under ordinary circumstances, the joints are implicated. First the great toes, then the heels, and ankles, afterwards the knees, the smaller articulations of the hands, the elbows, and lastly the shoulders and hips. There are it is true many exceptions to such a sequence, but these can usually be accounted for by the occurrence of blows, sprains, or other injuries. It will be observed that this order has a close relation to the conditions which favour the deposition of the urate of soda; for example the heels and ankles are much exposed to pressure, and are also remote from the heart; the knees are likewise under somewhat similar circumstances; the hips and shoulders, the least frequently affected, are the joints in which the circulation is most active, as they are near the large arterial trunks and the obstacles to the return of venous blood from them are slight; they are also protected by thick coverings of muscular tissue.

When deposits are formed in the more external parts of the body, those are commonly selected in which the circulation is sluggish; thus we have found the helix of the ear to be a favourite point, and probably this organ is colder than any other portion of the frame. I have before mentioned that in my experience, when patients have had chalk-stones about the joints and not in the ears, these latter were warmer than usual: I only remember to have seen them twice in the ears of women. May not this arise from their being generally kept warm by some covering?

It is not difficult to explain the sudden shifting of gout from one joint to another if we bear in mind the fact that deposition *precedes* inflammation. Let us suppose that deposition has taken place simultaneously in each great toe, the patient probably feels at first a little pain in both toes, and is doubtful which will prove the worse, when suddenly the one becomes intensely inflamed and the other gets rapidly well. The explanation is simple, as development of inflammation in one part, acting on the principle of derivation, relieves the other

but only for a time, for as soon as the first joint has become better, the other almost invariably takes on action. In advanced gout it is very common for deposition to take place in numerous parts at the same time, and this is the reason why one joint after another becomes inflamed when the patient in other respects is daily improving; for it seems essential that inflammation should ensue before any part in which urate of soda has been infiltrated is capable of remaining in a quiescent state.

The next question which naturally arises in the course of our inquiry is, Why do deposits of urate of soda so constantly take place in ligaments and cartilages, or other closely allied tissues? One reason may be that these structures possess but little vascularity, and the deposit is at once placed beyond the further influence of the bloodvessels, but, in addition to this, it is probable that the fluids of these tissues are less alkaline than those of many others, and certainly less alkaline than the blood itself. Sometimes, in old gouty cases, only a few hours after death, the reaction of the synovial fluid in the joints becomes distinctly acid, but that this is not constant will be seen in the accounts of several of the dissections in Chapter VI. These two circumstances, the slight vascularity of the tissues and the diminished alkalinity of the fluids, probably explain why such parts are more frequently attacked than others.

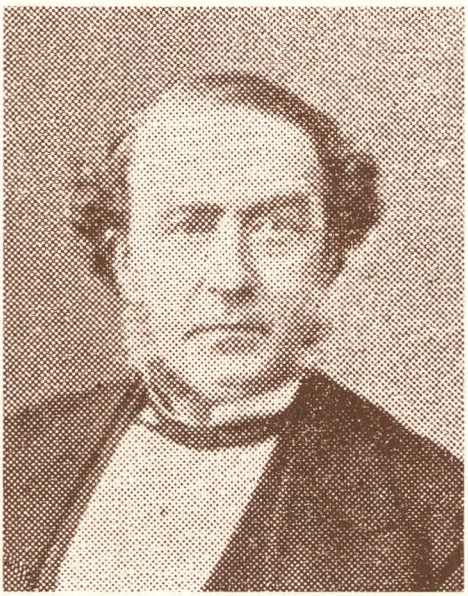
Why are females comparatively exempt from gout, at least in its more regular manifestations, and why does the disease so seldom attack young people? These questions can be readily answered. Women, although liable to the influence of hereditary predisposition, are to a great extent free from the action of many of those extraneous causes which both induce and excite gout, more especially excesses in wine and malt liquors; in addition to which they partly owe their immunity to the occurrence of the catamenial discharge during many years of adult life, which constantly tends to rid the system of superfluous blood without engendering debility. It is after the cessation of this function, or when it has become arrested by accidental causes, that gout is most apt to develop itself, and the aphorism of Hippocrates already referred to is practically correct. During youth, when the growth of the body is rapidly advancing, and excess of nourishment is required to build up the frame, and while the secreting functions are in full activity, there is little tendency to engender such a state of blood as would lead to the development of gout, and youth moreover is often exempt from many of the predisposing causes of gout.

It would thus appear that hereditary tendency alone is often inadequate to cause the full development of gout, and there are many examples on record of men who, though strongly inheriting the disorder, yet pass through life without a single attack; but in them, as well as in women, it is common to find strong evidence of their constitutional tendency in the manifestation of many symptoms of the masked forms of the disease; the same is occasionally witnessed in young people.

Lastly, it may be asked, Why does gout almost invariably recur, and why does it in the earlier attacks exhibit signs of periodicity in its return?

These phenomena are explained by the fact that in gouty subjects an impure state of the blood is generally present, arising either from an increased formation of uric acid in the system, or from its defective elimination; when, therefore, any exciting cause is more than usually active, a fit is at once induced; in the early stages this usually happens in spring or in autumn, when the circulating and secreting organs are peculiarly prone to sudden derangements, but after a time the seizures become more frequent, and are brought on by the opera-

tion of the slightest irregularities, because the causes both of the increased formation and of the defective elimination of uric acid are generally not only unremoved but even increased. Now and then only a single fit occurs during life, but such cases are quite exceptional. In individuals not hereditarily predisposed to gout, great care in diet and regimen and a completely altered course of life, will sometimes prevent a further recurrence, even after several attacks have been experienced.



SIR ALFRED BARING GARROD

Sir Alfred Baring Garrod (1819–1907), of London, was an eminent physician. Most of his professional life was devoted to the study of gout. His first book in 1859 established his interest in the field, but his views were established in the more readable third edition of 1876 from which this extract was taken (Chapter 9). Gout was known to the ancients and to physicians in all subsequent centuries. Garrod reviews the history of the great writings quite comprehensibly in the first chapter of this book. It was with the publications of this classic volume that the modern concept of gout began. It was Sir Alfred's son, Sir Archibald Edward Garrod (1857–1936), who later started modern rheumatology theories with his division of the arthritic syndrome into rheumatoid arthritis and osteoarthritis.

CLASSIC 48

Metal Hip Joint

A Case Report

AUSTIN T. MOORE (1899–1963)

HAROLD RAY BOHLMAN (1893–)

A report of the following case seems justifiable because of its unusualness. After searching the literature, no report of a similar case can be found. The patient was observed over a period of eight years, and during this time several operations were performed, the last one being the most interesting.

The patient, a negro male, aged 46 years, and weighing approximately 250 pounds, was first seen in September 1934. He had non-union of a fracture of the neck of the right femur. The fracture had occurred 15 months previously. He suffered severe pain and walked with difficulty by using crutches. Instead of doing a reconstruction operation, or a bone-grafting operation, it was decided to try to secure union by nailing the fragments together and drilling holes up through the neck and into the head to allow revascularization of the head and the fracture line. The operation was performed, and 3 Moore, adjustable, stainless-steel nails were inserted. Four days after the operation this large man got up and walked about the ward without permission. He was proud of the fact that he could walk. He wanted to "show-off." He was cautioned against weight-bearing and overuse of his hip, for it was feared that the fragments would not reunite, but he continued to bear some weight on the injured hip from this time on. The fragments were held well together with the nails, and in spite of weight-bearing solid bony union did result, with no pain and with good function of the hip joint.

In February 1936, he began to complain of some pain in the hip. On examination a large cyst was discovered in the upper end of the femur in the region of the greater trochanter. On reviewing the original roentgenograms it could now be determined that a small cyst had been present at the time of his injury. This cyst, which had escaped detection previously, had increased in size. Operation was performed, the cyst was curetted, and the cavity was filled with bone chips. Microscopic section revealed the

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This case was presented to the Columbia Medical Society of Richland County, South Carolina, December 14, 1942, and has been reported in *The Recorder* of the Columbia Medical Society, VI, 12, December 1942. It is contrary to the policy of *The Journal* to reprint material, but, since this publication is not available to many of the readers of *The Journal*, an exception has been made in this case.

(Reprinted here from: Moore, A. T., and Bohlman H. R.: Metal hip joint. A case report, J. Bone Joint Surg. 25:688, 1943.)

pathology to be a giant-cell tumor. Deep roentgenotherapy was administered, and the maximum dosage was given over a considerable period of time. At the time of this operation, even though a large cystic area was present in the trochanter, it was found that there was solid bony union of the previous fracture through the neck of the femur. The nails were no longer necessary, and so were removed. Improvement occurred following the curetting operation and deep roentgenotherapy, pain was relieved, and the patient got about with more or less normal function of the hip joint. (The authors have motion pictures to demonstrate his condition at that time.)

Approximately 2 years later there was a recurrence of pain, and roentgenograms showed further enlargement of the cystic area. Again roentgenotherapy was instituted, and the cyst was curetted. Hemorrhage during the operation was profuse and almost uncontrollable. It was feared that the patient might expire on the table. A large bone-grafting operation was performed by removing approximately ten inches of the upper end of the right fibula and grafting this across the upper end of the femur and down into the shaft. In addition, numerous bone chips were removed, and the cavity of the cyst was packed with these chips. An uneventful convalescence followed, and soon the patient was up and about, using his hip well, and with no complaint of pain.

Approximately two years later the cystic degeneration returned, and a pathological fracture occurred. Roentgenotherapy was again administered, and the fracture was treated by bed rest and skin traction. Union in good position was obtained, and there appeared to be some healing of the tumor region. Later, the tumor again began to increase in size, and on re-examination in September 1940 a large cystic mass approximately the size of a grapefruit was found in the upper end of the femur. The cortex of the bone was very thin, and it was realized that another pathologic fracture would soon occur.

By this time, every conservative means of treatment had been exhausted, and the tumor continued to enlarge in spite of every effort to control and eliminate its growth. The question then arose as to whether the limb should be amputated at the hip joint, or whether no treatment should be offered. In the latter event, the patient would have to resign himself to pathologic fracture and very likely malignant degeneration of the tumor, with metastasis and death. Amputation at the hip joint would be a very serious undertaking in so large a patient.

In an effort to do something for him, it was decided to resect the entire tumor region and to replace this portion of the bone with a metal appliance made in the form of the natural bone, and having in it various loops through which the various muscles and tendons could be attached, so that some reasonable postoperative function of the hip might be expected. Apparently no one had ever had the opportunity previously to replace such an extensive amount of bone as this case demanded. Calculations were made from roentgenograms of the bone, wax models were fashioned and from these models a mold was made, and a vitallium model of the upper end of the femur was finally produced. The appliance was about twelve inches long. It had a smooth, rounded head to fit into the acetabulum, and there were loops for muscle attachments to the upper end. The lower end of the appliance was fashioned so that it could be slipped over and be bolted to the lower fragment of the femur. One of the authors (H. R. B.) had for some time been interested in metal replacements, and had replaced the head of the femur with vitallium. He supervised the construction of the model.

Operation was performed under spinal anaesthesia on September 28, 1940. It was

realized that the shock of operation would be severe, and for that reason blood was prepared and administered prior to, during, and after the operation. A long lateral incision was made from the crest of the ilium to just above the knee. The femur was divided in half with a Gigli saw, and the upper portion, including the tumor, was removed by subperiosteal dissection. Great, large blood vessels and blood sinuses, some as large as the little finger, were encountered. Hemorrhage at times was profuse, almost uncontrollable. Many large packs were used. The dissection was continued up underneath the periosteum, the capsule of the hip joint was dissected free, and finally the head was removed from its socket by division of the ligamentum teres. When an attempt was made to fasten the vitallium appliance to the lower end of the femur, it was found that it was too small and would not slip over the bone. The bone had to be reduced in size, and the outer cortex was chiseled away. It developed that this was a serious mistake. Following removal of the hard cortical bone, there was little remaining strength in the soft more cancellous portion, and after the appliance had been slipped over the end of the bone and bolted into place, it was realized that the bone very likely would break as a result of the strong muscle pull. The head of the appliance fitted well into the acetabulum. Passive motion of the hip could be carried out in almost a normal manner. The capsule of the hip joint which had been dissected away was sutured, the muscles and tendon attachments about the trochanteric region were fastened to the appliance by suturing their ends through the metal loops provided. The deep fascia was closed, helping to hold the appliance securely in place, and the soft tissue of the wound was closed in layers without drainage. The limb was suspended in balanced traction in a hinged Thomas splint. The postoperative convalescence was somewhat stormy, but very satisfactory.

A few days after the operation it was found that in moving this large muscular limb, the bone had fractured as expected. With this sequestrum of bone separated and lying within the appliance where it could not be nourished by normal blood supply, there developed liquefaction necrosis, and a large amount of fluid accumulated in the deep tissues. It was feared that the entire area would break down with infection, and that the project would fail.

Six weeks following implantation of the appliance, another operation was performed. At this time the necrotic sequestrum of bones was removed. It was most interesting to observe that the soft tissues had adhered to the vitallium appliance so firmly that the periosteum had to be elevated in almost the same fashion that normal periosteum is stripped from normal bone. Following this observation, the authors were encouraged, and hoped that complete healing would take place, and that the appliance would be embedded in a normal bone involucrum. By means of skeletal traction the limb was held in suspension, and the lower fragment of the bone was kept in end-to-end apposition with the vitallium appliance. Healing progressed, and check-up roentgenograms revealed increasing bony union. Five months after the operation, union was solid, and the patient was allowed to be up and about on crutches, using a long thigh brace with pelvic band and large lacer cuff about the thigh to support the site of the fracture. Very soon, he was bearing full weight on the limb, and there was remarkable freedom from pain. There was voluntary active motion of the hip joint, of approximately 75 per cent of normal. Within 9 months following operation, he walked well without support, and only used a cane for long distances. One year following operation, he not only walked well, but picked up a grown man weighing

215 pounds, and walked about with him. Roentgenograms at this time showed a great mass of new-bone formation, extending from the intertrochanteric region of the femur at the capsular attachment downward, enveloping the vitallium appliance, and solidly uniting it to the lower femoral fragment. The patient continued to improve, and walked well without complaint. Moving pictures made 15 months after operation reveal an excellent functional result.

Approximately a year and a half following operation, he began to show clinical evidence of cardiac decompensation. There was some swelling of both hands and feet. An acute cardiac attack developed and he was treated in the hospital over a period of 3 weeks for cardiac failure. He returned to his home and was getting about well when, on June 2, 1942, while sitting on the side of his bed, he toppled forward and expired. Notice was received of his death, and consent for autopsy was obtained.

At autopsy, the entire femur and half of the pelvis were removed. A new hip joint with an almost normal appearing capsule and synovial lining were found. The bone specimen was preserved by boiling the bone in soapy water, and drying it in the sun. This specimen shows the extensive involucrum about the vitallium appliance. There was no evidence of recurrence of the giant-cell tumor. The vitallium appeared unaffected by its period of service in the body. It was just as bright and shiny as the day it was inserted and at no point on it was there any evidence of corrosion.

This patient was observed and treated over a period of approximately 8 years. An ununited fracture, 15 months' duration, of the femoral neck was cured by drilling and nailing with Moore nails. A giant-cell tumor was treated by roentgenotherapy, curettage, and massive bone graft. After six years, when tumor growth could no longer be controlled and pathological fracture had occurred, the upper ½ of the femur was resected and replaced successfully with vitallium.



AUSTIN T. MOORE

Austin T. Moore (1899–1963), and Harold Ray Bohlman (1893–) published an original case report in the Recorder of the Columbia Medical Society in South Carolina in 1942, and in the Journal of Bone and Joint Surgery a year later. This was the first known report on metallic hip replacement in a patient.

CLASSIC 49 The Intravital Method of Examining the Bone Marrow

M. I. ARINKIN

The composition of the peripheral blood, the quantity of the erythrocytes, the leucocytes and the blood platelets, and the morphology of these elements, give exact proof of the functional ability of the bone marrow and other blood-creating organs. When we have the corresponding sizes at hand we will be able to make a judgment as to the condition—the norm, the hyperplasia or the aplasia—of the total hematopoietic system, particularly the bone marrow.

The combination of the anamnestic statements, the results of the objective examination together with the careful study of the peripheral blood's morphology enables us to make very exact diagnoses of blood diseases, the affections of the blood-creating organs, and exactly to prognosticate the pathological findings in the organs. It presents no difficulty at present to discern a pernicious anemia, leukemia, secondary anemia, thrombocytopenia, aleukia, the real polycythemia etc., but such is the situation in cases where characteristic symptoms exist for the pathological process in question. Unfortunately, this is not always the case. Comparatively often we are in the position to be doubtful at the bedside of even atypically ill persons with disturbed functional ability of the blood-creating organs. In such cases neither the objective results nor the morphology of the blood is of assistance to the clinician. The question of the diagnosis, and consequently of the therapy, in such a case remains open; further examinations are needed that will give us the possibility to make a correct diagnosis of the illness and in this way begin a rational treatment. In the cases where the disease of the blood is accompanied by an enlargement of the lymphatic glands, a biopsy of the removed glands or sometimes their puncture will permit an exact diagnosis. In cases accompanied by the enlargement of the spleen some clinicians consider it possible for the purposes of diagnosis to make a puncture of this organ. However, many physicians consider that such an incision is an operation that is not without risk, inasmuch as it can be complicated through a profuse bleeding, especially in cases where there is a clearly-evidenced fibrosis of the organ and when due to this condition the contractility of the organ is considerably weakened, and therefore after the puncture the wound cannot close, even if a latent kind of hemorrhagic diathesis exists.

Taking this into consideration with regard to puncture of the spleen for the purpose of diagnosis, we must, naturally, disregard this incision even if it is very valuable for a diagnosis. It is easy to understand that the thoughts of the pathologists (Ghedini, Spiler and Schittenhelm, quoted after Seiffart[1]) turned to the bone marrow—the principal

center of the hematopoiesis—as the merit of Seiffart is in the suggestion of a more simple method for examination of the bone marrow. After previous anesthesia with Novocain-Adrenalin a 5 cm-long skin incision is made. The exterior lamella of the sternum is opened with a special trepan at the height of the third or fourth rib, and then with a sharp spoon the bone marrow is scooped out for examination and in cuts, with previous fixation in formol, taken from a Zenker or Helly mixture. The first samples of the bone marrow are taken with the platelet for the bacteriological examination. This method, however, has not been adapted in the clinic; many consider it a rather serious incision which, the same as every surgical operation, is exposed to the possibility of infection of the open wound.

Meanwhile, one might suppose that the examination of the bone marrow alone will not provide the possibility to find one's way in atypical cases of disease of the blood-creating organs, but that also in proportion to the gathering of the corresponding material, the researcher will discover facts that will enable him to clarify exactly the pathogenesis of the disease and establish the etiology which is unknown for the majority of diseases of the hematopoietic system, and therefore a rational treatment does not exist. Furthermore, the examination of the bone marrow must also open wide perspectives for experimental examinations of animals; everything now depends upon the method. It must really be a simple one, not require special instruments, not require considerable wounds in the skin and the bones, and therefore be without risk completely. It must also make it possible to examine the removed material histologically.

The above mentioned demands, in my opinion, give satisfaction to the method suggested by me, which first was tried on a corpse and which throughout gave satisfactory results on microscopic examination of the smears of the bone marrow. In every regard these samples corresponded to the biological picture in cuts of the organ obtained through trepanation of the sternum and first fixated, then embedded in paraffin.

The method consists of the following: making a puncture in the manibrium sterni with a needle having a point cut off in a blunt angle, with a diameter of 1–1½ mm which ordinarily is used for lumbar puncture, and definitely using a piercer which exactly fits a record syringe, observing all aseptic and antiseptic rules after local anesthesia of the skin and the subcutaneous tissue as well as the periosteum. After a relatively heavy pressure one gets a clear sensation of the cut in the front sternal wall, and then the needle hits the rear wall. This feeling of resistance is the actual indication that the point of the needle has reached the spongioid part of the breastbone. The piercer is now taken out, the needle is placed in a record syringe, and by means of moving the butt end upwards a sufficient quantity of the bone marrow is then sucked into the syringe. In this way it is possible to extract up to 10 ccm of the substance. The less of the sternal contents that is sucked into the syringe, the more marrow elements it will contain. The first drops are used for the sowing, and from the remaining segments (smears) are made which then are colored in accordance with the Leishman or Giemsa method.

On basis of the careful anatomic topographic examination of the sternum which has been made by university professor M. S. Lissitzyn, it is necessary to differentiate between two basic types of breastbones: sternum with a wide manubrium and sternum with a narrow manubrium. In the first case the compact lamellae are centrally located close to each other and are separated from each other by a thin layer of the spongioid tissue. In this case it is preferable not to make the puncture on the median line but on the side of it (0.5–1.0 cm). With a

narrow sternum, which usually is characteristic for asthenics, the puncture is made in the center, as in this kind of breastbones the spongioid substance is evenly distributed in the manubria.

In exceptional cases the sternal manubrium almost completely lacks the spongioid tissue. In such cases it is not possible to extract the sternal contents, and on such patients it is recommended to make the puncture in the corpus sterni where the spongioid tissue is well developed.

Now and then the compact substance is so strongly developed that it is impossible to prick through it with the needle. Naturally, in these cases it is necessary to resort to trepanation of the sternum in order to extract bone marrow.

It is interesting to note that the osteosclerotic process has no connection at all with the age of the person being examined.

Fortunately, the kinds of breastbones that cannot be pricked through with a needle, are rather rare (2 out of 180 cases). In most patients it is possible to prick through the sternum with a good lumbar needle and to extract the contents.

In one case, in spite of the successful puncture with the needle, it was not possible to extract the contents. In this case (acute leukemia) the bone marrow was composed of a tough substance poor in blood, and for this reason it was not possible to suck it out with a syringe. In such instances I recommend to make the puncture with a hollow needle, the lumen of which retains a piece of bone. Through smearing this piece of bone on the glass slab it is possible to achieve a very good sample.

Only in three cases out of 180 did this method not give the desired results.

The fixated preparations of the sternum punctates give a very clear picture. To a degree they show the elements characteristic of the parenchyma and the stroma of the bone marrow with preponderance of one or the other, with corresponding pathologic histologic changes in dependence upon the process existing in the patient. Now and then groups of cells are found with the same distribution as one observes on histological cuts of the bone marrow. In most cases, however, it refers to isolated elements of the organ which, of course, considerably diminishes the advantages of the method. In order to correct the mentioned deficiency it is necessary to have a thorough knowledge of the conditions that normally prevail between various elements of the bone marrow. At present this gap has been partly filled thanks to the examinations of the bone marrow in patients who show a normal composition of the peripheral blood without perceptible anatomical and functional changes on part of the inner organs.

On these patients the sternum punctate has given the following figures for the various elements. I give the maximum and minimum sizes achieved by Dr. Moiseioff when working with my material on variation statistics:

Using the method of variation statistics no success was achieved with the eosinophil polymorphonuclear elements when trying to calculate the maximum and minimum. That is why I make the statements about tests not based on this method. The calculation of the absolute sizes of the form elements in question that belong to the punctate, probably are not of importance because, as my observations have shown, on the one and same patient with the one and same number of white elements a different composition of same, and vice versa, is possible. The total amount of white blood corpuscles of the punctate as a rule is larger than the total amount obtained from the peripheral blood.

Some diseases give a very characteristic picture. When cutting the individual cell elements of the bone marrow, a forcible increase may be observed in the myeloblast (24.5%), the promyelocytes (8.8%) and the myelocytes, especially the basophilic

(8.3%). In all normal cases the latter elements were encountered only in tenths of percentages; furthermore, a considerable decrease in the erythroblast can be noticed. In ten cases of essential pernicious anemia the number of erythroblasts—as well new as mature ones—forcibly enlarged (19% + 24%); on the other hand the number of the mature neutrophile polynuclear was considerably lower; the cells of the stroma of the reticulo-endothelial system were through and through filled with pigment. In cases of aleukia a considerable reduction in all elements of the myeloid tissue exists, with percentage preponderance of the lymphoid elements, the cells of the stroma and the fat, which in most cases of other diseases were found only in the form of tiny droplets. Acute cases of reticulo-endotheliosis or the monocytic leukemia make a very interesting picture, where the number of cells of the reticulo-endothelial system was enlarged up to 89.2%.

The increase in stroma cells in cases of chronic hypoleukie with splenomegalia occurred to a lesser degree, yet was quite considerable (up to 27%). Further, in these patients an important reduction in the mature neutrophile polynuclears was established. Still more interesting results were achieved when examining the bone marrow of a patient suffering chills from paroxysmal hemoglobinuria with a positive test of Donath-Leind-Steiner. Here too a considerable increase (14.6%) was observed of the stroma cells in the punctate with monocytes in the peripheral blood (15%) which led me to voice the opinion, that the hemolytic autoambocepter was produced by the cells of the reticulo-entothelial system which is present in the total pathological process, at least in the bone marrow in the condition of hyperplasia.

In six cases of intermittent thrombocytopenia forcible degenerative changes in the megakaryocytes were found, which already had been described by Frank, and on the basis of which he had the possibility to differentiate the aleukia from the thrombopenia.

No important deviations from the normal were found in cases of capillary toxicosis in the megakaryocitic system.

I permit myself to take the liberty, on the basis of 180 cases, to assure that the method is completely without danger. We had no unpleasant complications whatsoever in any of the cases: some patients did complain about pains in the sternum and in the ribs, especially when 5–10 cm^3 of the substance was extracted, but these painful sensations disappeared fairly soon. In these cases it was possible, in the peripheral blood to observe symptoms of the irritation of the parenchymae in the bone marrow, i.e., we found erythroblasts in them and a considerable number of enlarged reticulocytes; sometimes the one or the other element contained myelocytes. This irritation reaction was evident only during the first 24 hours. However, in most cases the mentioned reaction did not take place, or it was so weak that it could not be measured.

It is important to notice that in the cases of subacute verrucose endocarditis in the sowing of the punctate we found diplococcus, streptococcus and other bacteria; one patient passed away and at the post mortem examination, on the spot where four days before death a puncture had been made, a hemorrhage the size of a poppy corn was found in the periosteum, while in the entire bone no changes at all could be noticed. In one case of acute lymphatic leukemia, which was complicated due to the appearance of hemorrhagic diathesis, after puncture of the sternum a considerable hemorrhage was noticed as well in the skin as in the periosteum; however, in the spongioid tissue of the manubrium sterni there was no bleeding at all.

In cases of chronic malaria with no parasites in the blood, even after the adrenalin

provocation, on preparations from the bone marrow of such patients plasmodia and pigment were established.

While taking the safety of the method into consideration I believe it is possible always to use it in those cases where the peripheral blood and the other objective statements do not make it possible for us to find our way in the present pathological process. The morphology of the blood-creating elements enabled us, in most cases, to foresee the pathological conditions of the bone marrow. This was, for instance, the case with the paroxysmal hemoglobinuria. However, in some cases, as for example with intermittent thrombocytopenia, which was complicated through continuous menstrual bleeding, the morphology of the blood gave a real atypical picture. The diagnosis fluctuated between thrombopenia and aleukia; meanwhile the examination of the bone marrow showed considerable changes in the megakaryocytes and the diagnosis could easily be made.

Furthermore I wish to mention, that the breastbone puncture not only is completely without risk but perhaps also in some pathological processes may be useful due to the above mentioned reaction of the bone marrow to this intervention. Thus in one case of a helminthic anemia continuing its torpid course even after elimination of the ascarides, the extraction of a small amount of bone marrow gave the impulse to increased activity as well of the erythroals as of the leukoplastic tissue. That is exactly the same as what we observed in a few cases of thrombocytopenia: the appearance of hemorrhagic diathesis abated, the quantity of thrombocytes and erythocytes started to increase rapidly.

Of course the surprising effect that was achieved in the above mentioned cases can not be attributed exclusively to the partial removal of the spinal marrow and that is why I believe that the puncture of the breastbone *perhaps even was useful*, as in all cases also other therapeutic means were applied: for instance with regard to thrombocytopenia daily we gave a solution of 10% calcium chloride in the 10 cm^3 dose, and for anemia with a torpid course, iron and arsenic was also administered. It is evident that these remedies exercised a beneficient effect and that the partial removal of the bone marrow was only an impulse expressing the intensified activity of the organs in question. The reserve powers of the bone marrow had already been mobilized, the prerequisite already existed and only a signal was needed to bring these powers into action. The breastbone puncture was such a signal as well as the partial removal of the bone marrow, which in these cases may be considered a "dismarrowing" operation which had been used earlier in the treatment of pernicious anemia but without success, probably due to the fact that while the bone marrow of the tubal bones was removed it differs considerably from the breastbone marrow.

The histological examination of the bone marrow in the above mentioned cases of anemia taking a torpid course evidently confirms the assumptions made. It was established that these patients had a relative large quantity of the myeloblasts, of the promyelocytes, of the myelocytes and a sufficient quantity of the proerythroblasts as well as erythroblasts. The microscopy showed the complete sufficiency of the bone marrow, at the same time as it was in a slumbering condition. Through the breastbone puncture we took it out of this condition and induced it to expand its activity.

The material at present in my hands is of interest not only from the standpoint of clearing up various pathological processes but also from the standpoint of biological clarification of the conditions between the elements of the peripheral blood and the bone marrow elements, especially between the monocytes and the cells of the bone marrow stroma.

The work continues. In my opinion the breastbone puncture merits very much attention and can without risk be used on patients.

It is important to refer to the fact that in some cases of disease over a period of 1–2 days the breastbone puncture was used 3 or 4 times without noticeable damage.

Consequently the method suggested by me permits the use of the morphologic composition of the breastbone puncture in various periods of the pathological process in question, inasmuch as the use of my method requires no cut in the skin and the puncture of the breastbone is completely without danger.

I have dwelled on a few facts only. The range of the article prevents me from presenting a more detailed description of the very interesting material that I have.



M. J. ARINKIN

Arinkin, a Russian, in 1927 introduced sternal puncture as a diagnostic procedure while working at the Military Medical Clinic in Leningrad. One of its more important applications is in the study of metastatic bone disease. This paper appeared first in the Russian language journal, Vestn. Khir. (30: 57, 1927), but was introduced into the general medical literature by its second presentation in the German periodical.

CLASSIC 50

Bemerkungen über chronische-ankylosierende Entzündung der Wirbelsäule und der Hüftergelenks

(Observations on Chronicankylosing Inflammation of the Vertebrae and Hip Joints)

A. STRUMPELL (1853–1925)

The foregoing article by Prof. Bechterew induced me to mention that I also have been familiar for a long time with this peculiarly characteristic form of joint disease, namely chronic arthritis limited to the spine and the hip joints which leads to stiffness and eventually absolute ankylosis of the affected joints.

Earlier as an assistant of the Medical Clinic at Leipzig I had the opportunity to observe such a patient for a long time, whom I still remember clearly because of his striking appearance and gait. I saw a similar case later at the Leipzig Policlinic and therefore was able to describe this particular form of chronic arthritis already in the first edition of my textbook (1884, Vol. 11,2 page 152) as follows: "as a peculiar and, as it seems to us, strange disease may be mentioned the illness which causes a complete ankylosis of the whole spine and the hip joints without pain, so that the head, trunk and thighs are tightly joined to each other and absolutely stiff, while the remaining joints retain their normal mobility. It is obvious that this causes a peculiar modification of the posture and the gait. We ourselves observed two similar cases of this curious disease."

Recently I observed the third case of this kind at the clinic here, however, the symptoms had not reached the extreme, as in the previous observations. For the purpose of drawing the attention of doctors more to this peculiar syndrome may I report here in short the history and also add a photo of the patient?

A.K., 39-year-old farmer from Firschbach. Patient states that he was in perfectly good health until about 3½ years ago. Then his present disease started without any known cause, very slowly with lumbar pain which however never was particularly violent nor continuous. For the past year the patient also suffered some light pain in the right hip joint which radiated into the right thigh and for a short time there was also corresponding pain in the left side. Occasionally the lumbar pain moved forward to the region of the stomach. Much more bothersome than the pain, however, was the continuously increasing "stiffness of the lower back." This caused walking and bending to become more and more difficult and slow. No particular Paraesthesias. No discomfort in the arms. General state of health quite normal.

There is no indication of a hereditary predisposition of the patient.

Status praesens: The patient is a tall, thin, but muscular man. The movements of the head, the cervical spine and the upper extremities are undisturbed. None of the joints of the arms and hands are noticeably abnormal. The upper part of the body of the patient is bent forward somewhat when standing and walking. The pelvis is also bent forward, so that the spinae ant. supp. and the pelvic bones jut forward very distinctly. The spine, with the exception of the cervical and upper thoracal

vertebrae, is absolutely stiff like a stick and remains that way, even when the patient is supposed to bend or make sideways movements of the trunk. Patient is able to walk alone but slowly, with rather small steps and always with the abnormally bent posture of the trunk. The back muscles along the spine appear atrophic and feel very tight and firm.

On the legs the strong tension of the muscles is striking. The patellar reflexes are very active, however the reflexes of the Achilles tendon cannot be evoked. Sensibility and skin reflexes are normal. In the right hip joint there is a constant moderate flexion contraction, while in the left hip joint only a minor contraction. The joints of the knees and feet are absolutely normal.

For the purpose of more thorough examination the patient was chloroformed heavily on July 24, 1897. Upon my request Prof. Graser was kind enough to examine the spine and the joints during the narcosis. It appeared then that the stiffness of the spine remained unchanged with completely relaxed muscles during narcosis. Also the movements in the right hip joint remained very limited in spite of the narcosis, and during rotation one could clearly feel crepitation. For therapeutical reasons in order to loosen the ankylosis as extensively as possible passive movements were applied.

Knee and foot joints absolutely normal. Internal organs, urine, also normal.

During the days after the narcosis the patient had a rather high temperature (39–40 C), probably as a consequence of the forced passive movements and also such severe ache in his back and hip joints, that he was not able to walk at all. However, after four days of complete rest improvement started which—with applied warm baths—has continued so far, that the patient was able to walk with much more ease than upon entering the clinic. On July 2 he was discharged upon his request.

Although the illness in this case was not yet as advanced as in the two previously observed patients, it obviously was also the same peculiar disease. In a slow way, without any noticeable cause, stiffness of the spine and the hip joints developed increasingly. Although anatomical findings in this connection have not yet been made as far as I know, it seems that the pathological process has its seat mainly in the joints of the vertebrae. The crepitation in the hip joints which most probably are diseased in the same way, justifies the assumption that there is a chronically inflamed nature of the existing changes. With it, however, no striking deformities nor exudations appeared, but the most characteristic seems to me the ankylosing of the joints which starts in the spine and develops later in the hip joints after a mild flexion contraction. The process develops without particularly severe pains.

Patient K stated that the illness started with pain in the lower back, but it was never very severe. I remember quite distinctly that my first patient who suffered from a complete ankylosis of the spine and the hip joints never complained about severe pain. The main disturbance is the deterioration of the mobility, the difficulty and slowing down of all the movements which are connected with the mobility of the hips and the spine. In fully-developed cases the patients can only stand or lie but not sit. The gait is very much changed on account of the peculiarly stiff, bent forward posture of the trunk, and the stiffness of the hip joints. My first patient walked, so to speak, only with the knee joints.

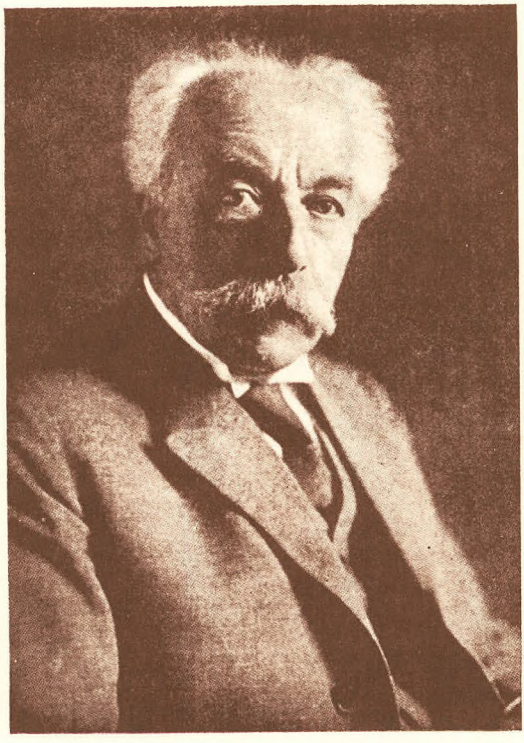
Whether the illness is etiologically related to the other forms of chronic arthritis, I am not able to say. In the common arthritis deformans the participation of the hip joints is a common occurrence, however, one sees the spine much less frequently affected. It is rather unusual with this form of chronic arthritis that primarily the spine and secondarily the hip joints are affected without the slightest participation of any other joint.

I am not able to decide whether my observations can be considered to be equal to those of Bechterew. In the cases of Bechterew the secondary participation of the spinal roots showed much clearer than in my patients. Also the affliction which Oppenheim (Lehrbuch der Nervenkrankheiten, p. 210) describes as "arthritisdeformans of the spine," does not quite conform with our observations inasmuch as it seems to regard here mostly a partial symptom of widespread arthritis deformans and pains as well as root symptoms are in the foreground of the picture. In the Bechterew cases the shape of the spine was kyphotic, whilst in my cases an abnormal straightness of the spine was in evidence.

It should also be stressed that my patients were in middle age and by no means in advanced years. In the so-called senile kyphosis there are frequently ankyloses of the spine;

however, these are obviously other circumstances than in my cases.

The foregoing short remarks do not claim to be an exhaustive treatment of the subject. I only meant, in connection with the Bechterew paper, to report in my own experiences, because I also am of the opinion that this peculiar disease merits the interest of physicians and in particular neurologists, because the curious disturbance of the patient's gait may in the beginning arouse the idea that this is a spinal disease. As an addition to the clinical observations, pathological-anatomical diagnoses would be most desirable. Besides the condition of the spine, that of the soft tissues next to the spine should be given particular attention; the long back muscles seemed to me strikingly atrophic and strangely rigid.



ADOLPH STRUMPELL

Ernest Adolph Gustav Gottfried Strümpell of Leipzig (1853–1925) published a 2-volume edition of the Lehrbuch der Speciellen Pathology and Therapie der inneren Krankheiten in 1883–84. He was among the leading internists and pathologists of his generation. The masterpiece went through more than 30 editions, translated into several languages, with the first in English appearing in 1887. The volumes are still valid references in pathology with a wealth of forgotten and rediscovered musculoskeletal material pertinent to contemporary studies. Rather than reprint the description from the original book,* which like all textbooks requires cross references in context, I have reprinted his classic paper of 1897. This more clearly delineates the spondylitic syndrome with which his name is eponymic.

CLASSIC 51 An Orthopaedic View of the Treatment of Fractures

SIR ROBERT JONES (1855–1933)

In an article on fractures written by an orthopedic surgeon, it is natural that the subject should be treated rather from the point of view that every fracture is potentially a deformity, and if it becomes a deformity will lead to impairment of function.

The object of treatment is the restoration of complete function with least risk and inconvenience to the patient and with least anxiety to the surgeon.

In attaining this object a clear idea is needed of the disabilities and deformities most likely to occur after fractures in each particular region, and also of the difficulties in treatment peculiar to each.

The smooth working of a limb depends on preserving the true axis of movement of the joints, so that the stresses of muscular action may act across the joint in normal lines. Otherwise, abnormal stresses will produce abnormal strains for we are dealing with living bone, in accordance with Wolff's law, which is the physiological equivalent of that universal law: Strain is proportional to stress.

In dealing with fractures of the shafts of long bones the first consideration therefore is to secure and maintain a true anatomical alignment of the bone, so that the axis of movement of the joints at the two ends of the bone may retain their correct relative positions. The best results are naturally obtained when the fragments at the seat of fracture are brought into correct reposition. Experience, however, has proved that meticulous exactness in replacing every fragment is not necessary to a perfectly good functional result.

In carrying out this principle of treatment every surgeon must frame for himself his own rules of procedure, being governed by his own experience of success with manipulative methods or with direct operative attack on the seat of fracture and applying splints immediately on the bone in the form of plates and screws. Those who have a large and varied experience of the manipulative treatment of deformity will probably have greater confidence in their ability to deal with deformities resulting from fractures by manipulation and external splinting. They will reserve direct operation for those cases in which they have found that their manipulative skill has not proved equal to retaining the limb in a correct position until union of the fragments has taken place.

In referring to particular fractures, the writer will therefore be drawing on his own experience with his own methods of securing that correct alignment which is the first object of every surgeon when called on to treat a fracture of a shaft of a long bone.

In this connection, it is not amiss to say that the virtue of a splint lies not so much

in its particular form, but in the way in which it is used. At the same time every workman carefully selects the tools he uses and has his favorites among them. In this respect the author is conscious that he has his favorite splints, but believes that for the purposes for which he uses them, and in the way in which he employs them, they are the most suitable, most efficient and most immediately available that he can find.

It is sometimes stated that the object of a splint is to keep the parts immovable. While this is true, it is desirable to remember that the first object is to maintain the alignment. For this purpose the traditional wooden board, still often used, is not the best and is often a trap for the unwary practitioner. No human limb will fit a flat board. If a limb is bandaged to a flat board firmly enough to make it immovable, the parts above and below the fracture may easily be put out of alignment. Of this, the treatment of fractures of the femur with the long Liston splint, has furnished many examples. A further objection is that a cylindrical limb only touches a flat splint along a line. Thus, if the bandaging be really firm there is a risk of undue pressure atrophy along this line. If thin metal is used (sheet iron of the same thickness as 24 wire gauge) this trouble is very largely overcome, and sheet iron can be got from the village smith as easily as a plank from the carpenter. Sheet iron of this thickness can easily be twisted or squeezed by hand to fit the varying curves of the limb, and yet being gutter-shaped, is quite rigid longitudinally. Further, having a curved cross-section and being slightly flexible, it distributes the pressure more evenly round the limb and not along a line. Hence the limb can be really firmly bandaged to the splint without fear of producing pressure sores. Of course in both instances the hollows in the limb must be suitably padded to avoid pressure on bony prominences, but in the case of thin metal splints this is much easier.

In dealing with fractures near joints or involving the articular ends of bones, difficulties of treatment are greater.

True alignment, especially of the axis of movement, is still of paramount importance, but there is also the difficulty that small fragments of displaced bone which would be of little importance in a fracture of the shaft, may here get in the way and effectively block movement by their mechanical obstruction.

The ends of long bones consist of cancellous bone containing red marrow. They are extremely vascular, and ready to undergo growth changes on very slight provocation, hence any conditions which maintain local irritation will tend to increase the amount of new bone formation with consequent obstruction of movement.

In purely traumatic cases these changes are known as traumatic osteoarthritis, but they arise chiefly from undue irritation by movement, occurring in the stages of repair. At this time, the area is more vascular than normal and the whole osseous structure of the part is therefore more susceptible to strains arising from stress of weight carrying. Examples of this will be found notably at the ankle and hip. Another factor is the stress of muscular action which, of course, is a factor in all cases, but in the upper limb it takes precedence of gravity.

This leads us to the consideration of the fact that muscles and tendons cross the joint and are often attached to the ends of the bone near the joint. They may be the surgeon's worst enemies or his best friends in the treatment of a fracture about or involving a joint, according to whether he uses them correctly or wrongly. As an illustration of this point no joint serves better than the elbow. At one time it was customary to attempt treatment of fractures about the condyles of the humerus, which are so common in children, on a right-angled internal splint. Frequently the result was a "gunstock" elbow with the lower end drawn backward, often also displaced outward by pres-

sure of the splint on the internal condyle, while the lower end of the upper fragment of the humerus projected forward, helping with its associated callus to produce a complete mechanical obstruction to flexion. Here, once the backward displacement of the lower fragment has begun, the triceps tendon will keep pulling the olecranon back and up. Any play means a see-saw struggle between the biceps and brachialis anticus and the triceps, with a continuous slight irritation of the part and a maximum formation of exudate and of osteogenetic formation in that exudate.

Now that these fractures are almost universally treated in the fully flexed position, the tendon of the triceps forms a comfortable, close-fitting posterior splint, any fragments in front are pushed out of the way and mechanical block to flexion cannot occur. The joint can be kept at complete rest without any play and therefore disturbing reflex contractions of the muscles do not occur, and fractures of this type have ceased to have terrors for the surgeon.

When absolute rest from movement is to be insisted on as a condition necessary for reducing the formation of obstructive callus to a minimum, some rule must be formulated to guide the surgeon when movement of the joint is again to be resumed. Here the old rule laid down by Owen Thomas can be taken as the first guide, namely, that a joint which is tender to palpation is not ready for movement. This tenderness means that excessive vascularity is still present in the bone, surrounding periosteum and tissues, and therefore that any attempt at movement will certainly injure the parts, producing fresh exudate and exciting increased formation of callus.

When this tenderness has entirely disappeared the joint may be moved through a small range of 5° or 10°. If this can be done without pain, a good prognosis may confidently be given. The patient may then be allowed to use the joint through a small range of movement, and if in two or three days the range of movement is increasing, then greater freedom may be permitted. If, however, the joint becomes stiffer and a little painful, then the time for movement has not yet come. A little later comes the time for passive movement. The indication for this is the belief that further movement is prevented by fibrous adhesions and shortening of ligaments. Passive movement should be done once in each direction in which movement is limited. It should not be followed by a reactionary swelling and stiffness which lasts for more than twenty-four hours. If the joint is stiffer twenty-four hours after a single movement it means that it is still not ready for movement, or the movement used has been too violent. To and fro passive movements are very likely to stir up a reaction of an inflammatory nature which leads to more effusion and more adhesions. In all such cases more time is lost by being in a hurry than by waiting a little longer than necessary before trying to restore motion.

So far we have said nothing of massage. At all stages of treatment we believe that massage is beneficial, provided it is of the lightest possible character and applied with skill without disturbing the fragments, or stimulating the young callus to fresh overgrowth. When in doubt on this point, it is certainly safer not to massage but to rely on absolute rest.

As we shall see when dealing with malunited fracture, young callus is very susceptible to irritation by shearing forces. Continued pain and tenderness is the great symptom indicating that the repair has not been allowed to become firmly consolidated before the stresses of muscular action or of gravity have been allowed to act on it thereby keeping up irritation.

NONUNION AND MALUNION

It is true that there are certain conditions of disease and constitution which retard the union of fractures. The age of the patient is certainly not a direct factor in the pro-

duction of nonunion, for the most perfect union may occur in the aged and feeble. Setting aside a few cases in which there is some actual condition of disease, experience shows that nearly all cases of "nonunion" are really cases of "delayed union."

This introduces the question of the time it takes for the fracture of any given bone to unite and consolidate. In textbooks of surgery definite periods are stated for each, but these are quite unreliable. The period necessary for the complete union and consolidation of a fracture varies in every individual and is a "personal equation" to which sufficient attention is not paid. Not only cases of nonunion, but as we shall see, cases of malunion are frequently due not to any fault in the method of setting or fixing the fracture but to the fact that in the individual patient union is slow, requiring twice or even three times the usual period.

Too often the practitioner is hasty in his judgments in this matter. The fracture he is treating shows no evidence of union at the time he expects it, instead of waiting for a week or two he proceeds to disturb the parts, rub the ends together and start afresh. Again at the appointed time there is "nonunion." When these cases are ultimately sent to consult the writer his usual practice is simply to begin again and wait. By this time there has been a great deal of fibrous repair, and osteogenetic repair has failed. The first thing, therefore, is to wake up the region of the fracture by rough handling to "freshen the ends" of the bone. In doing this, the procedure called "hammer and dam" by Owen Thomas is most effective. After hammering the whole region of the fracture with a padded or India-rubber mallet, a tight elastic band is applied both above and below the fracture at a distance of several inches. This allows the limb in this part to swell to much more than its normal girth, expanding all the capillaries and lymph paths in the fibrous tissue and allowing a new process of repair to start.

This method of passive congestion was employed by Owen Thomas fifty years ago long before passive congestion as a means of treatment had attained its present prominence.

The fracture is set in the usual way and repair is expected in a longer or shorter time. In those cases where the processes of osteogenetic repair are naturally slow nothing is gained by operation, for even after plating the repair process is a delayed one.

In some cases of complicated fracture in which tissue has intervened between the fragments, open operation may be called for, but in the writer's experience the majority of cases of "nonunion" are really unrecognized cases of "delayed union."

Malunion is a large and difficult subject, and while some generalizations can be made, the exceptions are numerous. First of all there is a type of malunion which is closely related to the question of delayed union. A patient with a Pott's fracture receives skillful treatment, the foot is kept well inverted, at the end of six weeks repair in good position is pronounced complete. For six weeks the patient goes gently and then recovering confidence takes more violent exercise. After that he begins to complain of pain about the ankle and appears to be getting flat-footed. When the surgeon runs his fingers down the fibula he finds tenderness at the seat of fracture. The new bone or callus has been strained, a reaction has set in, the callus is soft and tender, the fibula is bending at the seat of fracture and the foot is being forced by body weight into the valgus position. All the treatment necessary is to invert the foot by raising the inner side of the heel of the boot, so as to alter the line of the body weight. If the patient is heavy it is as well to add an outside brace and T strap. This frequently occurs in adults, but its nature is not always recognized. The same thing frequently occurs in children in fractures of both bones in the leg, but in this case the deformity is obvious. Similar straining of the union takes place in the forearm, leading to limitation in pronation and supination; also at the hip after fractures about the femoral neck often leading to obscure "rheu-

matic" pains. In every case the trouble is due to straining or shearing of the callus producing an erroneous alignment and throwing the joints out of true. Bearing these facts in mind, it is wise to protect a fracture, especially of the lower limb, from undue stress, even after it appears to be firmly united. On the other hand, it is to be remembered that physiological use is the best agent to assist in making the union solid. It is therefore good practice to let the patient walk as early as possible with a protecting brace for the leg (in a Thomas walking calliper if the fracture is in the femur) or if preferred in an ambulatory plaster splint.

There are other more gross cases of malunion which arise usually from failure to get the fragments into good position when reducing the fracture, or from failure to maintain the parts in good position after is has been reduced.

In some cases it is extremely difficult to get good position or good function on account of complicating injuries. Such cases must be met by the ingenuity of the surgeon as they arise. In consequence of this difficulty, there is a growing tendency to operate and plate fractures which seem to present difficulties. It must be remembered, however, that efficient bone operations require a considerable degree of special skill, and that an open operation over the seat of a fracture is necessarily a serious consideration to the patient.

It is possible to prevent many of the common forms of malunion with their associated disabilities, by anticipating them in the methods of setting. Some of these will be described in the brief survey of the principal fractures of the bones of the limbs which will be given in the end of this article. Many methods of manipulative treatment which are traditional can be improved on, and by improving our manipulative skill and technic we may hope to frequently avert the necessity of operating.

Similarly it is to be remembered that tenderness at the seat of a fracture is an indication that the callus is not yet hard. It may therefore be broken down by manipulation and the deformity directly reduced, or it may be corrected by splints or by fixing the limb in a corrective position, just as one can correct a bow-leg or knock-knee by splints, or an active case of coxa vara by extension in the abducted position.

The time that has elapsed since the accident is no indication of the solidity of the union. If the seat of the fracture is tender the callus is soft. Usually the patient complains also that the deformity is growing worse, that is to say, the callus is yielding. If it can yield in the direction of deformity, it will yield with equal readiness in the direction of correction if proper forces are applied to it.

Turning now to a brief review of the commonest fractures:

Fractures of the Clavicle

Fractures of the clavicle are generally well-treated, for it is recognized that the general alignment of the bone must be well maintained by keeping the shoulder back and out. The bone is subcutaneous and the practitioner can see and feel the position of the fragments.

Fractures of the Humerus

In fractures of the neck of the humerus the seat of fracture is deeply situated in muscles and we must be guided by experience.

Dissections and radiographs teach us that in malunions the upper fragment is frequently abducted and the lower fragment becomes united to its lower side. Clinical experience teaches us that the disabilities which are of greatest practical importance to the patient are limitation of abduction and of external rotation, so that he cannot place his hand at the back of his head.

In reducing this fracture it is often useful to have an assistant extend the limb downward till the fragments clear, then outward to a right angle with the body, and even straight upward by the side of the head. Meanwhile the surgeon with his hand in the axilla and on the arm can feel that the rough broken surfaces have engaged. The arm can then be gently brought to the side, and the arm fixed to the side in the usual manner. There seems to be little fear of the ends disengaging once they are properly apposed.

When union is sound, passive abduction and rotation once a day will soon reestablish a full range of movement.

When a case comes to me with a stiff shoulder and a limited range of movement, I place more reliance on passive movement, breaking down adhesions first under an anesthetic if necessary.

After fracture of the neck of the humerus, forcible breaking down of adhesions in the shoulder-joint should not be attempted for at least three months, as refracture may occur. During the operation the surgeon should remember that the movement most dangerous is not flexion, but internal and external rotation. In the meantime, an assistant should hold his fist firmly in the axilla to prevent dislocation.

In addition to his daily passive movements, he should practice reaching up the wall with his fingers, making a mark each time at the limit of his stretch and being careful to surpass it at his next attempt. I have been much struck by the extremely serviceable range of movement obtained by these means.

The so-called fracture of the surgical neck which usually includes both tuberosities with the head is really less troublesome. It occurs usually in old people and is often impacted. In these cases the arm may be left quietly by the side and a very useful range of movement can be obtained by exercise and passive movement later.

Fracture of the surgical neck complicated by dislocation is much more serious. The maneuver which I have found most useful is that already described of having the arm stretched straight upward by an assistant while the surgeon endeavors to manipulate the head back into position. If this fails, operation may be resorted to, and McBurney's hook is of great service in twisting the upper fragment into place.

Fractures of the shaft of the humerus may be troublesome from two causes—either on account of damage to the musculospiral nerve through injury or inclusion in callus, or due to nonunion, the latter being generally caused by inefficient fixation. Many cases of supposed permanent damage to the musculospiral nerve are cured in a few weeks by application of a splint which holds the wrist in dorsiflexion. The patient generally goes about from the beginning of treatment. There is not room for the thick splint frequently employed to lie comfortably in the axilla between the patient's arm and the body, and hence the arm is not as firmly fixed as it should be. Sheet metal splints occupy very little space. The best method I know of setting these fractures, especially when working single-handed, is the following: First get ready three sheet-metal splints. The external one extends from the external condyle to well above the shoulder and its upper end is bent over to form a sort of shoulder cap. A short splint extends from above the internal condyle to the anterior fold of the axilla, and a similar posterior one to the posterior fold of the axilla.

Flex the elbow to an angle of about 60° and sling the wrist to the neck, with the patient sitting in a chair. A loop of bandage is put round the flexure of the elbow and does not reach the floor. By putting one foot in this loop, the surgeon can apply as much extension as he chooses, while both hands are free to manipulate the fractured ends into correct position. The splints are

applied and squeezed up till they fit closely around the arm. A turn of sticking plaster now binds them into a cylinder fitting the arm. A sheet of wadding is then placed between the arm and the chest. The whole is secured with a broad bandage carried over the shoulder and the part of the external splint which is turned over like a shoulder cap. This prevents shortening, for the lower end of the cylinder fits round the arm above the condyles.

As the whole arm is in a close-fitting cylinder displacement cannot easily take place, and the patient is quite comfortable.

Except to free the musculospiral nerve from callus operation is rarely necessary, for even if there is some overriding of fragments a little shortening of the arm does not give rise to any serious impairment of function to the ordinary man.

All fractures through the condyles and indeed all fractures about the elbow, except fracture of the olecranon, are best treated in the fully flexed position. For the first few days the forearm, fully supinated, should be bandaged to the upper arm in fullest flexion, after this it is sufficient to keep the wrist slung short up under the chin.

In dealing with cases of stiff elbow after fracture through the condyles, especially in children, even if there is backward displacement of the lower fragment, I always first attempt to secure full flexion.

Under an anesthetic, with the humerus and forearm protected by local plints, the elbow is forcibly flexed, breaking or twisting the recent callus. The arm is then bandaged in the most flexed position obtainable. It is a remarkable fact that callus in front of an elbow-joint when subjected to continuous pressure in this way is rapidly absorbed, so that in a few days the elbow can be further flexed.

If necessary, the process may be repeated a second or third time till nearly complete flexion is obtained. The elbow is then left fully flexed till all reaction has disappeared. Then a gradually increasing range of movement is permitted, as has been already described.

Of course this treatment is not applicable to a case with actual bony ankylosis between the humerus and bones of the forearm, but such ankylosis is really very rare. If you can once get the callus on the move the progress toward recovery only requires about six weeks in the majority of cases.

In fractures of the shafts of the bones of the forearm the chief disability to be feared is inability to supinate the forearm completely. The trouble usually arises when both bones are broken. Here anatomical knowledge is of importance. The whole length of the posterior border of the ulna is subcutaneous and is practically straight. On this straight ulna the curved radius rotates like the handle of a bucket.

We must therefore attend to two points. First we must keep the ulna straight, second, we must not interfere with the natural curve of the radius. That is to say, there must be no pressure of bandage or splint on the middle of the shaft of the radius.

With anterior and posterior wooden splints, the middle of the forearm is often allowed to sag into a curve. Once the ulna is allowed to bend, both upper and lower radio-ulnar joints are thrown out of line. With gutter-shaped metal splints, which wrap themselves round the limb, the arm can be fixed with the ulna lying straight along the posterior splint and the radius will almost take care of itself so long as it is free to take its natural curve. This can be secured by fixing the splints at their two ends, at the wrist and elbow. When union has taken place, see that supination is possible before the callus is too hard to be twisted.

No mention is made of muscular action, because I hold that it is merely a reflex called forth by shifting of the parts. If the forearm is comfortably fixed in splints and slung

across the body at right angles to the arm, there will be no reflex muscular spasms. This question of muscular spasm will be dealt with more fully when dealing with the femur.

Movement of the fingers in forearm fractures seems to do good and not harm. It does not disturb the relations of the fractured bones, and provides a healthy physiological stimulus to the circulation and general trophic condition of the limb. In fact, if the patient cannot move his fingers without discomfort, it may be taken as an indication that there is something wrong. The surgeon should then ascertain if his alignment is faulty or if there is undue pressure.

Colle's fracture and Chauffeur's fracture, with or without fracture of the styloid process of the ulna, should give no trouble provided two things are attended to: first, the reduction of the displacement, and second, avoidance of strain of the callus by injudicious passive movement. The lower end of the anterior aspect of the radius is concave, with a very pronounced curve toward the prominent anterior edge of the lower articular surface. This curve must be preserved or the joint will be out of alignment, and the patient will complain of pain and stiffness until nature has had time to make necessary readjustments.

After reduction, a good anterior pad of wool is placed in the concavity of the radius already referred to, a similar posterior pad is placed on the dorsum of the wrist-joint and carpus, rather to the radial side. Firm pressure on these two pads maintains the correction.

Using sheet-metal splints the author puts a spiral twist on each. For the right arm the dorsal splint is twisted a half turn with the clock and the anterior splint a half turn against the clock. The lower end of the anterior splint should stop short with the radius and must not encroach on the thenar eminence. A turn of sticking plaster at the wrist secures the two parts in position. A second turn near the elbow secures the other ends of the splints near the elbow. The dorsal splint need only extend half way down the dorsal aspect of the metacarpals. A bandage over all makes everything secure. The patient should be encouraged to move the fingers from the first. If this be impossible the surgeon should find out why.

The splints may be left on for five weeks, for instance when a pretty result with a minimum of callus is desired in a lady's wrist. If the fracture is properly set, there is no fear of a stiff wrist.

In the author's experience, stiff wrists after Colles' fracture are due to two causes: incomplete reduction and injudicious movement producing strain of young callus. Patients with a Colles' fracture often imagine they have "only a sprain," go home and apply cold water bandages for a day or even two and then go to the surgeon with a painful swollen hand and wrist. When one of these cases appears lose no time, massage away as much of the swelling as possible and reduce at once. Delay only means increased difficulty in complete reduction, and the probability of more trouble from stiffness afterward.

The next point is that early passive movement of the wrist—not of the fingers—is apt to mean disturbance of the area of repair, and further reaction with pain and increased stiffness.

Cases with stiffness of the wrist and pain on any attempt at passive movement come for advice three to six months after the accident. There is a history that in spite of the most assiduous efforts to restore movement, the wrist has remained stiff and painful, and that the more it is moved the worse it is. In these cases a careful examination will nearly always reveal the fact that the deformity is not reduced. The presence of pain and reaction after movement is proof that the callus is still in an irritated or active condition and cannot be very hard. In such cases the author reduces with a Thomas wrench,

applying the jaws of the wrench just as he would have applied his own scaphoids had the case been a recent one. This operation can be done under gas. Incidentally adhesions are broken down and the fact that, when the patient wakes up with splints on, he can move his fingers as he could not do before, is a great encouragement to him.

There are other cases of malunion after a Colles' fracture of older standing, in which all pain at the seat of fracture is gone. The callus is solid but the patient cannot use his hand well. In these it is generally found that the patient cannot dorsiflex the wrist and therefore the grasp of the hand is feeble. Such cases should be treated like cases of fracture of the carpal bones—by restoring dorsiflexion.

Fractures of Bones of the Carpus

In the carpus, the bone most frequently fractured appears to be the scaphoid. Clinically the case appears at first to be a bad sprain. A diagnosis may be made, however, by the acute tenderness on pressure in the "anatomist's snuff-box."

The great disability complained of after this and similar injuries is stiffness and weakness of the fingers. On examination this is found to be due to inability to dorsiflex the wrist. Every schoolboy knows that the grasp of the hand is weakest when the wrist is flexed and strongest when it is dorsiflexed, but surgeons have been strangely slow to put this knowledge to practical use. Stiff wrists are nearly always slightly flexed wrists, therefore the treatment is clearly to keep the wrist quiet in dorsiflexion till the storm is passed.

Having diagnosed a fracture of a carpal bone, the writer always dorsiflexes the wrist and puts it up in this position on a palmar splint of sheet metal, known for many years in Liverpool as the "cock-up" splint. If a fragment of the scaphoid is displaced backward and obstructs dorsiflexion, he first tries to press it back into position and then dorsiflexes the wrist. If this fails, the fragment should be removed at once and the wrist put up in dorsiflexion. In cases of fracture the splint need not extend beyond the palm, the fingers being free.

In cases of stiff wrist with an inflammatory element, the palmar part of the splint should extend to the tips of the fingers until the inflammation has subsided.

As has been already indicated this treatment will increase the range of movement and improve the function of the wrist in certain cases of stiffness after old-standing Colles' fracture.

Fractures of the Lower Limb

In dealing with fractures of the lower limb, especially with fractures of the femur, muscular action has always been a disturbing factor, tending to produce shortening and over-riding of fragments.

Let it be said at once that the writer never employs weight and pulley extension. Extension by weight and pulley is a most inefficient method of attempting to control muscular spasm. It is by reflex nervous impulses induced by changes of tension in the muscle, that muscular spasm is produced. A patient lying in bed with a fractured femur cannot avoid constantly changing the state of tension of the muscles of his thigh if he has a weight and pulley attached to his limb. The counterpoise is the weight of his body. Every time he tries to shift the position of his shoulders by digging his elbows into the bed, he alters the tension on his muscles calling forth a reflex spasm. When he falls asleep and his muscles relax, when he moves in his sleep, when he is lifted upon a bed pan, or moved slightly by the nurses to have his bed put straight, there must be a reflex contraction of his muscles because there is a sudden change in tension. The muscles are always on the alert. Liston with his long splint used a perineal band and fixed the

ankle down to the lower end of the splint. This form of extension was absolutely sound in principle, but was abandoned because the perineal band chafed and made the groin and perineum sore. The real reason for this was that the perineal band was cloth, absorbed perspiration, and became septic and irritating.

Nevertheless the best method of fixing the thigh is by fixed extension such as Liston used, only the method can be much improved on. To illustrate this point consider a fracture of the middle of the shaft of the femur, with extension strapping of adhesive plaster applied in the usual way to the sides of the limb right up to the seat of fracture. At the lower end of the extension strapping there is a loop of webbing to which is attached a length of strong bandage, or better still of ordinary lampwick. Next slip the ring of an ordinary Thomas knee splint over the foot and up to the groin till it is firm against the tuber ischii; pull the extensions tight; take a turn round each side bar; and tie the ends together over the bottom end of the splint which of course projects 8 or 10 inches beyond the foot. For further control, place behind the limb a gutter-shaped sheet-metal splint extending from the buttock fold to the lower third of the leg with a good wool pad in the hollow of the knee. On the front of the thigh place another sheet-metal splint stopping short above the patella, and fasten the two together with a couple of circular bands. This gives excellent local control for the sheet-metal splints, each embracing nearly half the circumference of the limb. A couple of little transverse bandage slings suspend the posterior splint from the side bars of the knee splint, so that the center of the limb is exactly between the two side bars. The alignment from hip-joint to ankle-joint is perfect, being dependent on a straight pull.

Now the patient may raise his shoulders. His other leg can even be moved without altering the tension on his thigh muscles, and there is no reflex spasm of the muscles. Further, even if the muscles try to contract they cannot, for the upper end of the splint is firm against the tuber ischii. The muscles, therefore, do not remain on the alert, but come to rest. Starting pains are unknown.

A little attention is necessary to prevent soreness of the perineum. The ring of the splint is covered with leather, a wipe with a soapy rag slipped between the splint and the skin keep both clean and polished. Finally the nurse must several times a day press down the skin of the buttock and draw a fresh part of skin under the splint. After a few days the patient becomes so used to the splint that this is no longer necessary, but with a very fat flabby patient, the skin may begin to show signs of redness in half an hour and should therefore be attended to every half hour for the first day or two.

Having obtained the full length of the limb, all that is needed is to keep the extensions taut. This is a very different thing from hanging a weight of several pounds on to the limb to tire out the muscles.

All that is necessary is to prevent them from contracting. If a muscle has no play it is not nearly so ready to respond to reflex impulses as a muscle which is under elastic tension.

In a straightforward case where all the shortening has been corrected when the fracture was set, or within a day or two by tightening the extensions as the muscle relaxes, there is nothing more to do until the end of the fifth or sixth week by which time fair union has taken place. Now a walking caliper a quarter of an inch too long for the limb is substituted for the bed splint, and the patient is allowed to walk. As the splint is just a shade longer than the limb he cannot quite get his heel to the ground and therefore is not really carrying weight. Swinging the limb along improves its nutrition, and generally aids in hastening the process of re-

pair, for it is a modified form of the normal physiological function of the limb.

In dealing with malunited fractures of the shaft of the femur the same method of splinting is employed. First, however, there is the question of how to get rid of the over-riding. If there is tenderness and pain at the seat of fracture, especially if the deformity is increasing, it is quite safe to conclude that the callus is still soft even though many months have elapsed since the accident. In such a case by twisting and manipulating the limb the callus can be broken down. Then with block and tackle the muscles can be forcibly stretched as much as 2 inches or rather more at one sitting. The limb is then put up in the manner described, with fixed extension. Next day or the day after, the muscles will be adapted to their new length and by tightening the extensions an overlapping of 3 or 4 inches can readily be corrected in a few days and the limb made nearly if not actually as long as its fellow. At the same time with this straight pull, any angular deviations out of the true line are automatically corrected.

To deal with such cases, it is convenient to clip on to the bottom of the Thomas splint a small apparatus which consists of a central screw bolt at the end of which there is a little swingle bar to the ends of which the extensions are attached. As the muscles relax the nurse gives a turn to the screw and keeps the extension taut, in this way the muscles never get an opportunity of shortening, and it is astonishing to see how rapidly they relax. With this method one relies more on preventing contraction than on actually stretching the muscle by force except of course the pulling when the patient was under an anesthetic. That is very forcible. A good start means a great deal but once the bone is started to move, it can be continued without much trouble.

In cases where the callus is already solid, I operate with the limb forcibly stretched with block and tackle, endeavoring to correct the whole of the shortening there and then. If it is possible to get the whole of the shortening reduced at once, of course the next step is to fix with plates and put the limb up as already described.

Fractures of the neck of the femur are treated in a different way. The great deformity to be feared is that produced by the shaft traveling upward past the head and neck. Experience has proved that to avoid this varoid deformity the fracture should be treated with the limb in the abducted position. For this purpose, a double Thomas hip splint with the leg piece abducted is very convenient. The splint is fitted with extension bows. That is, a bow exactly like the lower end of a knee splint is attached to the ankle wings of the splint. Counterextension is by a groin strap well padded and covered with leather. This is usually put on the opposite groin, partly to avoid having pressure near the injured hip, partly because this allows the pelvis to tilt a little toward the injured side and so give a greater degree of abduction.

This apparatus and position are applicable to the treatment of all fractures above the trochanter minor whether in children or adults, of coxa vara in the active state, and of tuberculous disease of the hip. In fact, it is the position in which to treat any condition in which an adduction deformity at the hip is to be feared as a result.

It is equally suitable for the fracture of the femoral neck which occurs in infants as an obstetric injury, for the separation of the epiphysis of the head of the femur, for the strains of the neck which occur during school life, and for the so-called extracapsular fracture which occurs in young adults. It is also suitable for the treatment of intracapsular fracture in the aged, provided the patient can stand the recumbency and restraint. The least sign of hypostatic pneumonia is an indication for abandoning this method, putting the patient in a Thomas knee splint propping him up well or even getting him out of bed and making the best of the fracture. Even under these unfavorable conditions these pa-

tients can get about wonderfully well in a walking calliper even if union should fail.

The fracture in young adults is usually caused by direct violence applied to the trochanter major. It is associated with splitting and broadening of the trochanter, and often is impacted. The question of disimpacting these fractures has been much discussed. My practice is to disimpact before setting if there is rotation or if there is any material shortening. Rotation outward of the foot is a much more serious deformity than a little shortening. If the foot is in good position without any outward rotation and the shortening is not more than might reasonably be expected in any case, then it is not necessary to disimpact.

As already stated, I treat all fractures above the trochanter minor in abduction and all fractures of the femur below this point on a Thomas knee splint. The alleged disturbing action of the psoas muscle in my experience does not occur. This is to be attributed not necessarily to errors of observation on the part of those who report it, but to the fact that with fixed extension, reflex contractions of muscles do not persist. I do not believe that the desire to contract, unless it is oppressed, is as inherent in muscle as if it were original sin. My whole experience in the treatment of fractures, as in the treatment of such conditions as spastic paralysis, is that if muscles are efficiently controlled they come to rest and cease to struggle, but that if the control is inefficient or intermittent then reflex action is active and all muscles enervated from the same region of the cord share more or less in the excitability.

Similarly it is my experience that in supracondylar fracture of the femur the lower fragment is not flexed by the action of the gastrocnemius after the first twenty-four to thirty-six hours, provided the limb is efficiently controlled. One of my former house surgeons has told me of a case in which he had direct ocular proof in a case of compound fracture in which the bone was exposed. He saw the bone gradually return into line with the femur by the end of the day after the accident. After this the wound began to granulate and no more was seen of the bone. The functional result was excellent.

Of fractures of the leg there is little to be said until the lower fourth of the leg is reached. Fractures above this are comparatively easy to handle, even if both bones are broken, but in my experience fractures of the lower fourth of the tibia or of both bones in this region are extremely difficult to control even if the tendo-achillis be divided. The slightest error of alignment may mean constant pain and weakness in the ankle for months afterward.

Although I approach most other fractures with a feeling of confidence that I can treat them successfully by manipulation, I feel that in fractures of the lower fourth of the tibia and fibula operation is usually the wisest course for me. My usual practice is to attack the tibia. If it is secured with plates and screws the fracture of the fibula can usually be dealt with by manipulation.

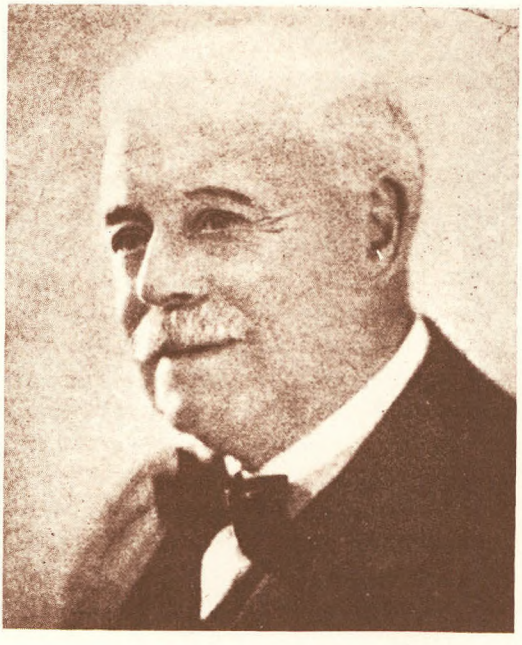
I have frequently seen a wedge of bone knocked off the anterior and outer part of the lower end of the tibia. This may occur by itself or as a complication of a Pott's fracture. The detached fragment is liable to slip down a little and block dorsiflexion and therefore interferes with walking. The treatment in the first instance is to get the foot into extreme dorsiflexion thus pushing the fragment out of the way. If the foot is fixed in this position for a few days the condition will not recur. In old-standing cases, the patient comes with a history of an injury to the ankle or of a fracture in that region, and complains of pain over the front of the ankle-joint. On inspection the foot seems rather fuller than its fellow in this region. The X-ray photograph shows some irregularity of outline chiefly due to irritation periostitis. The treatment is to operate, removing the offending portion of bone and making sure that the foot can be completely dorsiflexed. If the patient declines operation, then the

only thing to be done is to raise the heel of the boot so that the front of the astragalus does not impinge on the front of the tibia when walking.

There has recently been a great revival of interest in the treatment of fractures, stimulated by the revelations made by radiography, by the comparative impunity with which modern operative procedures can be attempted and by a growing dissatisfaction with the functional results frequently obtained by traditional methods of treatment.

In a single short article it is manifestly impossible to do more than touch on the fringe of so vast a subject.

The question before the modern surgeon is not whether operative treatment is to supersede manipulative. The problem before each of us is how can we improve our skill and technic in both manipulative and operative treament, and what means must we adopt in each individual case to give to our patients the surest, safest, and most complete restoration of function?



SIR ROBERT JONES

Sir Robert Jones of Liverpool (1855–1933) must be counted among the great teachers of modern orthopedic surgery. He was a nephew of Hugh Owen Thomas and succeeded in maintaining the great tradition of the Liverpool School which had been famous for 200 years. He headed the orthopedic section of the British Forces in World War I and contributed heavily to training the orthopedic surgeons of the A.E.F. in fracture care. Before the war, Sir Robert Jones had begun to exert great influence by his writings and lectures on surgery of skeletal trauma. The classic of this issue was a teaching lecture presented at a meeting of the American Orthopaedic Association in about 1912. Before that time, no textbook bearing the word "Orthopaedic" had dealt systematically with fresh fractures; general surgery and included the diagnosis and treatment of fractures. Sir Robert Jones' lecture is as educational today as it was 60 years ago, and it warrants rereading by educators and students alike.

CLASSIC 52

Responsibility and Research in Orthopaedic Surgery

ALFRED RIVES SHANDS, JR., M.D.† (1899–)

For vitality, strength, and progress in medicine and its specialties, there must be a sense of responsibility, vision, and research. This concept has been many times brought to our attention in Presidential Addresses of the past, but restatement and redefinition are constantly needed. Today your President, for this "his memorable occasion," would like to define for you some of our responsibilities and to discuss a means to extend our research. First, however, he wishes to pay tribute to the wisdom, foresight, and energetic leadership of the officers of this Association who have preceded him for the part they have played in the solid growth and sound development of American orthopaedic surgery and particularly of The American Orthopaedic Association. Also, he desires to express his deep appreciation of the great honor you bestowed upon him in making him your President and to tell you what great pleasure it has given him to serve you in this high office during the past year.

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RESPONSIBILITY

Nothing in the life of a medical specialty is more fundamental than the manner in which the specialty meets its responsibilities. It is the foremost quality by which a specialty is judged. This is as basic as are honesty, integrity, and a clear conscience in the character of man. A specialty must define these responsibilities frequently, face them squarely, and then take action with decision. Failure to recognize and to act on responsibilities constitutes the greatest single weakness a specialty can have.

Before beginning to outline some of our present responsibilities, we must define ourselves as orthopaedic surgeons. It has often been said that we should be physicians first, surgeons second, and specialists third. As physicians, we should be good diagnosticians, have a broad knowledge of medicine and of its specialties, and be quite familiar with all general medical practice. As surgeons, we must know surgical principles and techniques, be skilled in the use of our hands and our instruments, and at all times use good surgical sense and judgment. As specialists in orthopaedic surgery, we must clearly demonstrate knowledge and ability superior to those of other physicians in the management of the medical and surgical problems of bones, joints, and allied struc-

tures. If we do not meet these criteria of being physician, surgeon, and specialist, we cannot wholly qualify as orthopaedic surgeons. No specialty has closer affiliations with both medicine and surgery than orthopaedics; it has been stated that we must always be prepared to serve the two masters, medicine and surgery. Perhaps, as suggested by Steindler, we should rightfully be called orthopaedic physicians. When we become qualified as orthopaedic surgeons, we assume the responsibility of upholding the standards of our practice, the training of our new members, the advancement of knowledge through research, and the maintenance of amicable and understanding relationships with the medical profession and with the public.

Protection of the public and rendering good service are the first responsibilities of all physicians. (The public, according to Judson, wants "experts . . . to bear the responsibility of orthopedic cases" and is ". . . the final arbiter" of our very existence as a specialty.) How this can best be done is something which each specialty must decide for itself. In medicine, too often, practitioners of a specialty go off into a little world of their own, become completely oblivious of what other branches of medicine are thinking and doing, and forget what medicine as a whole and the public expect of their specialty. To preclude the development of such a situation in orthopaedic surgery, there must be a continuing evaluation of what is good orthopaedic care, what is good judgment in the application of this care, how this care relates to other medical and surgical practices, and particularly how it relates to the patient as a whole. To see that our trainees are properly prepared to practice good orthopaedic surgery, to see that all physicians recognized as orthopaedic surgeons by the public are practicing good medicine, and to see that all have a sense of loyalty to the specialty and a spirit of service to their patients and community, without too much thought of material gain—these are all important in our efforts to meet adequately the two great responsibilities, rendering of service and protection of the public.

We, as a specialty, are judged by the practices of all who do orthopaedic surgery, well trained and poorly trained, Board diplomates and non-diplomates alike. Board certification is only a beginning and does not necessarily result in better men and better practice. It is in reality only a method of evaluating by means of oral tests and written examinations the minds but not the practices of orthopaedic surgeons. Perhaps the time has come when our Board should extend its activities and establish a method of evaluating the practices of all orthopaedic surgeons. In 1919, Galloway pointed out that there were many poorly prepared surgeons calling themselves orthopaedists who were doing what they were unprepared to do, going over their depth in the surgical field, and failing to recognize their capabilities and their limitations. Although the relative number of poorly prepared orthopaedists may be less in 1954 than it was in 1919, it is still great and larger than it should be.

In the most recent Directory of the American Medical Association, published in 1950, 2,109 surgeons were listed as limiting their practice to orthopaedic surgery; up to 1950, The American Board of Orthopaedic Surgery had certified 1,534 surgeons. In the same Directory, 423 surgeons were listed as giving special attention to our specialty. Thus, the nearly 1,000 non-diplomates represented 40 per cent of the orthopaedic practitioners in the country in 1950. It is unlikely that this percentage has changed in the last four years. Since there were 2,230 diplomates of the Board on January 1, 1954, nearly 1,500 non-diplomates must now be practicing our specialty. Many of these 1,500 we know are doing excellent work, in some instances better work than that which is being done by many Board diplomates; but some are inferior, poorly trained, and are definitely not upholding accepted stand-

ards of good practice. Yet the public seldom knows the difference between this group and the well trained and well qualified group. In the minds of the people of most communities, we are labeled "bone surgeons," and the specialty is judged by the practices of all.

At the last meeting of the Academy, there were 477 registered guests. Who were these guests? Most were non-diplomates of the Board, practicing orthopaedic or traumatic surgery, who had come to learn—a healthy indication of the desire on the part of some of this group for further education. To reach the orthopaedic practitioners who should be guided into the path of better work, there must be an extension of the present programs of postgraduate education. In the past twelve years, our Academy, with its papers, exhibits, movies, and instructional courses, has contributed much toward such education; but this is not enough. The program should be extended and the responsibility for this education should be not that of the Academy alone, but also that of this Association. This teaching at the postgraduate level should be taken into the different sections of the country, through regional meetings, literally into the "highways and hedges" of general orthopaedic practice. Some may think that this suggestion is not practical and cannot be implemented. It is being done rather effectively, however, by some of the other specialities. It is being done by the American College of Surgeons in its state and national meetings on trauma and fractures. Many of us have participated in the fracture seminars, conferences, and demonstrations of the College. The improvement in fracture care which has been evident everywhere in the last two decades, and which certainly can be partially credited to this teaching, has more than justified all effort, time, and money spent on these meetings. Similar programs for our crippled children's work, our adult work, and our rehabilitation should be instituted. Such a program should demonstrate all good orthopaedic practices, ". . . teach the principles upon which sound treatment rests to secure good results,"[20] point out the common mistakes in practice, show how these can be prevented, discourage surgery of doubtful value, and thereby lead to fewer errors in practice and better care of the patient. This is a duty we owe the public. It can be accomplished if we of the Association will work together with the members of the Academy and accept this as one of our major responsibilities. It is an orthopaedic "house repair job," the putting of our house in order—a job long overdue.

Barr, in his excellent President's Address to the Academy in 1953, stressed our responsibility for protecting the public through the standardization of surgical materials. Under his leadership, a good start has been made in the establishment of the American Surgical Materials Association. Your President wishes for this new organization a long, useful, and successful life.

What shall we do, however, about the orthopaedic operative procedures which result from the development of these surgical materials? In recent years many new operations, particularly those associated with the use of metals and plastics, have not had "the test of time." It is as much our responsibility to protect the public from operations of unproved value as it is to protect it from the use of inferior materials. A young and partly trained practitioner proceeds more often with new surgical techniques, the results of which have not yet been accepted as satisfactory, than does a member of the older, more mature group. This is not wholly because of inexperience and the enthusiasm of youth; often there is an almost uncontrollable urge to be the first in a community to perform a series of new operations. Of yielding to this urge, I have been guilty; perhaps all of us have been guilty of it at some time in our careers. We must always be ready to discard the old if the new is better; but, before the old is discarded, let us be certain that there is ample and sufficient

proof that the new is really better, and that the new operation qualifies, as Nix has stated, in being ". . . as simple, as satisfactory, and as safe as possible."

Gallie, in 1948, wrote, ". . . we are dealing with human lives. How much more important, therefore, that we should test our ideas thoroughly before trying them on our patients or committing them to print." It is as much our responsibility to the public to discourage the use of a surgical procedure before it has been properly tested as it is to curb unnecessary surgery. There is no doubt that every new operation, whether it be in orthopaedic surgery or in another surgical field, ". . . has left its wake bestrewn"[4] with poor results and even surgical tragedies, ". . . before clinical experience plus scientific research [has] put it into a proper perspective."[4]

Personal experiences leave indelible marks on the memory, and your President has had an extraordinary experience in dealing with young surgeons and surgical procedures. During World War II, he spent sixteen months at a desk in the Air Surgeon's Office in Washington, across which passed each month a record of the successes and failures of hundreds of all types of operations performed in over 250 Air Force Hospitals by over 1,200 general surgeons and surgical specialists, not all of whom were mature in surgical judgment and performance. The reports of complications, mistakes, and surgical tragedies were numerous, in fact, at times, appalling. Most of the worst errors reported were in the records of the young enthusiasts who were attempting to perform operations for which they were not qualified by either training or experience. With the monthly analysis of this mass surgery at hand, the first logical step which was taken by our office to minimize these errors was a strict enforcement of the adage, "What is the best for the greatest number is the best for all." It rapidly became necessary for our office to outline to our surgeons acceptable and non-acceptable surgical procedures. In addition, regular educational conferences were held throughout the Air Force Hospitals. At these meetings emphasis was placed on the most common mistakes in judgment and therapy and on what should be done to prevent them. In the light of this record of the experience of military hospitals in wartime, which I am certain could be duplicated from civilian hospitals in peacetime if surgical reports were available, it is our responsibility to discourage and to minimize the widespread performance of new operations before reasonable proof of their safety and worth has been made available.

In orthopaedics, there are probably more different operations for the same purpose than in any other field of surgery. Boyd has said, "We have developed more operations than any other specialty. There seems to be no limit to the number of surgical procedures concerned with . . ." muscles, bones, and joints. We, more than those in any other field of surgery, need to list, to catalogue, and to recognize surgical procedures in terms of percentages of successful results or in categories of *usually successful, reasonably successful,* and *of doubtful success.* If such a classification is made by a "'Board of Respected Elders," if it is generally accepted as a fair appraisal of our surgery by the members of our specialty, and if careful consideration to this classification is given by all of us before surgery is performed, it could be a source of great good. The establishment of such criteria for orthopaedic operations would not only decrease the number of bad results, but would also inform the medical profession and the public that we in orthopaedic surgery were taking a most constructive step to meet more adequately one of our great responsibilities, the protection of the public.

Reginald Sayre, fifty years ago, stated, "Until the surgeon knows how to adapt mechanical principles to the cure of deformities, he is not competent to be an orthopedist. . . ." Eleven years later, Packard stated, "Advances in surgery must go hand in hand

vith a rational thorough method of treatnent by mechanical means," and if we '. . . simply develop the operative side of orthopedics, which can be executed with equal skill and technic by the general surgeon, our future existence will be problenatical." We should ask ourselves frequently whether we are teaching our students and residents what are the sound mechanical reatments in the cure of deformities. We hould further ask ourselves seriously whether we are not giving too much attenion in our training and teaching to the urgical procedures of our specialty and hereby risking a problematical existence in he future. If our interest in surgery coninues to become, as Painter has said, '. . . infected with the virus of operative uror" to the neglect of teaching the fundanentals of diagnosis, the principles of therapy, and the value of conservative nonperative procedures, is there not a great possibility that orthopaedic surgery may be orced to repeat its history of 100 years ago? Bradford stated that at this time, because the '. . . ambition of all men of energy prompted hem to emulate those monarchs of the operting-table," the specialty went into a deline from which it took years to recover. We must ever bear in mind the saying of Santayana, "Those who cannot remember he past are condemned to repeat it." Wiles, n 1952, wrote, ". . . however important urgery may be now, it should be the aim of all doctors, including surgeons, to limit nd ultimately abolish it." This opinion, oming from one of our distinguished Engish colleagues, should awaken our thinking. Perhaps we shall never arrive at the point of bolishing surgery, but certainly we can demphasize it in our training and lay greater tress on teaching the principles and fundanentals of our specialty to great advantage.

The failure of orthopaedic surgeons to ecognize their responsibility in the developnent of rehabilitation services has become ne of our most serious shortcomings in ecent years. In the Armed Forces during World War II, a rather general interest among all medical officers was manifested in the rehabilitation of the sick and wounded; and among a few of these physicians, there developed a very keen interest in all aspects of rehabilitation. In this latter group, there were many who carried their interest over into practice in civilian life. These physicians later joined the medical practitioners of physical therapy and formed the specialty physical medicine, to which was added later the name rehabilitation. Since the War, unfortunately most of the orthopaedic surgeons, with a few outstanding exceptions, have continued to believe that the pre-war pattern of medical and surgical after-care is adequate. However, the lay public has been shown the tangible benefits to patients and budgets of good rehabilitation programs — of what might be called the post-war concept. This has been followed by hospital boards and community-planning agencies insisting upon rehabilitation services being instituted. The orthopaedic surgeons generally, instead of taking the lead in the organization of these services in which the public has become interested, have assumed a most apathetic attitude. This has made it possible for the specialists in physical medicine to gradually acquire the leadership in this rapidly growing medical activity in which they are interested. In reality, we have only ourselves to blame if we do not approve of the present situation, in which, in many communities and institutions, specialists in physical medicine are directing programs of rehabilitation involving the after-care of orthopaedic patients. Our British orthopaedic colleagues since the War have taken a very active lead in the development of rehabilitation services, and in their country they are now directing most of this important branch of medicine. It is unfortunate that we have not followed their lead. How futile would be all of our treatment, particularly our surgery, without proper after-care, and how dependent we are on effective rehabilitation for our patients! Wiles has rightly said that recon-

structive surgery should never be attempted unless good facilities are available for rehabilitation and that these should be under the full control of the surgeons. The time is past due when every orthopaedic surgeon in the United States should consider rehabilitation to be one of his first responsibilities and should actively promote and participate in the rehabilitation services of his community.

Along with responsibility for the training of orthopaedic practitioners goes the responsibility for the training of orthopaedic teachers. For our specialty to go forward, we must have good teachers, the best we can produce. It has been said by many that we should train two types of orthopaedic surgeons, one for general practice in orthopaedic surgery and the other for full-time professorial positions, the latter to follow the paths of research and teaching. However, it should always be remembered that the good teacher and investigator should first have been a good clinician and practitioner, for, without this background, his vision may become warped and his patients may become second in importance to the laboratory experiment. If reasonable assurance of satisfactory teaching positions with adequate remuneration for those who show ability and aptitude could be given, there would be many young and promising trainees ready and willing to take this special training and to achieve higher learning in our specialty. It is my feeling that appropriate recognition in the form of special certification by our Board should be given to such training, which of necessity would be longer than the present three-year period. It is so important for orthopaedic surgery to have good teachers that serious consideration should be given to the subsidization by our specialty of selected teaching positions. At times, we become greatly concerned about the scarcity of strong, inquisitive, forward-looking minds, sufficiently talented to become our teachers and leaders. In 1926, Hoke wrote, "I do not bother about the oncoming of talented minds, for Nature has a way of producing young men from decate to decade who have the will to work, a determination to search and a vision of usefulness, which need only be appropriated and directed somewhat." We must be ever ready to recognize the man with a talented mind and to follow the concept of Michael Hoke of appropriating, interesting, and directing this type of individual into a teaching career and a position of leadership in our specialty.

Sound, logical, realistic policies should be adopted for orthopaedic surgery and its future development. These policies should be changed seldom and only after most careful thought and deliberation. A Policy Committee for orthopaedic surgery should be established; it should steer and guide our policies through the calm or the turbulent seas of changing economic and sociological conditions, not thinking always of what is happening today, but cognizant always of what may follow on the morrow. This Policy Committee should consist of our older and wiser heads and should become the strongest active force in American orthopaedic surgery. On this Committee should be representatives, perhaps many past presidents, of the Association and the Academy, and representatives of the Orthopaedic Section of the American Medical Association. Whenever matters of policy arise in the affairs of our specialty, matters which directly affect us all, they should be referred to this Committee for its deliberate and thoughtful consideration and recommendations before being acted upon by the referring group. In this Committee should originate policies for the improvement of our speciality. Such policies should then be referred to the Association, the Academy, and the Orthopaedic Section of the American Medical Association for discussion, adoption, and action. This Joint Committee would be the logical successor to the Caldwell Committee on the Advancement of Orthopaedic Surgery of the Academy. However, in no event should the decisions of this Committee be binding or

rthopaedic surgery or be considered more han recommendations to the whole member- hip of the organizations. To survive in the vay we should, we must follow, at all times, ;ood democratic principles and allow no mall dictatorial body to arise in our midst, or, as Clemenceau once stated, "War is oo important to be left only to the generals;" he members of this Committee might be kened to our generals. The establishment f a Policy Committee would evidence far ighted vision for the future. It would be ne of the most effective steps we could take) ensure the continuing vitality, strength, nd progress in our field of medicine which re so earnestly desired by all of us.

In 1922, Allison said that our specialty ad come out of its infancy, youth, and arly manhood, and had gone into a vigorous iaturity. Having been fully matured for ver three decades, we should, theoretically, ow be in our prime. We represent today ne of the largest and strongest of the medi- al specialties. Orthopaedic surgery has at- iined this position not alone because it is osely affiliated with medicine and all of irgery, but also because through wise lead- :ship and hard work on the part of its iembership over the years, it has rendered)od service to the public. Each of us iould now ask himself these questions: Will :thopaedic surgery stay in its prime? Will it iin greater strength? Or is our specialty)ing to show age, senility, and regression? we choose to be self-satisfied and compla- :nt, deterioration will inevitably set in. We ust be ever ready to change ourselves and ir concepts in light of changing conditions. ne of the greatest mistakes we can make to believe that, because we are large and rong today, our progress will be automatic. ur well-being and advancement will de- :nd entirely upon what we do, how we do and the direction of our vision. Particu- rly will it depend upon what we do to :engthen the foundations of our specialty. iis strengthening cannot take place without our devoting ourselves to the following which are essential for the development of any field of medicine—namely, (1) the meeting of responsibilities, both old and new, as they arise, (2) good clinical and basic science training programs for the development of practitioners and teachers, some of whom will become our leaders, and (3) sound basic research to provide good building material for future advances in therapy. Your President now wishes to discuss with you the third of these essentials, research, and the role it should play in the strengthening of orthopaedic surgery.

RESEARCH

Research has been mentioned prominently in ten of our Presidential Addresses and in eight of the Presidential Addresses of the Academy. Its first mention was in 1889 when Bradford stated, "Investigation is especially needed." Eight years later, Ketch wrote, "The desire for brilliant achievement in both mechanical and surgical procedures can well give way to study and research in the undiscovered sources of deformity, congenital and acquired, and also toward a solution of the many vexed questions regarding joint and spinal diseases." In 1920, Starr stated that research is needed to "help to establish our Association on a more scientific foundation." In 1924, Baer brought the great importance of research into clearer focus than has any other president before or since. In his address were such statements as research work is ". . . a duty one owes to his specialty and to the advancement of science." A ". . . *sine qua non* of a good teacher . . ." is his ". . . power to stimulate the spirit of investigation. . . . You are made immortal by the impression you can deliver to your students . . . [and] by the research work you do. . . . One should arrange his own time, and in organizing his staff provide sufficient time for them, that all may in some measure seek the Goddess of Truth by individual research."

In the last four Academy Presidential Addresses, Caldwell, Barr, McKeever, and Boyd have repeatedly emphasized the need for research. Caldwell wrote, "Research offers the best possibility for enlarging our field of endeavor. . . . So important is research to the future of orthopaedic surgery that we believe our Committee on Scientific Investigation should double its efforts to stimulate other centers to begin research work and to assist in obtaining the necessary funds and investigators to make this possible."

McKeever stated, "Orthopaedic surgery today is lacking in basic research . . ." and the orthopaedic surgeon ". . . has not himself . . . contributed enough of the blood, sweat, and tears which go into the advancement of general surgical knowledge as it applies both to the broad field of surgery and to his own specialty."

Barr spoke of the research needed in the study of surgical materials.

Boyd stated, "In the future, first, we should sponsor research which will develop new methods and new fields of activity for orthopaedists. Our deficiency in basic orthopaedic investigation should be corrected promptly."

Your President can do no more than to strongly endorse these opinions and state that he believes with Harris that our very future existence depends on our own creative spirits and what we ourselves do to carry on programs of fundamental research, or as Harris has so well expressed it, ". . . research into the nature and structure of bone, cartilage, muscles, and connective tissue." Research, as we all know, is dependent first on brains and second on money. Brains cannot be bought but must be found. Money is needed to support these research-talented brains after they have been found, and to provide the facilities necessary for their work. We can all do something to help provide this money. This is what your President wishes now to discuss with you.

During the past year, your Research Committee* has conducted a survey of the orthopaedic research which is being done by orthopaedic surgeons. Information has been obtained not only on what the present projects and their costs are, but also on what projects would be pursued if additional funds were available and what the probable costs of such new projects might be. It was believed by your President that these data should be obtained in order to present to you not a probable, but an actual need, and that information by name, project, and cost should be available before suggesting a means of finding the money to extend our research programs.

Through the Central Office of the Academy, questionnaires were sent to 2,250 orthopaedic surgeons, all of whom were members of the Association, or the Academy, or were diplomates of the Board. Of the 376 who replied, 189 orthopaedic surgeons in 150 institutions reported that they were carrying on 290 research projects. It is realized that this survey is incomplete, but it is believed that 80 per cent of the orthopaedic surgeons engaged in some type of research have reported. The projects were clinical studies in forty-eight of the 150 institutions (32 per cent), laboratory studies in thirty-five (23.4 per cent), and clinical and laboratory studies in sixty-seven (44.6 per cent). The approximate cost of the projects in 100 institutions was $490,300. On this basis the estimated cost of all current projects in the 150 institutions was $736,800. On seventy-two questionnaires were described 140 projects which were being deferred because of the lack of funds; their cost would be $346,450. On this basis, the total estimated cost of all such deferred projects would be approximately $600,000. It is interesting to note that the National Research Council reported, as of September 1, 1953, that there were on record in the Bio-Sciences Information Exchange 336 projects dealing

* Verne T. Inman, M.D., Chairman; Paul C. Colonna, M.D.; and Carroll B. Larson, M.D.

with research on the connective tissues and the musculoskeletal system, that is, basic orthopaedic research. Financial support being given to these projects was approximately $5,500,000. In these projects there were included twenty-two investigations by orthopaedic surgeons in thirteen institutions (6.5 per cent)—a very small part of the total.

On many questionnaires, it was stated that the obtaining of money did not present the problem that the difficulty of finding time, personnel, and facilities presented. As we all know, funds are available from many sources for good, basic research, but they are definitely not available from many of the same sources for the orthopaedic surgeon who is untrained in research techniques, unless the circumstances of his request are unusual. Many of you will recall experiences of your own in applying to some of the foundations for research grants.

If we as a specialty are to further more extensive programs of research among ourselves and especially among our trainees and younger members with inquisitive minds and original thoughts, we must have research funds of our own, under our own control. Such funds must be raised by us. How can this be done? The answer is to establish a non-profit, tax-exempt Orthopaedic Research Foundation to which we, our patients, and others may give and which may receive bequests from wills and other sources. It should be operated and controlled by American orthopaedic surgery with a Board of Trustees representing the Association, the Academy, and the newly organized Orthopaedic Research Society. The National Research Council, through its orthopaedic or other appropriate committee, should be asked to assist in decisions concerning what constitutes research worthy of support by the funds of such a Foundation. The urologic surgeons have led the way among the specialties in this and have operated very successfully since 1952 an American Urological Research Foundation. We should do the same, for there is nothing more important to the progress of our specialty, and nothing more vital to ourselves, than sound investigation. With careful planning and judicious management, such a foundation could prove a tremendous incentive to the growth of American orthopaedic surgery. It would be one of the most effective steps which we could take to inform medicine and all of science that we in orthopaedic surgery are now prepared to go farther than we ever have in the past to help ourselves through research. Your President hopes that such a Foundation may become a reality within the coming year.

CONCLUSION

Orthopaedic surgery of today has been left a great heritage by our forebears. It is our duty not only to preserve and to cherish but to enhance this proud inheritance. On the south portico of the Archives Building in Washington, there is a statue of a beautiful woman holding an infant against a background of stalks of ripened grain, under which appears the inscription, "The heritage of the past is the seed that brings forth the harvest of the future." The great orthopaedic surgeons of the nineteenth century and of the early part of the twentieth century were our forefathers who not only created this heritage but also planted this seed. The seed which was sown has borne fruit and has created "the harvest of the future," the orthopaedic surgery of 1954. We of this generation should be doing as our forefathers did for us; we should be "sowing the seed" to bring forth "the harvest of the future" for the oncoming generations. This should be done, as Willard has expressed it, ". . . in such a way that we may pass on to our successors a still more perfect inheritance of which both we and they may be very proud." This is perhaps our first and greatest responsibility. How we meet this responsibility will be determined by our vision. We must always remember the proverb, "Where there is no vision, the people

perish." Upon our vision rests the future of orthopaedic surgery. We can only hope that our Creator may grant to all of us and to our line the strength, wisdom, and courage to carry steadfastly the torch of our proud heritage, and at all times to maintain a clear, bright, and unobstructed vision for the future.

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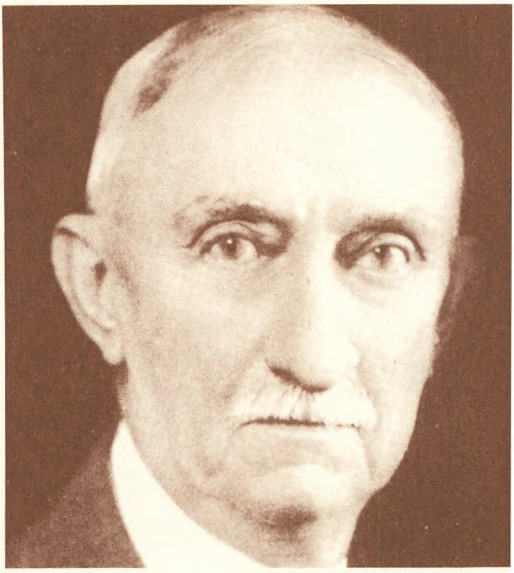

ALFRED RIVES SHANDS, JR.

Alfred Rives Shands was for many yea Chief of the Alfred I. duPont Institute The Nemours Foundation in Wilmingto Delaware. Among his many contributio was his classic in medical biography, *Ear Orthopaedic Surgeons of America* St. Lou C. V. Mosby, 1970.

CLASSIC 53

Control of Bone Growth by Epiphyseal Stapling

A Preliminary Report

WALTER P. BLOUNT, M.D., (1900–)
AND
GEORGE R. CLARKE, M.D.

When Phemister reported the operative arrest of longitudinal growth of bone in 1932, a new principle was introduced in the correction of excessive length and angular deformity of extremities. Previous to this time, bone-shortening operations[16] had been used to a limited extent to equalize limb length. These procedures were only slightly less extensive than those for bone lengthening[1, 2, 11] and, like them, were attended by the risk of grave complications. Growth was an uncontrolled force which had to be considered. Phemister utilized this growth factor in an operation of much less magnitude.

Another advance was made in 1945, when Haas proposed the retardation of bone growth by a wire loop. He tried this first in laboratory animals and later in children, and proved that longitudinal growth at an epiphysis could be held back mechanically with a wire loop. Even more important, he proved that growth was resumed when the wire broke or was removed. The implications were tremendous. Instead of attempting to compute the probable future growth of both extremities and to arrest growth at the proper time, Haas suggested earlier temporary arrest. He proposed removing the retentive wire when the deformity or inequality of length had been corrected sufficiently.

Stimulated by this work of Haas, in 1944 we began to employ rigid staples of the type popularized by R. E. Burns. The method of epiphyseal stapling was reported by one of us (W. P. B.) at a meeting of the Chicago Orthopaedic Society on December 14, 1945, and was published by Hodgen and Frantz. Haas continued his experimental work on dogs, using staples rather than wire loops.[6]

Staples were used in American bone surgery in 1906,[3] and Venable and Stuck report that they had been employed in Europe long before that time. Notching or roughening them to prevent extrusion has had many ramifications. When they are to be used for growth control, it is important that they may be removed without traumatizing growing bone. Simple, smooth wire staples have been used to date. Various sizes and gauges of wire have been tried. The authors are now using $\frac{3}{32}$-inch rods of 317 M stainless steel with a Rockwell hardness between 33 and 35 C. Staples are beveled on the outer sides and formed cold with dies under hydraulic pressure. Two sizes are adequate for use in the femur and tibia. The legs should be ¾ of an inch long, the cross member ⅝ or ⅞ of an inch (Fig. 1). The smaller staple is used in the proximal end of the tibia, the larger one in the distal end of the femur. If the growth of the fibula or

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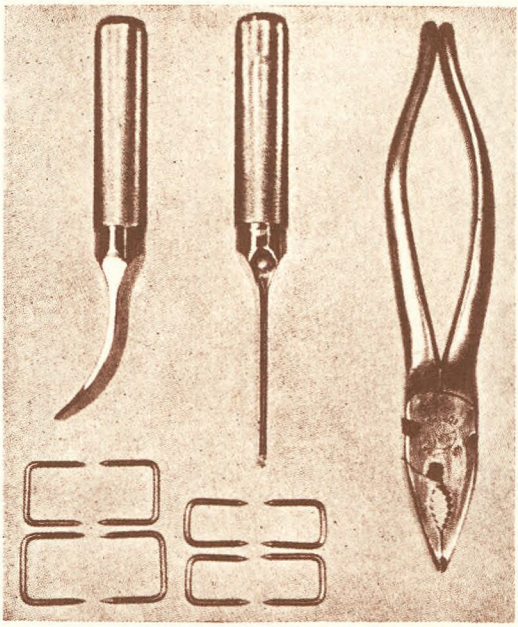

FIG. 1. Staples of $\frac{3}{32}$ inch 317 M stainless steel. The legs are $\frac{3}{4}$ of an inch long; the cross members are $\frac{5}{8}$ and $\frac{7}{8}$ of an inch. Modified pliers and set help place the staples close together. The extractor is necessary for removing the staples.

other smaller bone is to be similarly controlled, a smaller staple will be desirable.

Further experimentation may suggest a more efficient mechanical design which will still be compatible with quantity production. A physicist, a mechanical engineer, and their co-workers have been interested in the problem. Many helpful suggestions have been made by orthopaedic surgeons who have tried out the method; further comments will be most welcome. The use of a single heavy staple has been proposed frequently. This would displace more bone and would require greater accuracy of placement. The method would be less adaptable, and insertion of the staple in the proximal end of the tibia might be difficult.

Excessive bending and extrusion are mechanical problems which are easily solved by the use of an adequate number of staples. To date, no serious complication has occurred from a staple pulling out. It is a simple matter to remove, reinsert, add, or move staples. Patients must be followed closely, so that any mishap may be detected and remedied. It is wise to do the stapling while there is still sufficient growth potential to permit correction of any inadvertent angular deformity.

If one staple is inserted on each side of the end of a long bone so as to bridge the epiphysis medially and laterally, the staples will bend and break (Fig. 4 B). If two staples are used, they will bend (Fig. 6 D) and occasionally break. In this manner the growth is only temporarily or inadequately retarded. If three staples are inserted on each side of an epiphysis, growth will be stopped immediately and almost completely. The staples will usually bend slightly. There is some drifting or slipping, like wire cutting through a piece of ice, but this is negligible in relation to the shortening to be obtained. It may even be desirable to allow some slipping, so as to maintain the viability of the epiphyseal plate. Complete arrest might cause premature epiphyseal closure. More efficient staples will be tried out experimentally.

The authors' routine is to use three staples as a unit unless there is a reason for another combination. Interesting growth changes can be obtained. In a long lower extremity with knock-knee, one may put three or four staples on the medial side and one or two on the lateral aspect. The drift on the lateral aspect will equalize the knock-knee at about the time the inequality of length is overcome.

OPERATIVE TECHNIC

The extremity is shaved and washed from ankle to groin on the day preceding operation. A tourniquet is applied at the mid-thigh; the knee is prepared surgically; and the foot is wrapped in a small sheet. The knee is supported on a block in flexion of 30° to 70°. Medial and lateral incisions, 5 to 8 centimeters long (depending upon the amount of subcutaneous fat) are made obliquely through the skin and subcutaneous fat centering over the epiphysis to be stapled.

Above the knee, the incisions should slant from anterior-proximal to posterior-distal; below the knee, from posterior-proximal to anterior-distal (Fig. 2). The scarring is less if two incisions are used instead of a single long one, for exposing simultaneously the femoral and tibial epiphyses. The deep fascial layers are split in the direction of their fibers and the periosteum is exposed. Mobile soft parts must not be impaled.

Staples may be inserted "blind" without actually cutting through the cartilage cap and exposing the epiphyseal plate. Roentgenograms in two projections are imperative. After the position has been verified, it is often a good plan to cut the periosteum and cartilage along the cross members of the staples and to sink the staples flush. Some surgeons will prefer to incise the periosteum and overlying cartilage and raise two flaps, so as to expose the epiphyseal plate. In children under 10, thick flaps are necessary. It is not desirable to bury the staples deeply, if they are to be removed.

The easiest approach is at the medial aspect of the distal femoral epiphysis. With the knee flexed, the vastus medialis need not be split. It is displaced anteriorly, while the hamstring tendons fall posteriorly. The movable fascial layers are split in the direction of their fibers. By sharply flexing the knee, the posterior aspect of the femoral condyle may be reached without difficulty. By straightening the knee and strongly retracting the vastus, staples may be placed anteriorly.

Exposure of the lateral aspect of the distal femoral epiphysis is only slightly more diffi-

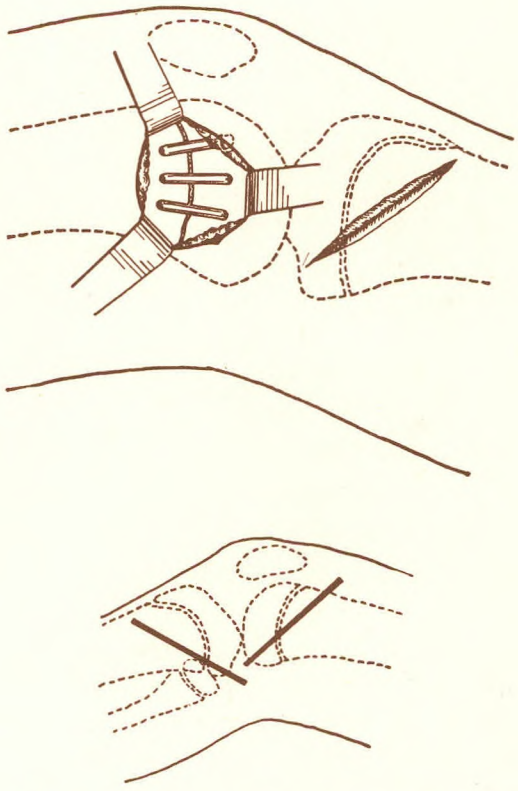

FIG. 2. Oblique incisions are most satisfactory; they afford adequate exposure and cause less scarring.

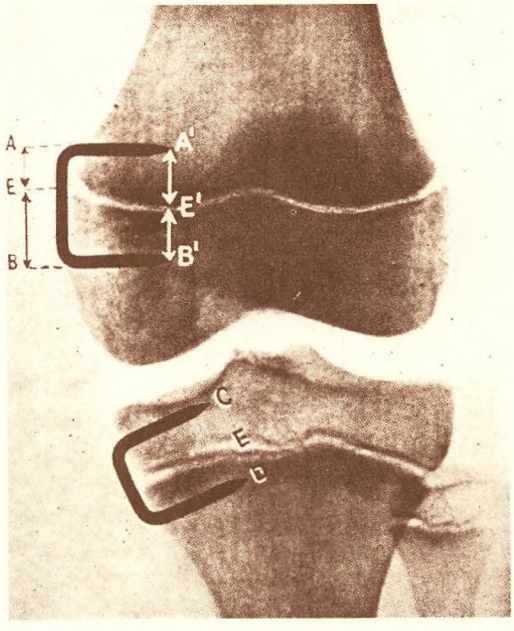

FIG. 3. The epiphyseal plates undulate, as seen in both projections. (See Figs. 8 D and 10 B for lateral views.) For the legs of the staples to be equidistant from the femoral epiphyseal plate, it is necessary that AE be considerably less than EB. Then $A'E'$ will approximately equal $E'B'$. At the proximal end of the tibia, it is necessary to include more of the epiphysis, which is cancellous bone. CE should be greater than ED.

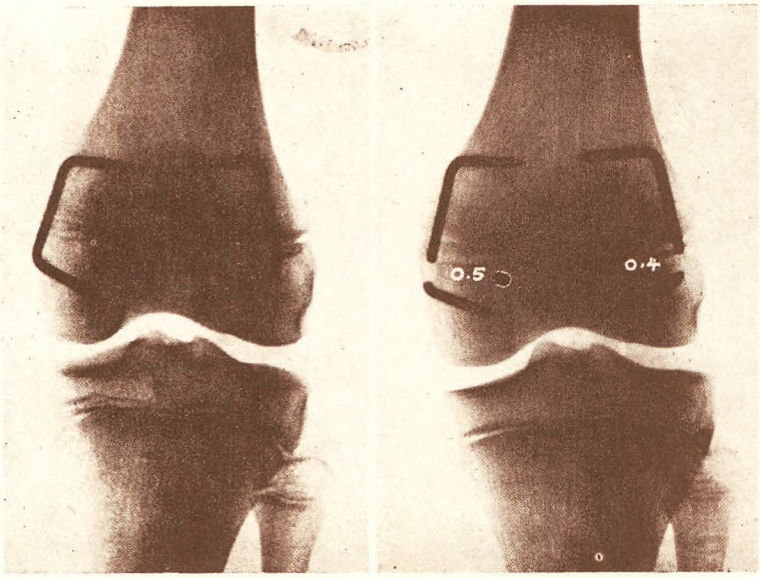

FIG. 4 A–B. A, J. B., aged 11. October 8, 1945, 3 months after stapling. One staple on each side will bend. Note that the maximum bending is in the soft epiphyseal bone. B, Three months later (January 7, 1946), the staples had broken. Three weeks after this roentgenogram, the fragments were left in as markers and new staples were inserted.

cult. It is a mistake to incise the fascia lata with the knee extended. With the knee flexed, the thin dorsal expansion of this fascial layer may be split longitudinally, just dorsal to the iliotibial tract, which is then retracted posteriorly. The vastus lateralis is displaced anteriorly without division of any of its fibers. The mobile soft parts may be retracted easily to expose the condyle, either anteriorly or posteriorly.

Below the knee, it is necessary to cut more of the soft tissues. On the lateral aspect of the tibia, the deep fascia is split longitudinally, just anterior to the head of the fibula. The incision is developed by elevating the fibers of the extensor digitorum longus from the fibula and the tibiofibular ligament. Through this incision, staples may be inserted on the lateral and posterior aspects of the tibia. Posterior staples must be tilted

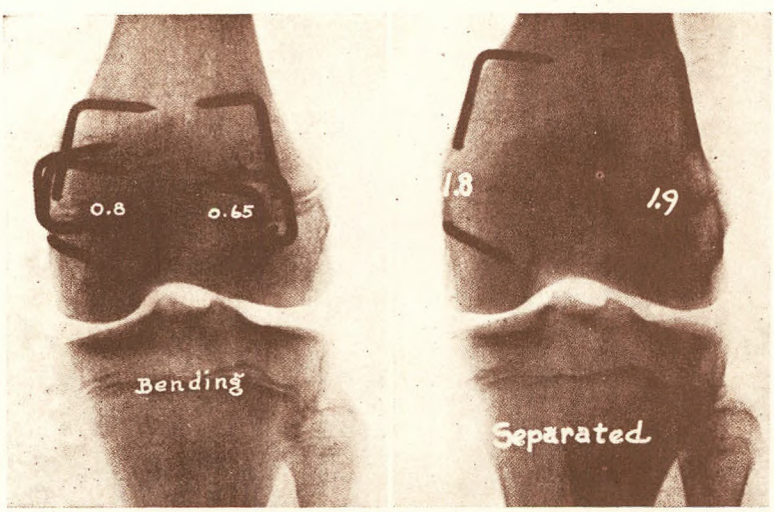

FIG. 4 C–D. C, May 6, 1946. Four months later, and 3 months after insertion of new staples. D, May 24, 1948. Twenty months after removal of the last staples, and 27 months after insertion of the second group of staples. There had been 1.1 cm of growth since Fig. 4 C was taken: 0.3 cm occurred during the time the staples were in place (slippage and bending); 0.5 cm in the first 3 months after removal; and only 0.3 cm in the next 13 months. In the next 10 months there was no growth, although this roentgenogram shows that the epiphyseal plate is just closing.

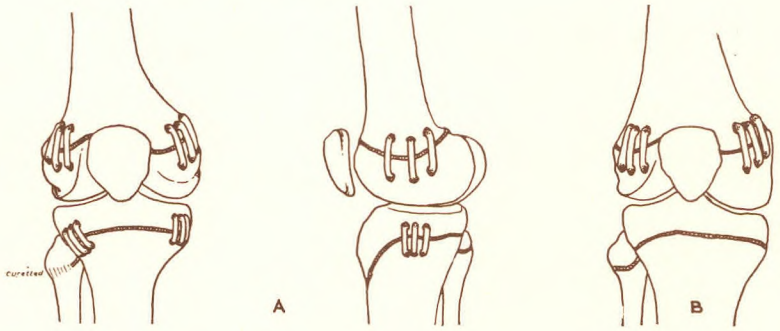

FIG. 5 A–B. Diagrammatic representation of the control of linear growth. Three staples are a unit. A, Total involvement. Femur and tibia are both too long. B, Femoral involvement. Only femur is too long.

anteriorly, to keep the distal leg of the staple from missing the bone and protruding into the popliteal space. If the staples must be placed anteriorly, they are best inserted "blind," just posterior to the tonguelike projection of the epiphysis. The thick ligamentous tissue can then be split along the cross member, and the staple can be buried. It requires some care to keep the staples from protruding into the knee joint.

It should be noted in the roentgenograms that the epiphyseal plates undulate. To obtain maximum efficiency, the staples are placed slightly farther distally on the femur than would appear necessary from the peripheral level of the cartilage; at the proximal end of the tibia, the center of the staple must be slightly proximal (Fig. 3). At the distal end of the femur, anterior or posterior staples must be inserted somewhat proximal to the middle ones (Fig. 5).

While the roentgenograms are being developed, the proximal fibular epiphysis is exposed by elevating the periosteum on the anterior aspect. The peroneal nerve is guarded by bone-elevating retractors. One-half or more of the epiphyseal plate is curetted away. A few bone chips from the metaphysis may be inserted into the defect. It is certainly undesirable to let the fibula grow too long, but there is no particular disadvantage in having it slightly short. Simple curetting has proved so satisfactory that the writers have not used staples at this epiphysis, although they would be preferable in a young child. Staples of the standard sizes are too large for this purpose.

On the medial aspect of the tibia, an oblique incision splits the anterior fibers of the pes anserinus. The tendinous expansion of the sartorius and gracilis may be retracted posteriorly for anterior or medial insertion,

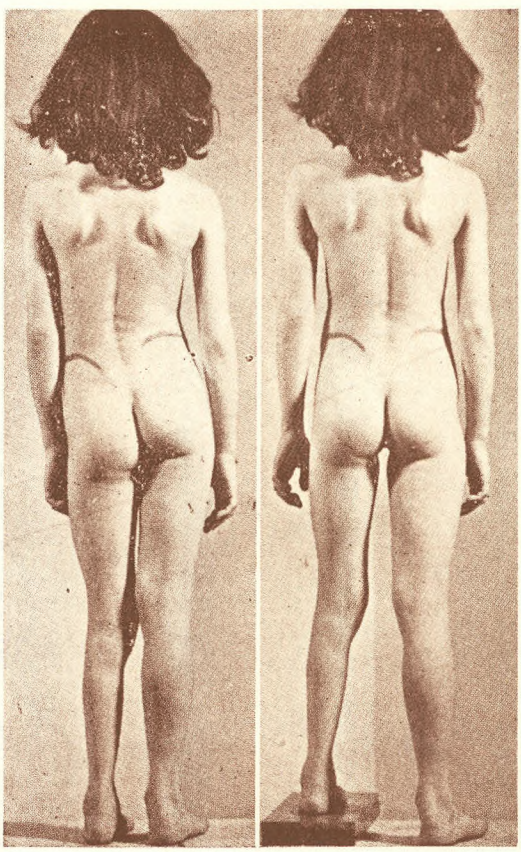

FIG. 6 A. H. H., aged 9. April 3, 1946. Patient has short left tibia following poliomyelitis; triple arthrodesis of left foot has been done. Elevation of 1½ inches fails to level the pelvis.

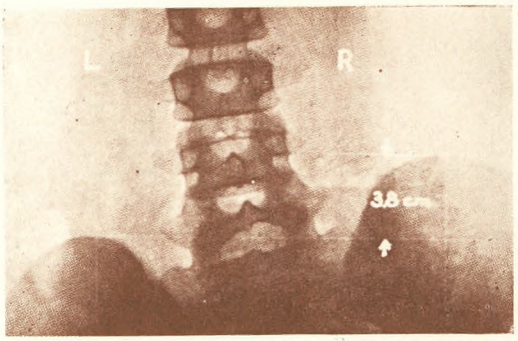

FIG. 6 B. April 3, 1946. Roentgenogram, by White technic, demonstrates total shortening, pelvic tilt, and functional curve.

but cannot well be mobilized for posterior placement. If the surgeon wishes, and particularly if the staples are to remain in permanently, the epiphyseal plate may be exposed. A 1-inch longitudinal incision is made through the periosteum and the cartilage cap. Short crosscuts are made at both ends of this incision. With a thin osteotome, which is curved on the flat, two flaps are raised, exposing the epiphyseal cartilage. It is important to center the staples accurately in the anteroposterior direction. Displacement forward (Fig. 10 C) will result in back-knee, while a backward location will produce the opposite deformity. Three staples are driven so as to bridge the epiphyseal line. Special instruments are not necessary. An inserter or specially prepared pliers and a set (Fig. 1) will facilitate the operation and permit the insertion of staples close together through a small incision.

After all of the staples are in place, roentgenograms are taken in both the anteroposterior and lateral projections. A true lateral view is necessary to prove that both legs of a posterior staple are actually in the cortex of the femur or tibia. If any staple is placed incorrectly, it may easily be withdrawn. For this purpose, a special wedge-shaped, curved-on-the-flat extractor is desirable. The extractor should be driven under the staple, so as to avoid damage to the epiphyseal plate. The staple is then reinserted with the other staples as guides. Roentgenograms in two projections are taken again.

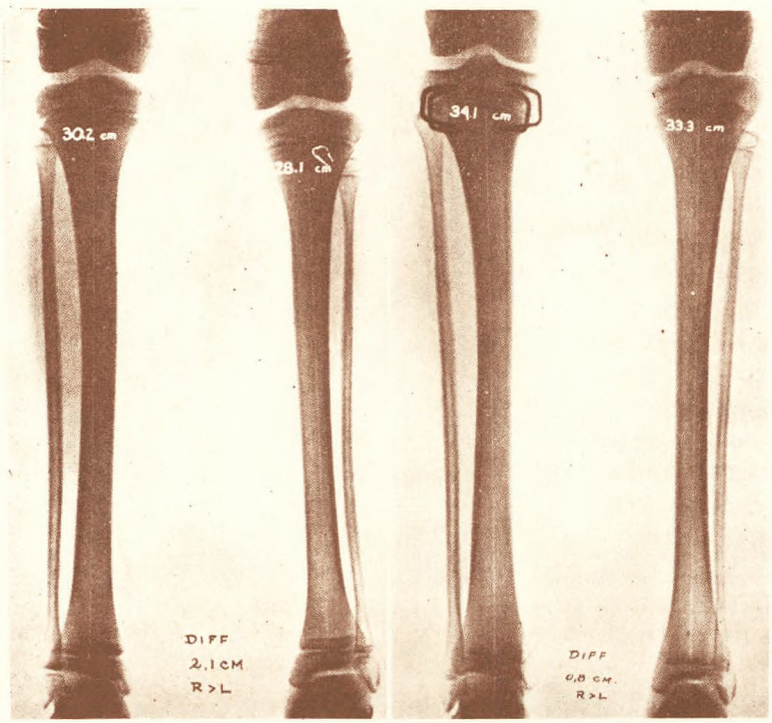

FIG. 6 C–D. C, April 3, 1946. Roentgenogram at 6-foot distance, before stapling. D, December 11, 1948. Roentgenogram at 6-foot distance, 30 months after stapling. Staples have bent. Three staples should have been used on each side instead of 2.

After the exact location of the staples has been verified, the wounds are closed in layers. As is customary following epiphyseodesis, a cylinder cast was applied for three weeks in our earlier cases. When short oblique incisions are used, this not necessary.

By experience, the authors have learned: 1. To use the staples of appropriate size; 2. To use three staples as a basic unit; 3. To study carefully the undulations of the epiphyseal plate in the preoperative roentgenograms (Fig. 3); 4. To obtain accurate roentgenograms in both anteroposterior and lateral projections *in the operating room.*

REMOVAL OF THE STAPLES

The old incision is opened or the scar is excised. If the staples have been driven through the periosteum, it is an easy matter to locate and remove them. If the staples have been buried and considerable bone has grown over them, removal is more difficult than insertion. The periosteum is elevated and chips of bone are removed tangentially with a chisel. Probing with a straight needle is sometimes helpful. If the staples are not discovered immediately, they should be located by roentgenograms. Markers are inserted and roentgenograms taken in the anteroposterior and lateral projections. More bone may then be removed, but mutilation of the epiphysis is not necessary. No growth arrest has been encountered, even if considerable bone has been removed. Care has been taken not to replace bone, which would produce a grafting effect across the epiphysis.

After the cross member of a staple has been uncovered, it is an easy matter to drive the wedge-shaped extractor under it and to "break out" the staple. Extraction with a periosteum elevator or any ordinary instrument is difficult.

COMPLICATIONS

Before the necessity of biplane roentgenograms in the operating room was appreciated, avoidable errors in technic were made.

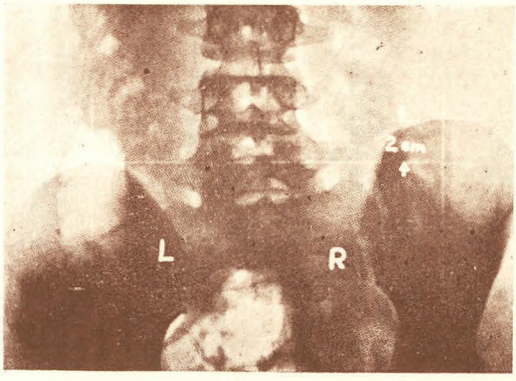

FIG. 6 E. December 11, 1948. Six-foot roentgenogram, by White technic, indicates that total shortening had been reduced to 2 cm. This is almost enough correction because of the drop-foot on the left.

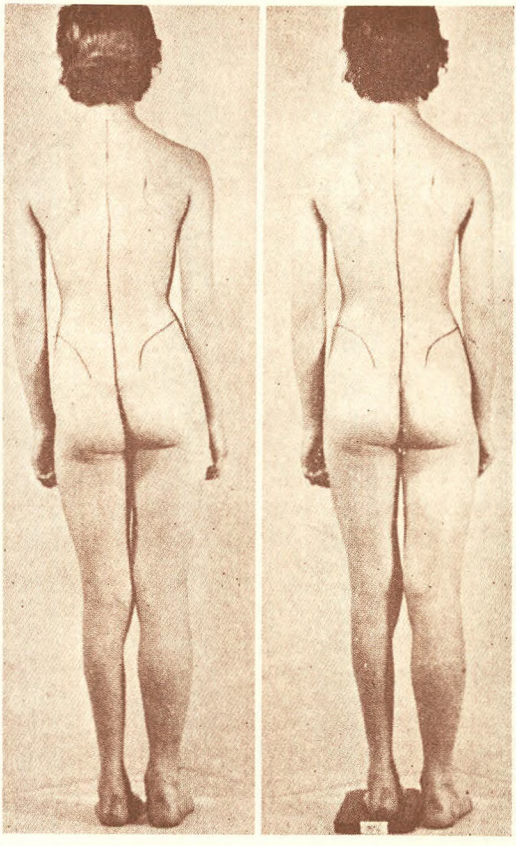

FIG. 6 F. December 11, 1948. Thirty months after stapling, gait had improved. A lift of ¾ of an inch completely corrects the pelvic tilt.

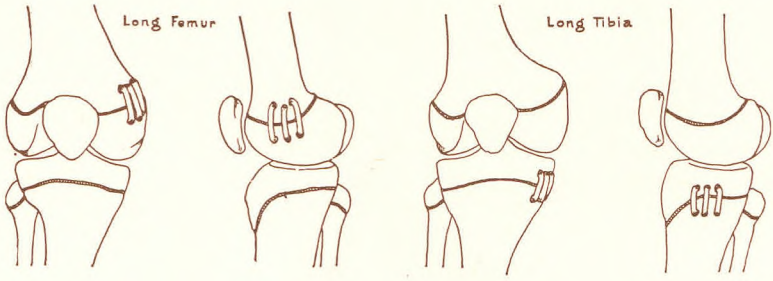

FIG. 7. Diagram of staples placed to correct knock-knee. Femoral and tibial epiphyses could both be stapled in an extreme case.

One staple was left protruding into the knee joint. It was removed and reinserted without subsequent ill effect. On several occasions, the posterior staple at the proximal end of the tibia or the distal end of the femur was wrongly placed. One leg of the staple failed to engage the sloping cortex of the bone. Aiming the staple toward the center of the bone will avoid this mistake, and will also prevent the points of the staples from protruding into the popliteal space. Any such error in technic should be discovered in the operating room; it is easily remedied by reinserting the staple. If later roentgenograms show that one of a group of staples does not change while the adjacent staples start to spread, there is proof of improper insertion of the staple with parallel legs.

Angular deformity and overcorrection have occurred when the patients have failed to report regularly for observation. The serious deformities reported by Straub, Thompson, and Wilson; Regan and Chatterton; and others have not been observed. Deformities which are produced by mistakes of prediction or of technic may be corrected without osteotomy by rearranging the staples, if the child continues to grow.

DISCUSSION

In 1862, Hueter noted the relatively greater growth of bone structures which are under diminished compression. Seven years later, Volkmann laid the foundation for epiphyseal stapling when he referred to the observation of Hueter and added that abnormal differences of compression cause unequal, asymmetrical growth of a joint. On the side where pressure is abnormally increased, growth is retarded.

There is no doubt that growth may be arrested by epiphyseal stapling (Figs. 6 A to 6 F, 8 A to 8 D, 9 A to 9 E, and 10 A to 10 D), and that growth is resumed when the staples have been removed (Figs. 4 A to 4 D). Two questions were raised by Haas[6] with regard to the progress after removal of the staples: (1) Is growth less rapid than would ordinarily be expected? (2) Is growth terminated earlier? We can answer these questions in part.

In most children, prolonged observation after removal of the staples will be futile, as growth will stop within a year or two. In 13 cases, the staples have been removed for 6 months or longer. It might seem expedient

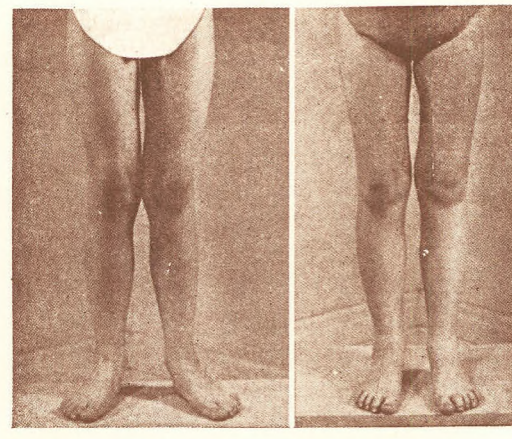

FIG. 8 A–B. A, G. O., aged 9. October 11, 1948. Photograph of patient with hereditary knock-knee, before stapling. B, February 7, 1949. Three months after stapling, there was complete correction of knock-knee.

to chart the subsequent epiphyseal growth as compared with that on the "normal" side. Of the 13 cases, however, only 7 operations were performed primarily for linear deformity and 6 for angular deformity: In several cases, both deformities were present and were corrected simultaneously. Even if we consider only the linear cases, the figures become meaningless. Either the stapled side is abnormal (osteomyelitis. Figs. 9 A to 9 E), or the opposite side is atrophic (poliomyelitis, Figs. 6 A to 6 F), has a mechanical derangement of the epiphysis (trauma), or in some other way is vitiated as a control.

More significant is the observation of the 6 cases of angular deformity in which stapling was done on one side only. All of the extremities were symmetrically aligned with the opposite side at the time the staples were removed (Figs. 8 A to 8 D and 10 A to 10 D). There has been no change of alignment since.

In 2 cases, markers were left in situ after removal of the staples. In one girl, aged 14, the distal femoral epiphysis grew 5 millimeters in the first 3 months. In the following 13 months it elongated only 3 millimeters. In the next 10 months there was no growth on either side, although the epiphysis remained open until the termination of this period. A second girl, aged 7, grew 2.3 centimeters at the distal femoral epiphysis in the first 10 months after removal of the staples. Such variations are probably due to temporary growth spurts and not to the previous stapling.

It is difficult to confirm clinically the excellent experimental work of Haas.[6] We agree when he says: "It is difficult to determine definitely whether or not growth is as active after temporary retardation by a wire or staples. It was not so active as on the normal side, but it is possible that injury to the circulation and trauma to the plate disturbed the growth. There was evidence of premature closure of the plate in some of the experiments."

Growth is "not so active as on the normal side" in his dogs, but in children it is not infrequently *more* active. An epiphyseal plate which has become thin as a result of stapling rapidly regains its former thickness after removal of the staples. Growth is temporarily accelerated, probably due to the stimulus of the operation for removal of the staples. There should be nothing in this operation to retard growth. Significant epiphyseal injury has not been observed. Haas's

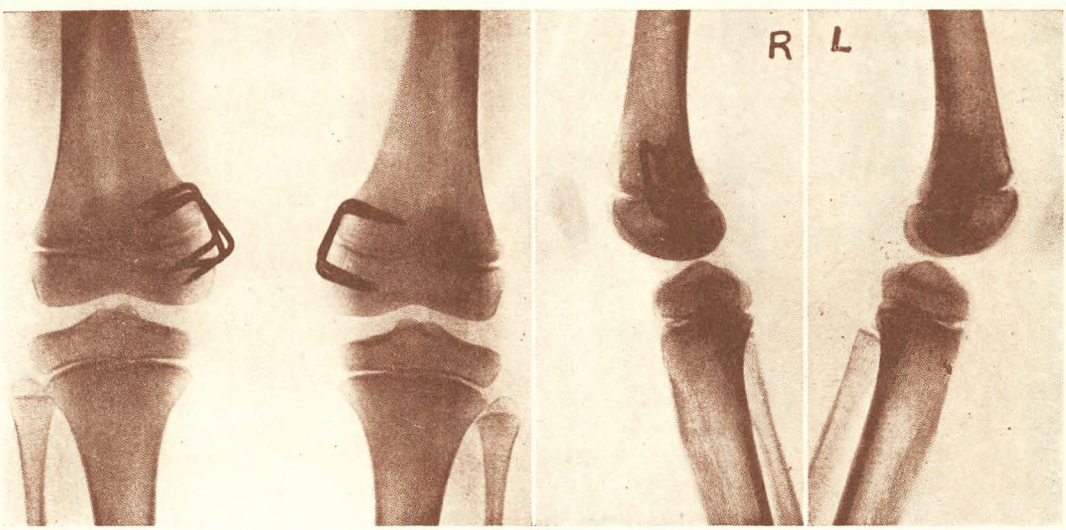

FIG. 8 C–D. February 7, 1949. Valgus had been corrected. Staples were ready for removal.



FIG. 9 A. D. G., aged 7, November 7, 1946. Chronic osteomyelitis of right tibia with overgrowth, valgus knee, and valgus foot.

staples should consider the following example: A 10-year-old child breaks one femur in the middle third. Healing occurs with staples were very large for the size of the bones. The trauma to the epiphysis which he mentions need not occur in children. His observations on unilateral stapling in puppies, with large staples, are not applicable when ¾-inch staples are used in children. Clinically, the effect on longitudinal growth is less and the correction of angular deformity is more than Haas observed when his unilateral staples extended clear across the bone.

In our early personal communications, no untoward epiphyseal closures were reported. We have had none yet. Whether staples are removed or left in situ, epiphyses which have been operated upon usually fuse from 2 to 6 months early. This acceleration of a developmental process is probably due to the stimulus of the operation and not specifically to the stapling. It comes at a time when growth on the other side is minimal or absent, and is not very significant.

Those who want tables and graphs to prove the rate of growth after removal of

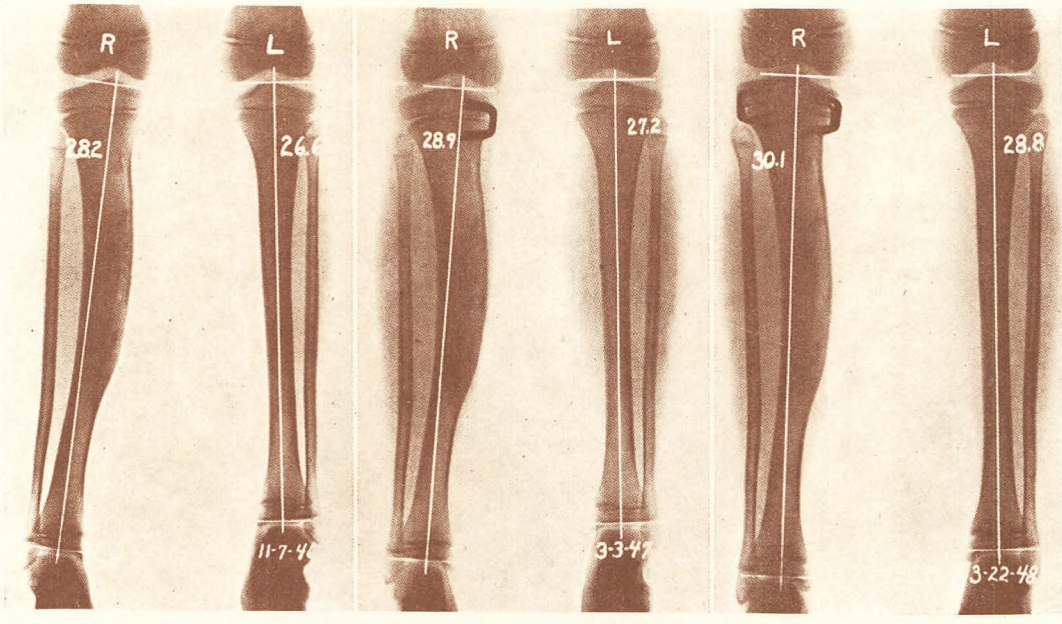

FIG. 9 B–D. B, November 7, 1946. Anteroposterior roentgenogram shows angular deformity on right side. The difference in length of the tibiae was 1.6 cm. C, March 3, 1947. Four months after stapling, the angular deformity had been corrected. The linear deformity was unchanged. Staples were then inserted on the lateral aspect. D, March 22, 1948. One year after second stapling, linear deformity had been corrected by 0.3 cm.

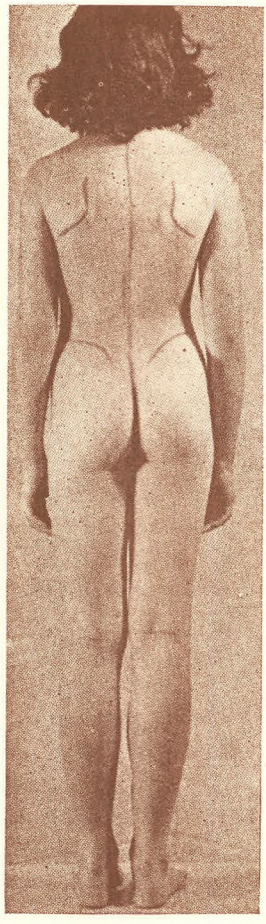

FIG. 9 E. December 18, 1948. Nine months later, additional correction of 0.3 cm had been obtained (total correction of the tibiae of 0.6 cm.

bayonet apposition and one centimeter of shortening. One of 3 things may happen:

1. The bone will probably overgrow, due to the stimulus of the fracture. Accurate measurement at the end of six months will show that the femora are about equal in length.

2. There may be no overgrowth of bone, but persistent shortening of about one centimeter.

3. There may be excessive overgrowth of bone, so that the injured femur is as much as one inch too long. When the results of a simple fracture in a normal bone vary so much, we can attach little value to statistical studies of growth increment in abnormal bones.

The best way to test growth after the removal of staples is to watch a case of idiopathic knock-knee in a boy of 10 to 12 years. In a boy of this age there is little tendency to further change in angulation. If 3 staples are inserted on the medial aspect of each distal femoral epiphysis, the deformity will be completely corrected in from 3 to 8 months (Figs. 8 A to 8 D). The exact time depends upon the extent of the deformity and the rate of growth during the control period. If the staples are then removed and photographs and roentgenograms are taken, a record of the straightness of the

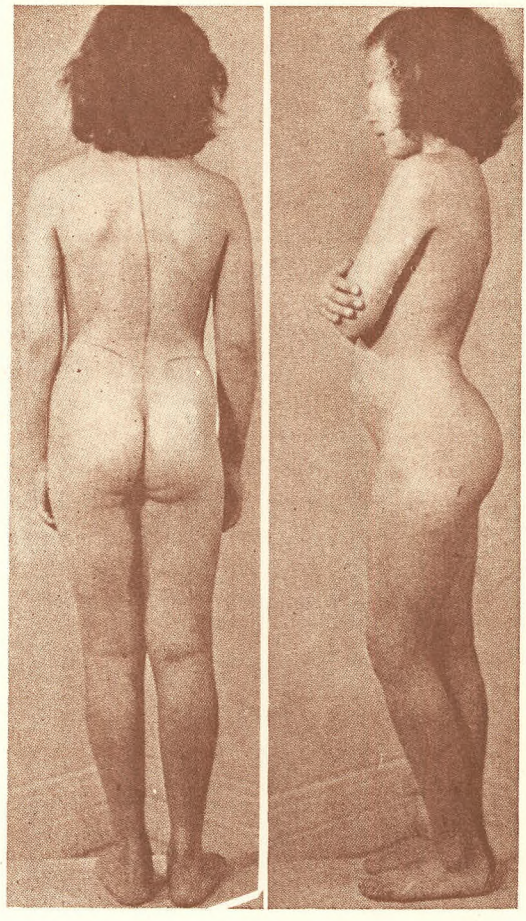

FIG. 10 A. C. P., aged 9. February 4, 1948. This child had had monarticular atrophic arthritis of the left knee at the age of 2 years. The active process subsided, leaving flexion deformity of 25° of the left knee and overgrowth of the left femur.

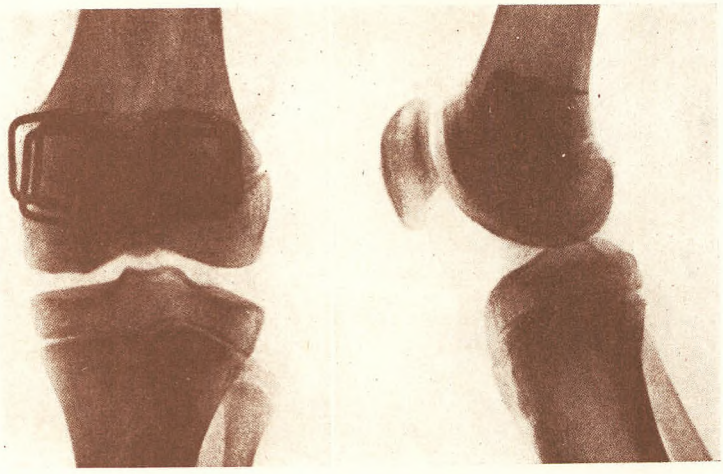

FIG. 10 B. June 11, 1948. Four months after stapling to correct both linear and angular deformities.

lower extremities is established. If the existing state is maintained, then we have clinical proof that essentially normal growth of the epiphysis has been resumed. The untouched lateral aspect of each epiphysis acts as a control. Two such cases have been observed for 10 months or longer without change in alignment. If several such cases are observed until growth has ceased, we shall have valuable proof to report in a future paper

"More difficult than the actual technical procedure is the decision as to when the operation should be performed and which epiphyses should be fused." This was the decision of Wilson and Thompson, after describing an elaboration of Phemister's technic with the removal of large grafts, curetting, and cauterization of much of the epiphyseal plate. Stapling simplifies the operation, and it also answers their questions.

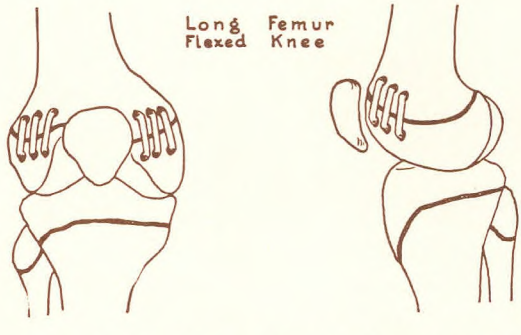

FIG. 10 C. Diagram of staples placed to correct overgrowth and flexion deformity simultaneously.

The operation should be performed several years earlier than appears necessary from the actuarial charts. It should be performed at a time that is convenient to the patient; the exact date makes little difference. When the deformity has been corrected, the staples are removed.

The decision as to which epiphysis to staple is no longer a serious matter. Both the proximal tibial and the distal femoral epiphyses should be stapled. When the individual bone is of the proper length, the staples are removed.

Sixteen years after the publication of Phemister's article, there is still no unanimity as to a method of estimating growth. White's simple annual increment,[17] the percentage factor of Wilson, Thompson, and Straub,[13, 18] and the various tables and graphs of growth expectancy of Green and Anderson and others are all inadequate in the face of individual variations. We have not discarded these approximations; they furnish valuable help in planning stapling operations. When the staples are in, however, further decisions are based upon clinical observation and not upon calculation. Actually, only 2 precautions are necessary to ensure successful timing: (1) The staples must be inserted early enough (but not usually before 8 years) to assure correction before growth is com-

pleted. (2) The patient must be observed frequently, so that the staples may be removed at just the right time.

The indication for removal of staples is not determined by measurement, but by watching the patient walk. This is particularly true when an unstable hip, stiff knee, drop-foot, or other abnormality influences the decision. It is helpful to have the patient remove the shoe on the side of the longer extremity so that the effect of further shortening may be observed. In the presence of multiple deformities, the removal of staples becomes the "micro-adjustment" of disability correction. With increased experience, we frequently operate for discrepancies of length that are less than the average error in prediction by the actuarial method.

We do not know how long one may safely leave staples in situ with the assurance of growth after removal. In 1945, Phemister[10] suggested that the interval be limited to 2 years. In adhering to this rule, we have encountered no untoward epiphyseal closures. It is probable that a longer interval is safe in most cases. Further studies will be made with reference to this important point.

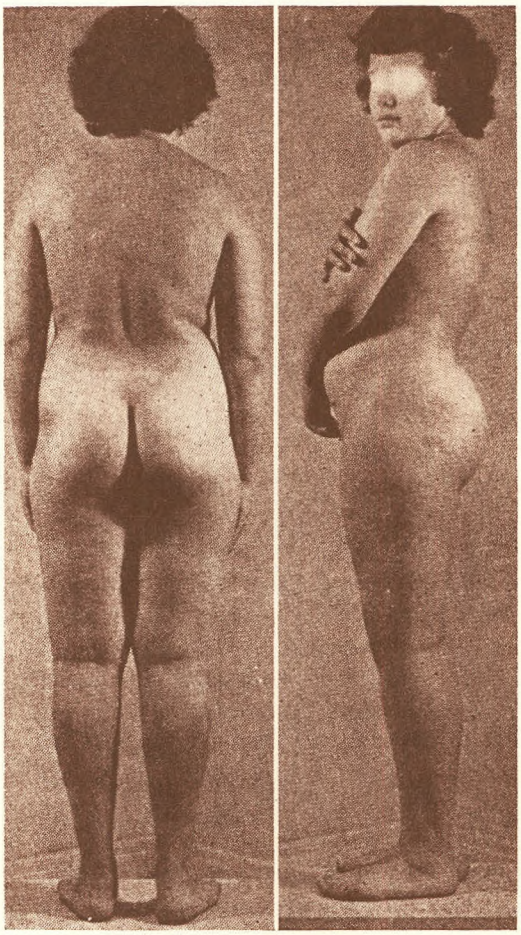

FIG. 10 D. January 5, 1949. Staples were left in place 10 months. Photographs, taken one month after removal, show that left knee is straight and pelvis is level.

CONCLUSIONS

1. Efficient stapling of the distal femoral and proximal tibial epiphyses stops the elongation of bone at these epiphyses immediately and almost completely.

2. The operation is less extensive and the risk of complication is less than with other operative methods of controlling bone growth.

3. Angular deformity may be corrected during the growth period. Knock-knee, bow-leg, back-knee, flexion deformity, or combinations of these deformities are rapidly overcome.

4. The occasional complicating irregularities of growth following stapling should be detected clinically and corrected immediately by rearrangement of the staples.

5. After removal of the staples, growth at the epiphysis is resumed at about the same rate as would be expected on the other side, if both sides were normal. It is sometimes faster and sometimes slower. The variations in rate are usually caused by factors other than staples.

6. The best proof of the normal rate of growth after removal of staples is the persistence of a straight extremity after correction of an idiopathic knock-knee.

7. Several important questions are being studied further:

A. What is the ideal size and design of staples?

B. For what length of time and for what ages is it safe to leave staples in place?

C. What are the factors influencing epiphyseal closure?

D. What is the rate of growth after removal of staples which were inserted for various conditions?

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WILLIAM PUTNAM BLOUNT

Walter Putnam Blount (1900–) of Milwaukee, was Chief of Orthopaedic Dept. at the Medical College of Wisconsin. This original contribution of stapling ephysises which unlike previous processes, permitted subsequent correction, was one of the most innovative of his many contributions. The other was his work on the "halo" brace (The Milwaukee Brace).

CLASSIC 54 An Obscure Affection of the Hip Joint

ARTHUR T. LEGG, M.D. (1874–1939)

We are at times painfully aware of the fact that there are many symptoms which we readily recognize in our clinical observations to which we can assign no cause, and it is also an undoubted fact that there are many conditions even which exist today of which we are ignorant, simply from our neglect to observe, or from faulty observation, or, again, from faulty deduction even from good observation.

The cases which I bring to your attention today seem to me illustrative of the fact that we, in the past, have not observed certain conditions which truly exist, and that now, having observed, we naturally must ask ourselves, Are our observations faulty or are they correct? and, assuming them to be correct, what is the cause of the condition?

I invite your attention to the report of five cases, four of which I have followed at the Children's Hospital and one which is a patient of Dr. Joel E. Goldthwait, for the privilege of reporting which I am indebted to him.

The first case, a well-developed girl of eight, was brought to the Children's Hospital in October, 1907, with a history of a fall nine months before, immediately followed by a limp on the right which had persisted. There had been no pain or constitutional symptoms.

Read at the annual meeting of the American Orthopedic Association at Hartford, June, 1909.

Examination showed normal flexion of the right hip with all other motions much limited. There was very slight spasm, slight atrophy of the thigh and calf, but no shortening. There was a slight amount of thickening anterior to the neck. The motions of the left hip were normal.

A traction hip splint was applied, which she has worn since. She has had no acute symptoms, nor pain, and has remained in excellent general condition. The very slight spasm present at the first examination disappeared in about a month.

Examination of the right hip at the present time shows motion in flexion to 100°, abduction to 50°, adduction normal. Internal and external rotation is possible to about 45°. The thickening about the joint has remained the same, and the right leg now measures one quarter of an inch longer than the left.

There has been no pain or limp on the left, and the motions of this hip are normal. A slight amount of thickening, however, is felt about this hip.

The Von Pirquet test was negative. Roentgenological examination shows the head of the right femur to be flattened and apparently spread out. The neck appears thickened and shorter than normal. An area of increased radiability appears in the upper part of the head and neck. The left or apparently normal side shows the same condition with the exception of the area of increased radiability.

The second case was an active boy of eight who first came to the Children's Hospital in January, 1908. In May, 1907, he had fallen, fracturing his right humerus. Two months later

a limp on the right was noticed which had persisted. No pain or constitutional symptoms had been noticed.

On physical examination the right hip showed 20° permanent flexion and 10° permanent adduction. There was considerable limitation of motion in flexion and outward rotation, while other motions were normal. There was atrophy of the thigh and calf, but no shortening. There was slight spasm.

A flannel spica was applied, allowing him to use the leg as he wished. At the end of six months the permanent adduction was 15°, the great trochanter was more prominent than the left, and the thickening about the trochanter was greater. There was still no pain or constitutional symptoms.

A plaster spica was at this time applied, which treatment has been followed since. He now shows no permanent deformity, with motion in flexion to 90°, abduction and adduction 45°, and rotation one half of normal. The legs are of equal length. The Von Pirquet test was negative. The roentgenogram of this case shows a flattening of the head of the femur, with an irregular area of increased radiability near the epiphyseal line. The neck seems shorter and thicker than the other side and there is no atrophy of size of the shaft. The left hip is apparently normal.

The third case was a well-developed Italian boy of five, who came to the Children's Hospital in August, 1908, with a history of a fall ten months previous and a limp on the left for nine months.

Extremes of motion in flexion and abduction were the only motions limited. There was slight atrophy of the thigh and calf and no shortening or spasm.

He was put under traction treatment, which has been followed since.

He now shows on physical examination motion in flexion to 100°, in abduction 45°, and in adduction 30°. Rotation is normal and there is no spasm. The left trochanter is more prominent than the right and there is slight thickening anterior to the joint. The left leg measures one quarter of an inch longer than the right.

There has never been any pain or constitutional symptoms, and the Von Pirquet test was negative.

The Roentgen examination of this case shows a flattening of the head and a spreading out, as seen in the first case. The neck is shorter and thicker than on the right.

The fourth case, a boy of six, came to the Children's Hospital in January, 1909, with a history of limp on the right for a year and a half, immediately following a fall from a ladder.

Examination showed only slight limitation of motion in abduction and internal rotation, with no spasm. There was very slight atrophy of the thigh and calf, but no shortening. The examination of the left hip was negative.

This case has been under protective treatment by a flannel spica since his first visit and has shown no change on physical examination, nor has there been any pain, spasm or constitutional symptoms. No thickening about the hips was palpable in this case.

The Roentgenogram of this case shows a small, flat head with a short thick neck on the right. On the left, where there are no symptoms, a similar condition is seen, but to a more marked degree. On this side is seen a small area in the neck near the epiphyseal line similar to a necrotic area.

The fifth case (Dr. Goldthwait's) was a boy of six, who came to him in December, 1908. One year previous he had a fall in which the legs were spread apart. He was lame for a week, and apparently recovered. Seven months later a limp on the left was noticed. He was restless at night and had indefinite pain referred chiefly to the left groin. A short time before this he had an abscess of the ear.

In the extremes of motion there was slight limitation. There was slight atrophy of the thigh, but none of the calf, and no shortening was present. There was distinct thickening over the neck of the femur.

The Roentgenogram showed a flattened head and a distinct necrotic area just outside the epiphyseal line in the neck, with apparently some thickening of the neck. The focus was curetted out, it being approached through the great trochanter. A culture from the necrotic material obtained showed a staphylococcus growth. The case is now under protective treatment.

In reviewing these cases, the following facts in a general way are observed:

(1) Age, five to eight years.

(2) History of injury.

(3) Limp.

(4) Thickening about the neck of the femur.

(5) Absence of pain.

(6) Absence of constitutional symptoms.

(7) Little or no spasm.

(8) Absence of shortening.

I have to record one exception to the above. You will observe in Case V that indefinite pain was a symptom. This is the case in which there existed a low grade of infection in the neck of the femur.

It is worthy of note that all these cases sought advice solely on account of the limp. It is also of interest that in two of the cases (the first and the fourth) the condition of flattening of the head of the femur exists on both sides; and it is of the greatest interest that in both cases there was entire absence of symptoms in one of the hips.

We have considered a group of cases all presenting practically the same conditions, both positive and negative, and which are to my mind atypical of any condition heretofore described, and granting that our observations are correct, we naturally seek a cause for this most interesting clinical picture. In so doing we must consider some of the possibilities.

Is this condition the result of congenital deformity or faulty development?

Is it the result of a constitutional disease?

Is it the result of direct injury?

Is it indirectly due to the injury?

We see in many cases of congenital dislocation of the hip a deformed and poorly developed head of the femur. None of these shows a condition similar to the one described, and the history would seem to rule out this possibility.

In rickets and in syphilis the nutritional impairment affecting the bones never to my knowledge produces a condition of this kind, and the general condition of these cases is apparently excellent.

Direct injury, if severe enough, might cause a flattening of the head of the femur, and in children of this age the head is certainly impressionable. Should this be the cause in these cases, the thickening and shortening of the neck without evidence of fracture remains unexplained. We all know that the history of injury, especially in children, should be given much latitude, but in this group of cases, with a history of distinct injury in all of them, it seems to me that it must be considered, and at this time it seems to me that a possible explanation of the conditions is that the injury may indirectly cause this condition by causing injury or displacement at the epiphyseal line, whereby the nutrition of the head, coming mostly through the neck, is impaired, and by the poorly nourished epiphysis bearing on the acetabulum, it becomes flattened. From such an injury a hyperemia of the neck of the femur would occur, and by this to stimulate bone growth the thickening of the neck may be explained.

Of the occurrence of a similar condition appearing in the apparently normal hip, I shall not, at this time, attempt to offer any explanation. Contre-coup and sympathetic inflammation may be considered, but these are, to my mind, very remote possibilities.

If a hyperemic condition is present in the neck of the femur as a result of a deranged circulation, it may be the explanation of infection taking place at this point, as is seen in the fifth case. It does not seem probable to me that the change in the head in this case is secondary to the infection in the neck, for we see many cases of infection in the neck, and in none of these have I seen the condition described present in the head.

It is unnecessary for me to say in closing that in reporting these cases I make no claim to any definite conclusion, both on account of the small number of cases observed and from the length of time they have been under observation; still, I am glad to have brought them to your attention in the hope that in so doing more cases of this type may come under observation and that by further study their true etiology may be determined.



ARTHUR THORNTON LEGG

Arthur Thornton Legg (1874–1939), while Junior Assistant Surgeon at Children's Hospital in Boston, presented a description of osteochondrosis of the femoral head before the American Orthopaedic Association meeting in June of 1909. The presentation appeared in print as this Classic. The lesion was later described by Perthes in the German literature (Perthes, G. C.: Über Arthritis deformans juvenilis, Deutsch Z. Chir. 107-111, 1910) and by Calvé in the French (Calvé, J.: Sur une forme particulière de pseudo-coxalgie greffe sur des déformations caractéristique de l'extrémité supérieure du femur, Rev. Chir. (Paris) 42:54, 1910). All three papers appeared in 1910.

Rang, in his Anthology, has recently noted that Perthes in a later report courteously acknowledged Legg's priority and Legg acknowledged the fact that Perthes had made the lesion more widely known. It is at present known as Legg-Calvé-Perthes disease.

CLASSIC 55 On the Fracture of the Carpal Extremity of the Radius

ABRAHAM COLLES, M.D. (1773–1843)

The injury to which I wish to direct the attention of surgeons, has not, as far as I know, been described by any author. Indeed, the form of the carpal extremity of the radius would rather incline us to question its being liable to fracture. The absence of crepitus, and of the other common symptoms of fracture, together with the swelling which instantly arises in this, as in other injuries of the wrist, render the difficulty of ascertaining the real nature of the case very considerable.

This fracture takes place at about an inch and a half above the carpal extremity of the radius, and exhibits the following appearances.

The posterior surface of the limb presents a considerable deformity; for a depression is seen in the fore-arm, about an inch and a half above the end of this bone, while a considerable swelling occupies the wrist and metacarpus. Indeed, the carpus and base of metacarpus appear to be thrown backward so much, as on first view to excite a suspicion that the carpus has been dislocated forward.

On viewing the anterior surface of the limb, we observe a considerable fulness, as if caused by the flexor tendons being thrown forwards. The fulness extends upwards to about one-third of the length of the fore-arm, and terminates below at the upper edge of the annular ligament of the wrist. The extremity of the ulna is seen projecting towards the palm and inner edge of the limb: the degree, however, in which this projection takes place, is different in different instances.

If the surgeon proceeds to investigate the nature of this injury, he will find that the end of the ulna admits of being readily moved backwards and forwards.

On the posterior surface, he will discover, by the touch, that the swelling on the wrist and metacarpus is not caused entirely by an effusion among the softer parts; he will perceive that the ends of the metacarpal, and second row of carpal bones, form no small part of it. This, strengthening the suspicion which the first view of the case had excited, leads him to examine, in a more particular manner, the anterior part of the joint; but the want of that solid resistance, which a dislocation of the carpus forward must occasion, forces him to abandon this notion, and leaves him in a state of perplexing uncertainty as to the real nature of the injury. He will therefore endeavor to gain some information, by examining the bones of the fore-arm. The facility with which (as was before noticed) the ulna can be moved backward and forward, does not furnish him with any useful hint. When he moves his fingers along the anterior surface of the radius, he finds it more full and prominent than is natural; a similar examination of the posterior surface of this bone, induces him to think that a depression is felt about an inch and a half above its carpal extremity. He

now expects to find satisfactory proofs of a fracture of the radius at this spot. For this purpose, he attempts to move the broken pieces of the bone in opposite directions; but, although the patient is by this examination subjected to considerable pain, yet, neither crepitus nor a yielding of the bone at the seat of fracture, nor any other positive evidence of the existence of such an injury is thereby obtained. The patient complains of severe pain as often as an attempt is made to give the limb the motions of pronation and supination.

If the surgeon locks his hand in that of the patient's, and makes extension, even with a moderate force, he restores the limb to its natural form; but the distortion of the limb instantly returns on the extension being removed. Should the facility with which a moderate extension restores the limb to its form induce the practitioner to treat this as a case of sprain, he will find, after a lapse of time sufficient for the removal of similar swellings, the deformity undiminished. Or, should he mistake the case for a dislocation of the wrist, and attempt to retain the parts in situ by tight bandages and splints, the pain caused by the pressure on the back of the wrist will force him to unbind them in a few hours; and if they be applied more loosely, he will find, at the expiration of a few weeks, that the deformity still exists in its fullest extent, and that it is now no longer to be removed by making extension of the limb. By such mistakes the patient is doomed to endure for many months considerable lameness and stiffness of the limb, accompanied by severe pains on attempting to bend the hand and fingers. One consolation only remains, that the limb will at some remote period again enjoy perfect freedom in all its motions, and be completely exempt from pain: the deformity, however, will remain undiminished through life.

The unfavourable result of some of the first cases of this description which came under my care, forced me to investigate with peculiar anxiety the nature of the injury. But while the absence of crepitus and of the other usual symptoms of fracture rendered the diagnosis extremely difficult, a recollection of the superior strength and thickness of this part of the radius, joined to the mobility of its articulation with the carpus and ulna, rather inclined me to question the possibility of a fracture taking place at this part of the bone. At last, after many unsuccessful trials, I hit upon the following simple method of examination, by which I was enabled to ascertain, that the symptoms above enumerated actually arose from a fracture, seated about an inch and a half above the carpal extremity of the radius.

Let the surgeon apply the fingers of one hand to the seat of the suspected fracture, and, locking the other hand in that of the patient, make a moderate extension, until he observes the limb restored to its natural form. As soon as this is effected, let him move the patient's hand backward and forward; and he will, at every such attempt, be sensible of a yielding of the fractured ends of the bone, and this to such a degree as must remove all doubt from his mind.

The nature of this injury once ascertained, it will be a very easy matter to explain the different phenomena attendant on it, and to point out a method of treatment which will prove completely successful. The hard swelling which appears on the back of the hand, is caused by the carpal surface of the radius being directed slightly backwards, instead of looking directly downwards. The carpus and metacarpus retaining their connexions with this bone, must follow it in its derangements, and cause the convexity above alluded to. This change of direction in the articulating surface of the radius is caused by the tendons of the extensor muscles of the thumb, which pass along the posterior surface of the radius in sheaths firmly connected with the inferior extremity of this bone. The broken extremity of the radius being thus drawn backwards, causes the ulna to appear prominent toward the palmar surface, while it is possibly thrown

more towards the inner or ulnar side of the limb, by the upper end of the fragment of the radius pressing against it in that direction. The separation of these two bones from each other is facilitated by a previous rupture of their capsular ligament; an event which may readily be occasioned by the violence of the injury. An effusion into the sheaths of the flexor tendons will account for that swelling which occupies the limb anteriorly.

It is obvious that, in the treatment of this fracture, our attention should be principally directed to guard against the carpal end of the radius being drawn backwards. For this purpose, while assistants hold the limb, in a middle state between pronation and supination, let a thick and firm compress be applied transversely on the anterior surface of the limb, at the seat of fracture, taking care that it shall not press on the ulna; let this be bound on firmly with a roller, and then let a tin splint, formed to the shape of the arm, be applied to both its anterior and posterior surfaces. In cases where the end of the ulna has appeared much displaced, I have laid a very narrow wooden splint along the naked side of this bone. This latter splint, I now think, should be used in every instance, as, by pressing the extremity of the ulna against the side of the radius, it will tend to oppose the displacement of the fractured end of this bone. It is scarcely necessary to observe, that the two principal splints should be much more narrow at the wrist than those in general use, and should also extend to the roots of the fingers, spreading out so as to give a firm support to the hand. The cases treated on this plan have all recovered without the smallest defect or deformity of the limb, in the ordinary time for the cure of fractures.

I cannot conclude these observations with out remarking, that were my opinion to be drawn from those cases only which have occurred to me, I should consider this as by far the most common injury to which the wrist or carpal extremities of the radius and ulna are exposed. During the last three years, I have not met with a single instance of Dessault's dislocation of the inferior end of the radius, while I have had opportunities of seeing a vast number of the fracture of the lower end of this bone.

Stephens Green
February 21, 1814



ABRAHAM COLLES

Abraham Colles (1773–1843) held the Chair of Surgery at the Royal College of Surgeons in Dublin for over 30 years and was considered one of the leading surgeons of his time. He and his contemporaries were the founders of modern surgery. Colles wrote extensively on venereal disease. He was famous for having ligated the subclavian vein and innominate vein, and he was probably the first to accomplish the operation successfully. The eponym "Colles' fracture" comes from the classical clinical description in this article.

CLASSIC 56 Principles Involved in the Treatment of Congenital Clubfoot

J. HIRAM KITE, M.D.† (1891–)

The purpose of this paper is to make a plea for conservative treatment of congenital club-foot and to call attention to certain mechanical and pathological principles involved. It is the author's experience that cost club-feet can be successfully corrected by a series of plaster casts and wedgings, without the use of anaesthetics, forcible manipulations, or operative procedures, and with far better results.

Before the era of modern surgery, numerous machines were devised for the forcible correction of club-feet, and a variety of braces were worn. With the advent of aseptic surgery there were described in rapid succession a large number of operations, first on the fascia and tendons, and a little later on the bones and joints of the foot. It seems that the chief object of these operative methods was a rapid anatomical correction of the club-foot deformity, without giving much thought to the future function of the foot.

It must be admitted that most club-feet are improved somewhat in appearance by forcible manipulations and operations, and occasionally a foot is restored to almost normal appearance with very little functional impairment. However, when a series of these cases, in which operations had been performed by the author and by others, were followed for a number of years and studied critically, it was found that there were many relapses, and that many patients had stiff, rigid feet, a few of which were more disabling than the original deformity.

After reviewing the literature and studying a series of operative cases, it seemed that if progress were to be made in the treatment of club-foot, it would not be made by devising a new operation, or by doing more accurately the operations which had already been devised, but that it would be by a method which did no harm to the foot, and which caused no adhesions in the many joints of the foot.

Inspired by a clearer understanding of the mechanics of the foot as taught by Dr. Michael Hoke, as well as by his meticulous attention to details in the application and molding of the cast, the writer followed the principles which Dr. Hoke recommended, and finally obtained a good correction of a club-foot, without resorting to any operative procedures. The treatment extended over a long period of time, but the surprisingly good functional result repaid for the addi-

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tional time and effort. During the past fifteen years the author has personally treated over 400 patients with club-feet. The observations made here are based on a study of this group.

The writer has previously shown roentgenograms of cases where all the bones in the posterior foot had fused to each other and to the tibia, following forcible manual manipulations under an anaesthetic. Such extensive ankylosis is not the rule. However, when any force is used in manipulating a foot, some injury is done to the joints in the foot. The cartilage is often cracked, and the bones are partially crushed, forcing bone cells into the joint spaces. When the foot is held for a month or two in plaster casts following the manipulation, it is not surprising that fibrous ankylosis, or often bony ankylosis, occurs.

A microscopic study of some of these joints following forcible manipulations of the feet has been made by Dr. Everett L. Bishop. These joints were removed when operation was done later for correction of the deformity. He states: "This condition may be described as a chronic, non-infectious, inflammatory reaction due to pressure, with organization of the tissue and fusion of the bones—first by fibrous connective tissue, later by some new ossification —the bones finally becoming fused together into a fibro-osseous mass."

Another type of injury which may follow operative treatment is illustrated by a patient under treatment at the present time. This boy had had an operation on the medial side of the ankle and foot when he was a year old. When he was two and a half years old the deformity had recurred, and another surgeon did a similar operation at the same point. The distal tibial epiphysis was injured and later it fused. Roentgenograms made at the ages of four and five and a half years show that the fibula has continued to grow, while growth has ceased in the lower end of the tibia. The foot is being forced around in varus, and the deformity is increasing with time.

Space does not permit a long summary of the harm that may come to a foot following operative procedures, but many examples can be found in the relapsed cases brought to any club-foot clinic.

Club-foot deformity may be divided into three parts: adduction, inversion, and equinus deformities. The forefoot is *adducted* when compared with the posterior foot. The os calcis is rotated inward under the astragalus, causing the entire foot to assume an *inverted* position. The *equinus* deformity may be divided into two parts: the forefoot is plantar-flexed when compared to the posterior foot, giving "forefoot equinus"; the entire foot is plantar-flexed in the ankle joint, giving "ankle equinus." Each of these three deformities must be completely corrected, and in the order mentioned.

When the forefoot *adduction* is corrected, the navicular, which was medial to the head of the astragalus, is drawn around in front of the head of the astragalus. The weight thrust down the tibia is transmitted through the astragalus to the navicular and straight forward to the toes. If an attempt is made to dorsiflex the foot before the navicular is in the proper position, the latter will be forced up on the medial side of the head of the astragalus. If much force is used, the navicular may become fixed on the medial side of the head, and later it will be found very difficult to move. If the navicular is still on the medial side of the head, when the treatment is discontinued and the child is allowed to walk, the weight thrust will fall obliquely on the side of the navicular, and push the forefoot back into the adducted position. If the forefoot is carried outward too far, the navicular may be drawn around lateral to the head of the astragalus into a flat-foot position, which is undesirable. Care should be exercised to correct the adduction deformity completely without overcorrecting it.

Correction of the *inversion* deformity is of sufficient importance to justify a more detailed discussion. The value of thoroughly correcting this deformity was not fully appreciated until about five years ago, when a study was being made of a series of cases of recurrent club-foot. The original photographs and roentgenograms in this recurrent cases showed no unusual inherent deformity that might account for the relapse. The importance of the correction of the inversion deformity was realized during the treatment of the following two cases.

A five-year-old girl with bilateral club-foot, the correction of which had previously been attempted elsewhere, was treated with a series of plaster casts and wedgings. The feet appeared to be well corrected when she was dismissed. A few months later she returned, walking on the lateral border of each foot. Roentgenograms made on dismissal were thought at that time to have shown a satisfactory correction. It was later realized that the author's interpretation was in error and that the roentgenograms really showed that the inversion deformity had not been corrected.

At about this same time, another girl with bilateral club-foot, who had been treated with casts and wedgings, returned for observation. She placed the right foot in the normal position, but walked on the lateral border of the left foot. The anteroposterior roentgenogram showed that the inversion deformity of the posterior foot had been corrected on the right, but that it had not been corrected on the left.

The inversion deformity is recognized in the anteroposterior roentgenogram by the fact that the os calcis is rolled in under the astragalus, so that the shadow of the anterior end of the os calcis is directly under the shadow of the head of the astragalus. When the inversion deformity is corrected, the os calcis is rolled outward to its normal position, so that the anterior ends of the two bones are separated. The mid-line of the astragalus then points toward the first and second toes, and that of the os calcis toward the fourth and fifth toes.

The left foot of the second patient mentioned was wedged in eversion until the inversion deformity had been corrected, and then the foot was easily brought into dorsiflexion. The patient was seen recently, some five years after the last treatment, and the correction of the deformity is well maintained.

There was another child under treatment at the same time, who had bilateral club-foot. When the feet were wedged in dorsiflexion, the right foot was very difficult to bring into this position, and a "rocker bottom" developed in spite of the use of great care in applying and wedging the casts. The left foot came into dorsiflexion without difficulty, and without breaking in the mid-tarsal joint. There was no great difference in the appearance of the feet at the beginning of the treatment. Roentgenograms were taken at the time when difficulty was experienced in bringing the right foot into dorsiflexion. The anteroposterior view of the resistant right foot show that the inversion deformity has not been corrected. The inversion deformity has been corrected on the left, and this foot could be brought into dorsiflexion with little difficulty. The right foot was plantar-flexed, as this is necessary to relax the subastragalar joint, and then wedged in eversion. Later it came into dorsiflexion without difficulty, and without producing a "rocker bottom," and the correction has been maintained in both feet for more than five years.

For the last five years it has been the author's custom to take anteroposterior roentgenograms of all feet after the forefoot adduction and the inversion deformity appear to be corrected. If the anterior ends of the astragalus and os calcis are separated, the foot is ready to be brought into dorsiflexion. If they are still superimposed, the heel should be wedged in eversion.

The *equinus* deformity is corrected by gradually bringing the foot into dorsiflexion. The anatomists tell us that the chief motion in the subastragalar joint is rotation,—that is, in eversion and inversion. When a club-foot is brought into dorsiflexion, there seems to be a gliding forward motion also in the subastragalar joint. The os calcis is drawn forward. Lateral roentgenograms before treatment frequently show the astragalus extending forward over the os calcis by half the length of the astragalus, while, at the completion of the treatment, the anterior ends of the two bones are on the same level. At the same time the body of the astragalus is pushed backward under the tibia, restoring the normal relationship between the bones.

Pressure upward on the forefoot, with the heel in inversion, only binds together more tightly the os calcis and the astragalus, so that the deformity can never correct itself spontaneously. When more pressure is used and the treatment is continued, the transverse tarsal joint yields, and continued force fails to correct the inversion and equinus deformities of the posterior foot. If the condition is not recognized, and if the foot is held for a long period in dorsiflexion with the os calcis in inversion, adhesions form between the os calcis and the astragalus, binding the two bones together so tightly that they cannot later be rotated to the normal position without operation. In such cases, at the time of operation, it is difficult to introduce a periosteal elevator into the subastragalar joint, because of the adhesions.

A study of these feet seems to substantiate the following statements: When continued pressure is made on the bones forming a joint, in such a direction that the joint can move, little harm is done to the joint. When the direction of the force is such that the joint cannot move, or that the motion is blocked, the pressure causes atrophy, and, if the pressure is continued, the trauma will produce adhesions in the joint. Later, if force is applied correctly, the deformity frequently cannot be corrected, because of the adhesions which bind the bones together. It is for this reason that recurrent club-foot is often more difficult to correct than untreated club-foot. For the same reason we should be sure that the adduction and inversion deformities are thoroughly corrected before beginning dorsiflexion.

The details of the application of the casts and the method of wedging the casts have been published, so they need not be repeated here. Ninety per cent of all cases of club-foot which the author has treated have been corrected by plaster casts and wedgings. The remaining 10 per cent, composed chiefly of older children and patients who had been treated previously by operative procedures, were corrected by a Hoke club-foot stabilization. The non-operative method is recommended, because it does no harm to the foot, preserves function, and restores the foot to a normal appearance.

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JOSEPH HIRAM KITE

Joseph Hiram Kite (1891–) is generally associated with the Scottish Rite Hospital for Crippled Children in Decatur, Georgia. He was trained at Johns Hopkins Hospital and practiced in Atlanta. His greatest work, however, was done at the hospital in Decatur, an institution which primarily served the children of the Kentucky-Tennessee mountain country where little medical care was available during and before the 1930's. At a time when congenital clubfoot was already being treated in infancy in the large cities, Kite received many neglected cases in older children for whom more aggressive therapy was required. His early interest in these cases became known, and the paper reprinted here, read before the American Academy of Orthopaedic Surgeons on January 17, 1939, became a classic contribution to the treatment of clubfoot. Lorenz had "broken" the deformity over a pyramid, but the slower, gradual correction in plaster produced infinitely better results, if surgical intervention became necessary, much less bone was involved in the "corrected" foot than in straightening a deformed one. This editor had seen Lorenz's cases in Vienna in 1928 and saw the method used in England and the United States subsequently. Following publication of this article, Kite's method became standard practice for advanced deformed cases throughout the orthopedic world.

CLASSIC 57 Transplantation of a Portion of the Tibia into the Spine for Pott's Disease

FRED H. ALBEE, M.D. (1876–1945)

The following is a final development, from a series of studies, on the application of osteoplasty in the treatment of Pott's disease of the spine.

I was induced to undertake this experimental work on the spine, on account of the excellent operative results obtained in tuberculosis of joints elsewhere in the body where bony union with its perfect support and immobilization has caused the tuberculous process to disappear so rapidly, although only a fractional part of the tuberculous tissues was removed. This has been especially exemplified in my ankylosing operation on the hip, when applied to tuberculous ostitis of that joint, and also in erasion of the knee under similar circumstances. The fact that it is only necessary to secure bony stiffening in tuberculous joints, by operation or otherwise, in order to get a rapid disappearance of the tuberculous process has been emphasized very strongly in the recent writings of Ely, both in his clinical and his pathologic studies. Previous to the herein reported cases, five patients were operated on and 3 or 4 spinous processes were split with a chisel or bone forceps for from 1 to 1⅓ inches from their tips, into equal halves, either through a plane approximately parallel with the long axis of the trunk or at right angle to it. The tip of the lower half of the superior vertebra was then brought into approximation with the tip of the superior half of the next lower vertebra after green-stick fractures of each and fastened with heavy kangaroo tendon. Chips of bone from the spinous processes were then placed in between so as to insure further bone union between these vertebrae. Mechanically this event (the union of spinous processes of neighboring vertebrae) acts in two ways: First, if we consider each vertebra a lever (as it properly is) with the fulerum at the lateral processes, its short arm, the body of the vertebra and the long arm of the lever, the spinous process, then by causing a bony union of the posterior part of the lever, we shall prevent by leverage a crushing together or approximation of the bodies or the anterior arm of the lever.

Nature has done this, i. e., a fusing together of the posterior portions of the vertebrae involved, but unfortunately rarely, as pointed out by Brackett. This prevents absolutely any crushing of the bodies of the vertebrae and thus any further progress of the kyphosis or deformity. Secondly, and possibly not least, this formation of a bony bridge, connecting firmly the diseased vertebrae with the healthy ones on either side, acts directly as an internal splint on the vertebrae involved and furnishes more per-

fect support than any mechanical apparatus could possibly accomplish.

These assumptions are based, of course, on bony union of vertebra to vertebra as well as union of the green stick fractures of the vertebral halves.

This union has been satisfactory so far as can be ascertained, but on account of its uncertainty and the large amount of cartilage in the vertebrae of small children, with its slowness of union and early lack of support, it has seemed best to devise a procedure which would be possibly more reliable and also give support from the beginning. These requirements can be fulfilled in no other way except by a strong bone-graft.

The different sources from which to secure a strong bone-graft for an internal splint, which would give immediate support to the spine, were considered and the crest of the tibia was selected as by far tthe most desirable and accessible.

CASE REPORTS

Case 1. *History*. With this in view, R.C., a child aged 4, referred to me by Dr. E. H. Johnston, of Waterbury, Conn., was admitted to the Post-Graduate Hospital.

The past history was negative up to the time the trouble with the spine began. Several months before, the child had begun to have night "cries and sweats," and coincidentally began to support herself with her hands on her knees. The mother thought that there had been a loss of weight and that the child was getting pale. There had been pain in the region of the stomach for the past 2 months. About 3 weeks before examination, the lump on the child's back was first noticed.

Examination. This was negative except for a considerable kyphosis at the first and second lumbar vertebrae. The child stooped to pick up things from the floor with difficulty. The spine was rigid to passive and active motion in the region of the kyphosis.

Operation. The patient was operated on June 9, 1911. Under ether, with the patient in the ventral position, an incision was made, directly over the tips of four spinous processes, with the kyphosis in the center. Each process was then split longitudinally for about one inch and a quarter into two portions with one-third of the process on the left and two-thirds on the right. The soft tissues between the processes were then merely separated by blunt dissection or by a scalpel, parallel with the muscles. Green-stick fractures were then produced at the base of the one-third portions of each of the processes. A wedge-shaped cavity was thus produced, ready to receive the bone graft. A compress of hot saline was then placed over the wound. The left leg which had been prepared for operation was then flexed on the thigh, so that an incision over the crest of the tibia anteriorly could be made. A prism-shaped piece of the tibia from its anterior-internal aspect was then removed by means of a chisel, with the periosteum intact on two of its surfaces. The graft taken was about 4 inches by 1 inch, by ½ inch. It was quickly removed and immediately placed in the interval between the portions of the spinous processes. The dense fascia over the tips of the processes was then approximated by interrupted sutures of No. 3 chromic catgut, thus holding the bone-graft very firmly in place. The skin was closed by a continuous suture of No. 1 plain catgut. The leg wound was treated in a similar way. The time of operation was fifteen minutes. There was no shock.

Result. The child made a fine recovery from the anesthetic. The wounds healed by primary union. The child was discharged from the hospital July 17, 1911. The convalescence has been extremely satisfactory thus far. Muscular spasm of the spinal muscle has diminished very materially. However, it is obvious that it is too early to draw any definite conclusion concerning the final results of any of the cases herein reported, and this is a record of progress only.

Case 2. *History*. The patient, J.M.C., male, was a carpenter, aged 28. His family history was negative to tuberculosis. His present trouble began eight months ago with pain in his back which started in the lumbar region and shot into the thighs. He had night sweats all last winter, but no cough. There was a little pain in his right side when the patient walked and later there was pain in the left side also. There was a mass in the right groin for six months previous to the examination.

Examination. This was negative except for moderate kyphosis involving the eleventh and twelfth dorsal vertebrae and the right psoas abscess, the size of a fist, just below Poupart's

ligament. The spine was very rigid to all motion, both passive and active, in the lower dorsal and lumbar regions. The patient bent the spine with pain and difficulty.

Operation. June 27, 1911, the Post-Graduate Hospital. Precisely the same operation was done as described in the previous case. The bone-graft from the tibia was much larger, however. It measured about 6 inches by 1⅛ inch by ½ inch. Both wounds healed by primary union. This case was discharged from the hospital July 15, 1911. The patient has gone back to work, wearing a Taylor spinal brace.

Case 3. *History.* The patient, W.D., was a boy aged 4½ years. His past history was negative except for measles and typhoid fever one and two years ago. He began to rest his chin in his hand eight months before examination. There was pain in the neck, which grew progressively worse, and which was complained of at about the same time. A lump on his back was noticed about six months ago.

Examination. This was negative except for the spinal condition. There was a large angular kyphosis including the last cervical and first two dorsal vertebrae. There was a marked muscular spasm from passive motion. The patient bent with difficulty to pick things from the floor.

Operation. July 14, 1911. Post-Graduate Hospital. This operation differed from the preceding ones only in reference to the bone-graft. On account of the angularity of the kyphosis, the bone-graft had to be molded into the segment of a circle in order that the corners would not project beyond the tips of the spinous processes distal from the kyphosis. The graft was about 4 inches by 1 inch by ¾ inch, and included four spinous processes. Both wounds healed by primary union.

This patient is still on a modified Bradford frame. The convalescence has been very satisfactory thus far.

We have at present two cases on reversely bent Bradford frames for the purpose of securing a recession of the kyphosis before operating, and feel confident of holding the correction by the bone-graft.

SUMMARY

1. The inefficiency of present methods in the treatment of dorsal Pott's disease was tersely expressed by Schapps in 1905 as follows: "It is universally admitted that the forms [of portative apparatus] in general use and described in the standard text-books on orthopedics do not, even in the most skilled hands, control the deformity."

2. A firm bony splint with bony union to the vertebra involved and the healthy vertebrae on each side is supplied by this method, which assures not only the prevention of further deformity in two mechanical was as stated above (leverage and splint action) but should also cause the immediate disappearance of the tuberculous process.

3. This method is believed to be preferable to any, where breaking or cutting of the spinous processes destroys entirely, or for the time being, until union takes place, the desired leverage of the spinous processes and their muscles and ligaments. Union is also uncertain where motion from breathing is present.

4. If bony union should not occur the same mechanical effects would still be largely obtained from the union of the internal bone splint to the ligamentous structures.

5. Perfect immobilization of the few involved vertebrae in the respiratory area of the spine is secured, which is a mechanical impossibility by means of any external apparatus, on account of the constant movement of the ribs, and the vertebrae attached.

6. Fortunately, on account of the anatomy of the part it is not necessary to enter the focus of disease; therefore primary union of soft tissues with immediate bone union can be expected.

7. The normal leverage action of the spinal muscles and the supporting ligaments on spinous processes is not interfered with.

8. The operation is by no means a formidable one. The technic is very simple.

9. When possible it is well to secure a recession of a kyphosis by long recumbency

on a reversely bent Bradford frame. This method offers great promise of holding the correction obtained.

10. A bone-graft is far superior to an internal metal splint, because, by following Wolff's law it will become thicker and stronger if necessary to hold the weight or strain brought to bear on it, whereas in the case of an internal metal splint, suture or screw applied to the bone, no dependence can be placed on them to hold weight or strain, because of the bone atrophy and absorption which takes place directly around the metal. This occurs even when no strain is present.

I have found silver wire and screws which were placed through bone only a few months before, in the soft tissues where they had fallen through or out of the bone without being influenced by strain. For this reason and the always present danger of sepsis about buried metal, it would seem that bone-grafting will prove preferable to the internal metal spinal splint of Lange.



FRED HOUDLETT ALBEE

Fred Houdlett Albee (1876–1945) was Assistant Professor (Head of Department) of Orthopedic Surgery, Cornell University; Professor and Adjunct Professor of Orthopedic Surgery, University of Vermont, and Post-Graduate Medical School and Hospital, New York.

Heterotopic bone transplantation for defects in the human skeleton had been attempted since the beginning of surgery. In the modern period experimental attempts at bone transplanting or grafting go back to Meekren in the seventeenth century, and then to John Hunter, Flourens, Wolff, Ollier, MacEwen and many others. However, these reports describe only occasional experimental attempts to place heteroplastic bone or replace autoplastic bone splints in fractures. Bone graft surgery as a planned, carefully designed procedure started with this 1911 paper by Fred Houdlett Albee (1876–1945) of New York City. His method was immediately recognized and very quickly adopted by orthopedic and trauma surgeons throughout the civilized world.

CLASSIC 58 De Viribus Electricitatis in Motu Musculari Commentarius

(The Effects of Artificial Electricity on Muscular Motion)

ALOYSIO LUIGI GALVANI (1737–1798)

Since I wish to bring to a degree of usefulness those facts which came to be revealed about nerves and muscles through many experiments involving considerable endeavor, whereby their hidden properties may possibly be revealed and we may be able to treat their ailments with more safety, there seems no better way for fulfilling this desire than by publishing these discoveries at length (such as they are). For after reading of our experiments, learned and distinguished scholars will not only be able to develop them through their own studies and investigations, but even to carry out other experiments which we may have attempted but perhaps could not bring to conclusion.

It was likewise my wish to publish a treatise, even though it were far from being a finished and complete work (something I perhaps never could have done), one at least which was not crude and only half begun; but since I realized that I had neither the time, leisure, nor ingenuity to accomplish this, I preferred to sacrifice this clearly reasonable wish of mine to expediency.

I thought my efforts would be rewarded, therefore, if I presented a brief and accurate account of the discoveries in the same order of circumstance that chance and fortune in part brought to me, and diligence and attentiveness in part revealed. I hoped to do this not only that more might not be attributed to me than to fortune, nor to fortune than to me, but that we might either light the way for those who have wished to embark upon this same course of experiment or that, in any event, we might satisfy the honest curiosity of scholars who are interested in the source or origin of things which embody an innate and unusual element.

Now, I shall occasionally add inferences, conjectures, and hypotheses to the account of the experiment with the primary purpose of paving the way for the undertaking of new experiments. But if, in this way we are unable to arrive at the truth, we will at least have opened a new approach to it.

The course of the work has progressed in the following way. I dissected a frog and

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prepared it as in Figure Ω Table 1.† Having in mind other things, I placed the frog on the same table as an electrical machine Figure 1, Table 1, so that the animal was completely separated from and removed at a considerable distance from the machine's conductor. When one of my assistants by chance lightly applied the point of a scalpel to the inner crural nerves, DD, of the frog, suddenly all the muscles of the limbs were seen so to contract that they appeared to have fallen into violent tonic convulsions. Another assistant who was present when we were performing electrical experiments thought he observed that this phenomenon occurred when a spark was discharged from the conductor of the electrical machine, B. Marvelling at this, he immediately brought the unusual phenomenon to my attention when I was completely engrossed and contemplating other things. Hereupon I became extremely enthusiastic and eager to repeat the experiment so as to clarify the obscure phenomenon and make it known. I myself, therefore, applied the point of the scalpel first to one then to the other crural nerve, while at the same time some one of the assistants produced a spark; the phenomenon repeated itself in precisely the same manner as before. Violent contractions were induced in the individual muscles of the limbs and the prepared animal reacted just as though it were seized with tetanus at the very moment when the sparks were discharged.

I was fearful, however, that these movements arose from the contact of the point, which might act as a stimulus, rather than from the spark. Consequently I touched the same nerves again in other frogs with the point in a similar manner, and exerted even greater pressure, but absolutely no movements were seen unless someone produced a spark at the same time. Thus I formed the idea that perhaps in order to produce this phenomenon there were required the simultaneous contact of some body and the emission of a spark. I therefore again applied the edge of the scalpel to the nerves and held it motionless. I did this at one time when sparks were discharged and at another when the electrical machine was completely quiet. The phenomenon occurred, however, only as often as a spark was produced.

We repeated the experiments with the same scalpel and found, to our astonishment, that at times, when a spark was produced, the aforementioned movements were evident, and at others, they were absent.

Excited by the novelty of the phenomenon, we began to make tests and experiments of various kinds, but always using the same scalpel, in order to understand, if possible, the reasons for this unexpected difference. Nor was this additional diligence without its reward, for we discovered that the answer to the problem lay in the part of the scalpel we held in our fingers. Since the scalpel had a bone handle, we found that when this handle was held in the hand, no movements were produced at the discharge of a spark. They did occur, however, when the fingers touched the metal blade or the iron nails that secured the blade of the instrument.

Now since dry bones exhibit an idioelectric (or non-conducting) nature while a metal blade and iron nails exhibit an anelectric (or conducting) nature, as they say, we began to suspect that perhaps when we held the bone handle in our fingers, there was no way for the electric fluid to flow (by whatever means) into the frog, but when we took hold of the blade or nails and brought them in contact with the frog, a path was opened.

To place this conclusion beyond all doubt, therefore, we used at one time a thin glass cylinder, H, wiped clean of all moisture and fine dust, in place of the scalpel, and

† This and other illustrations can be found in the Burndy Library English translation.

at another, one of iron, G. At the time when a spark was discharged, we were not only touching the crural nerves with the glass rod, but were actually rubbing them. Our efforts were unsuccessful, however, since the phenomenon did not reappear although numerous strong sparks were discharged from the conductor of the electrical machine at close range to the animal. On the other hand, when the iron rod was only lightly applied to the same nerves and when only weak sparks were emitted, the phenomenon once again occurred.

This clearly confirmed what we had suspected to be true, namely that the contact of a conducting substance with the nerves is necessary to produce the phenomenon. But in this experiment use had been made of both the substance, by which the nerves were touched and the man who touched them; so we applied the iron rod, G, to the same nerves but did not hold it in our hands. In this way we hoped to ascertain whether the phenomenon should be ascribed to the man and the iron rod together or to the latter alone. When the experiment was made in this way, no movement of the muscles occurred when the spark was emitted. In place of the cylinder, therefore, we used a very long wire, KK, in order to see whether or not this could somehow compensate for the absence of the man. And behold! the muscles contracted when the sparks were discharged.

From these observations it became clear to us that not only was a conducting substance that touched the nerves required to produce the phenomenon, but one also of determined size and length. Hereafter, for the sake of clearness rather than brevity, allow us to call a conducting substance of this sort a nerve-conductor.

Now, to the end of this conductor, we attached a small hook which was fastened to the frog's spinal cord. At one time we placed the frog near the electrical machine and at another we arranged its conductor in such a manner that now the frog was near to the electrical machine and now removed at a distance from it. Because at one time the feet and at another the prepared nerves were turned towards the electrical machine, the latter now had the conductor before it and now behind. No matter what the arrangement was, contractions of equal intensity were always produced.

We investigated, moreover, whether the phenomenon took place in prepared animals even when the experiment was performed at a distance from the electrical machine and very long nerve-conductors were employed. We were able to ascertain that when an iron wire of one hundred and more ells in length was attached to the frog, muscular contractions occurred at the emission of a spark, even though the distance from the electrical machine was very great. We carried out the experiment in the following way. We suspended an iron wire, FF, by silk threads and thereby insulated it, as the natural philosophers say. Then we fastened one end by a silk thread to a nail, F, driven into the wall; the other end we carried away from the electrical machine through various rooms as far as the wire reached. To the latter at point, C, we joined another iron wire, B, from whose end a frog was suspended. For the sake of convenience, we enclosed the frog in a glass jar, A, whose bottom was covered with some conducting material, e.g. water or very small lead shot of the kind used by hunters (the latter brought about the best experimental results). When a spark was discharged from the conductor of the electrical machine, the limbs of the prepared frog moved, even at so great a distance—which was truly extraordinary—and almost jumped. The same phenomenon occurred when the frog was removed from the glass jar and was hung in a similar manner from the conductor, EE. This happened much

more quickly if some conducting body, which was in contact with the earth, were fastened to the feet of the animal.

Since these results had been observed with an insulated conductor, we next investigated what would happen with one that was not insulated.

We attached the iron wire, EE, therefore, to the various hinges of the doors of the rooms of my house, six in number. All things were arranged as in the previous experiment. When a spark was discharged, only small contractions were produced in the prepared frog, but nonetheless there were some.

Having made these observations, we now wished to find out whether the force of this electricity moved and spread out equally in all directions in a circle, as seemed reasonable. To this end different nerve-conductors were arranged at some distance from, and in a circle around, the conductor of the electrical machine. A prepared frog was fastened on each of these. When a spark was produced, what a gratifying sight! The individual frogs time and again moved in unison, particularly when a conducting body was attached to their feet, as in the preceding experiment. The reaction was particularly strong when the conducting body was grounded, a thing easily accomplished by either fastening a long metal wire to the individual feet of the frogs or by holding them in the fingers.

Consequently, when we became aware of the usefulness, or even the necessity of fastening conducting bodies to the feet of the animals, we were eager to attempt new experiments embracing this problem. Once these were performed, it became clear that the conducting bodies which we attached to the muscles to bring about contractions either were at times sufficient by themselves to produce this effect without nerve-conductors, or, at any rate, made no small contribution to the effect. Moreover, the larger the conducting bodies were and the more they were possessed of a strong conducting power the greater were the contractions, particularly if the conductors were in contact with the earth. They were at least as effective as those conductors which we were accustomed to attach to the nerves.

Hereafter we shall call these conducting bodies muscle-conductors to distinguish them conveniently from the so-called nerve-conductors.

Now, in an experiment where the nerve-conductor, extended to some distance from the electrical machine, is intercepted by some non-conducting body which was intentionally made, as it were, in part of a conducting substance, like metal, and in part of a non-conducting substance, like glass, resin, or silk, we see no contractions following the production of a spark although we have attached conductors to the individual muscles. An example of this would be if conductor, B, were not joined to conductor, EE, at point, C, but were suspended by a silk loop, D. This is new and indubitable evidence that electricity is dissipated through conductors of this kind.

We also carried out the experiments with the conductor not only intercepted by a non-conductor but completely interrupted, and with the ends of the interrupted conductor placed as close as possible to one another. The phenomenon of contractions was completely absent.

And again, in another way we sought to intercept the free flowing of electricity through the conductor. We placed a prepared animal on a non-conducting surface. We did not join its nerve-conductor as before with either the nerves or the spinal cord, but arranged it on the same surface in such a way that its end was several lines and occasionally even a thumb's width away from the nerves or spinal cord. When a spark was produced, contractions occurred. They also occurred when the limbs were placed on a conducting surface and the nerves on a non-conducting surface

with the nerve-conductor the same distance away. This was also the case when the nerves were held up in the fingers with just a short nerve-conductor attached, or a long one, whereby the animal was either near to or far from the electrical machine. The contractions were completely absent, however, if the nerves with their conductor separated from them, as in the foregoing experiments, were placed on a conducting surface.

We did not omit investigating whether this electric force of whatever kind it might be, also excited those contractions which we have often mentioned, when it was only flowing freely through the substance of the conductors, and not the surface. Hence we covered and completely enveloped—with a non-conducting substance, such as common wax, sealing-wax, or pitch—except for the ends—the iron wire which served as a nerve-conductor. When a spark was produced, contractions occurred as through a free-conductor.

Consequently, when these different problems were investigated and their results confirmed in a long series of experiments, we felt permitted not only to attribute the phenomenon of muscular contractions to electricity, but even to consider the conditions of the experiment as certain laws by which it was bound.

Muscular contractions of this sort, then, seemed to us within certain limits to stand in a direct proportion to the strength of the spark and of the animal as well as to the length of the conductors, particularly the nerve-conductors. They seemed to stand in an inverse proportion, however, to the distances from the conductor of the electrical machine. These contractions, moreover, appeared generally stronger to us when the animal was set on the same table with the electrical machine and the table was covered with an oily coating, or when the animal was removed from the table and laid on a non-conducting, rather than a conducting substance.

I have said, to be sure, that a direct proportion seemed to me to be maintained in the contractions, but only within certain limits. It has been found, for example, that if you shorten a nerve-conductor of a length which is sufficient to bring about contractions, the contractions do not diminish, but disappear. If, however, you lengthen it, the contractions in fact grow stronger, but only up to a certain point, beyond which—however far you extend the nerve-conductor—the contractions are augmented imperceptibly, if at all. The same can be said about the other elements of the proportion I have set forth.

Now since we had observed the great capacity of a spark discharged from the conductor of an electrical machine to produce muscular motion, it seemed to us that an electric flash which resulted from the discharge of a *quadratum magicum* promised even greater contractions. The experiment turned out quite differently, however, for to our astonishment, no movements appeared in an animal prepared in the usual way.

Now since these experiments had been carried out with so-called positive electricity, it remained for us to undertake similar experiments with negative electricity. At first, therefore, we insulated the electrical machine and the man who turned it. We brought the frogs which were provided with their own conductors, as was necessary, close to an iron rod which the assistant held in his hand. The frogs were set on a glass surface so that they would obtain no electricity from neighboring bodies. Then the aforementioned assistant, who was turning the machine, intentionally produced sparks from the neighboring objects with the iron rod. We saw contractions take place in the prepared frogs in the same manner as they occurred when sparks were discharged from

the conductor of a non-insulated electrical machine.

In addition we experimented with negative electricity in the following manner. We set a nerve-conductor at a certain distance from the negative surface of a Leyden jar. Then we produced sparks from the positive surface, as the natural philosophers say, or that surface to which electricity had been given. The frogs reacted in the same way as with positive electricity. It is notable that this even occurred when the iron wire which served as a nerve-conductor was at some distance from the external surface of the jar and when it was completely enclosed by a long glass tube and the frog itself was confined in a glass receptacle. The only requirement was that the open end of the tube touch the outer surface of the aforementioned jar. These same contractions were obtained, moreover, if a spark were produced from the hook of a Leyden jar at the same time that it was being charged with electricity, as they say or a little later. They also occurred if a spark were emitted either in the same place in which the jar was being charged, or elsewhere after it had been removed at a distance from the electrical machine.

These results furthermore, were obtained when the frogs were provided not only with a nerve-conductor but also with merely a muscle-conductor. In a word all the results of this experiment with the Leyden jar approximated the corresponding experiment with the electrical machine although the prepared animal could receive no electricity from the outer surface of the jar, from nearby bodies, or from any other possible source.

Now in even another way we sought to experiment with surfaces charged with negative electricity and by producing small sparks from them, to investigate the resulting contractions. I placed a frog, prepared of course, on the upper side of a magic square to which the electricity from the electrical machine was directed to flow. I produced a spark from the lower side when the electrical machine was at times at rest and at times in motion. Now when the electrical machine was turning, the accustomed contractions were always observable, but when it was at rest only rarely did they occur and then only immediately after the electrical machine came to rest.

After these experiments utilizing the electrical machine had been carried out, we also employed the electricity of the electrophorus, so as not to pass over any kind of electricity that produces a spark. We discharged a spark, therefore, from the plate of an electrophorus and the accustomed phenomenon of muscular contractions appeared. This occurred not at great distances, as when the spark was discharged from the conductor of the electrical machine, but only at small distances. Even at that the contractions were very slight. Although we scarcely—and not even scarcely—seemed in a position to have any doubts about the cause of the phenomenon, with so many experiments having been carried out which were concerned with the forces of electricity, nothing seemed more suitable, nevertheless, for firmly establishing the cause than to apply a very sensitive electrometer to the animal-conductors.

Thus we attached a small electrometer, fashioned after the design of the renowned Volta, to the conductors. We covered one side of the straw leaves of the electrometer with very thin tin foil, that they might be more suitable for the experiment. At first, when the conductors were insulated, the leaves were frequently drawn apart from one another at the turning of the electrical machine, but at the production of a spark, they often fell together. When the wires were freely conducting, however, the leaves did not withdraw from each other at all at the turning of the electrical ma-

chine. It was only at the discharge of a spark that they gave out little jumps and vibrations, which clearly seemed to indicate some passage of electricity through the conductors of the animal when contractions were produced.

Now then to place the results of the experiment beyond all doubt, we sought in various ways to prevent the electric fluid from the electrical machine from passing (in whatever way this might be done), into the animal and its conductors. First, therefore, I enclosed the animal in a glass jar. Then I made an opening in a wall which was near the electrical machine and inserted a glass tube through the hole. (This hole penetrated the thickness of the whole wall.) I so glued the mouth of the jar to the opening in the wall that the nerve-conductor, passing through the inserted tube, hung from the opposite side of the wall in the next room. When a spark was discharged from the conductor of the electrical machine—see! there were muscular movements.

I arranged the animal and its conductor, moreover, in the reverse manner: that is, the conductor was placed in the jar where the animal had been originally and the animal hung where the conductor had been at first. Then employing the same technics, I arranged everything as before. When I produced a spark, the same movements were evident.

But although in this type of experiment every course of the electric fluid from the electrical machine seemed to have been completely blocked, nonetheless, I designed and built a little instrument which was much simpler and more convenient than the apparatus described above. This could readily be set at various distances from the electrical machine, and the animal—as well as the nerve-conductor and the muscle-conductor—could easily be placed and enclosed within it.

The design of the little instrument is as follows. It is composed of two glass jars, one of which rests upon the other. In the top jar is the nerve-conductor, which, for the sake of convenience, can be made up of the small lead shot used by hunters. In the bottom jar are the animal and similar pellets which can serve as the muscle-conductor, since the animal, set up as though it were standing on its feet, has these pellets in contact, as it were, with its muscles.

The animal is easily held in this position and is in communication with the conductor in the top jar by means of an iron wire which suspends the animal through its spinal cord. The wire is fastened in the cork stopper of the top jar and, projecting into the jar cavity, is surrounded and covered by the lead shot.

A stopper of this kind prevents the lead pellets from falling out when the top jar is inverted and is placed on the bottom one. In order that the top jar, moreover, may not be easily separated from the bottom one and that the electric fluid cannot gain access for itself through the cracks which may exist between the openings of both jars, the mouths of the jars are joined by a certain special cement made of wax and turpentine. This is done in such a way, however, that the jars can be separated at will but can again be joined together when the occasion demands.

Now when this little instrument was placed on the same table with the electrical machine at a certain distance from its conductor, not only similar, but even more vigorous movements were seen at the discharge of a spark than when the animal and its conductors were in the open air. The muscular movements followed the laws which we mentioned above in the same proportion. After these results had been seen, I would easily have given up my original postulation that the electricity, excited in the conductor of the electrical machine,

in some manner or other motivated these muscular movements through the discharge of a spark, had not the experiments which were carried out above—and the growth of a certain strong suspicion that the phenomenon certainly ought not be ascribed to the electricity on the inner surface of the jar working on the animal and its conductors at the time a spark was discharged—recalled me to my first opinion. Not only did subsequent experiments that were undertaken, but more particularly the motions of an electrometer placed inside of the little instrument, completely confirm my suspicion. For the very light shot and wires within the electrometer immediately changed position and were separated from one another when the electrical machine was turned. When the sparks were discharged, however, they were restored to their former position and resumed contact.

Now, after we had performed and thoroughly analyzed these and other experiments, it became apparent that we should also experiment on living animals in order to make our work even more useful.

So as not to kill the animals, we experimented on the crural nerve within their dissected upper thighs rather than that within their abdominal cavities. Then we proceeded to separate the nerve from the surrounding tissue, to draw it out from the muscle, and to attach it to a conductor. When a spark was discharged, the limb reacted by contractions, which seemed to be less violent, however, than those in a dead animal.

Since, in the several experiments that had been analyzed thus far, the animal, its conductor, and the machine communicated with one another through an intervening layer of air, I determined to investigate what would happen when this communication was interrupted and then completely broken.

I proceeded in this way. First I placed the little instrument with its prepared animal and conductors under a glass jar. This was set at close range to the electrical machine and when a spark was discharged, the customary contractions were produced.

I placed this same jar with the little instrument under another much larger jar and this under a still larger one. Again contractions occurred when a spark was discharged. The more jars there were and the greater their thickness, however, the more sluggish the movements were.

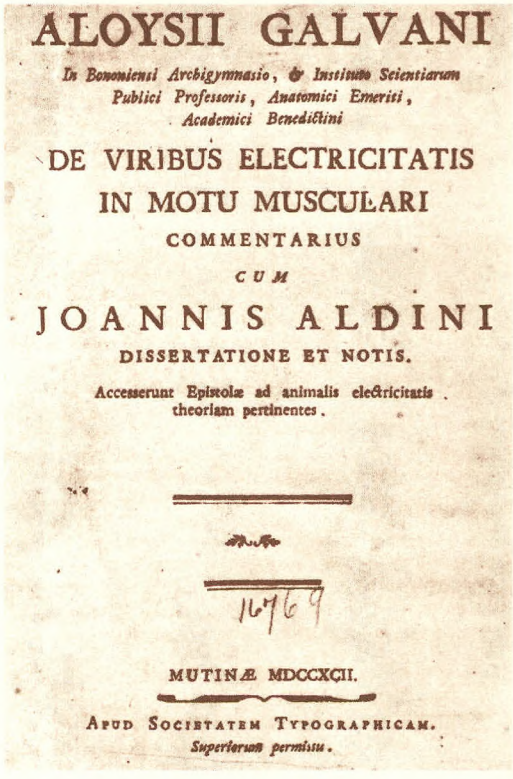
Then I prevented all communication through the layer of air between the animal and the electrical machine by setting the same little instrument with its animal under the receiver of a pneumatic pump at some distance from the conductor of the electrical machine. I made an opening in the top jar so that it could be evacuated by the pump through repeated exhaustions. Sparks were discharged both when the air was being evacuated and when it was not. In either case, apparently similar contractions were produced.

After we had carried out numerous different experiments with electricity that becomes activated through a spark, we sought to discover, not without perseverance and hard work, whether this same electricity also produces its effect on muscular movement through other means. We frequently observed muscular contractions if the nerve-conductor were set as close to the conductor of the electrical machine as possible and then if the plate of an electrophorus were lifted from the resin disk, or if (when the electrophorus had been set at a considerable distance from the aforementioned conductor) the same plate were brought very near to it, in both cases without a spark discharge.

All the foregoing experimentation was performed on so-called cold-blooded animals. After we had made these discoveries, we were very eager to carry out the same or similar investigations also on warm-blooded animals like chickens and sheep. We engaged in these experiments and the

results were substantially the same for both kinds of animals, although by necessity the preparation of the warm-blooded animals was different. We first had to cut loose the crural nerve, not within the abdominal cavity, but externally in the thigh itself. Then we separated it from the surrounding tissue, drew it out, and attached its conductor. After that a spark was discharged from the conductor of the electrical machine when the limb was either attached to the living animal or had only recently been severed from it. For otherwise, if the usual procedure for preparing frogs were followed, contractions were absent, perhaps because the muscles lost their ability to contract before the long and complicated preparation could be completed.

In conclusion, there are several unusual and useful facts connected with these experiments using both kinds of animals, which, to my way of thinking, are worthy of notice and came frequently to our attention. The first is that the older the prepared animals are, the whiter their muscles, and the less blood they have, the more subject they are to muscular contractions: hence this phenomenon can probably be excited more quickly, easily, and for a longer period of time in cold- than in warm-blooded animals. The former have thinner blood of a type that coagulates more slowly, and for this reason it flows much more easily from the muscles. The second is that the prepared animals which were subjected to the electrical experiments became putrified and rotten long before those that had not been exposed to the force of the electricity. Finally the phenomena we have described occurred only if the animals had been prepared for experimentation in the manner we have mentioned above; otherwise the contractions failed to take place. For if conductors are applied and even attached to the brain or muscles rather than to the exposed spinal cord or nerves, as we have been accustomed to do, or if the nerve-conductors are further extended to the muscles, or if the nerves are improperly separated from the surrounding tissue, the resulting contractions are trifling or do not occur at all. We are convinced that most of the facts we discovered from these experiments are the result of this technic of preparing and separating the nerves.



ALOYSII GALVANI

In Bononiensi Archigymnasio, & Instituto Scientiarum Publici Professoris, Anatomici Emeriti, Academici Benedictini

DE VIRIBUS ELECTRICITATIS IN MOTU MUSCULARI

COMMENTARIUS

CUM

JOANNIS ALDINI

DISSERTATIONE ET NOTIS.

Accesserunt Epistolæ ad animalis electricitatis theoriam pertinentes.

16769

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Apud Societatem Typographicam. *Superiorum permissu.*

Title page from Galvani's first edition.



ALOYSIO LUIGI GALVANI

Aloysio Luigi Galvani (1737–1798) was born in Bologna (Fig. 1). He was a graduate of its university (with a thesis on the development of bones in the human skeleton), taught anatomy there and died there at the age of 61, an emeritus professor.

His interest in electrophysiology became the point of origin of the continuing study of neuromuscular physiology in modern times. He first published his early studies serially in the volumes of the Bolognese Academy and within the same year published them in book form (Fig. 2). The importance of his observations were immediately recognized throughout the 18th century European world of scientific scholarship. For almost two centuries his book was known only through the writings of two of his contemporaries, Volta of Pavia and his nephew, Aldini of the University of Bologna. Not until 1937 was there an Italian translation by the Academy of Bologna in honor of Galvani's 200th birthday anniversary, and in the same year a Russian translation was published in Moscow. In 1953 Dr. Foley published the first English translation. I am indebted to the editors of this edition, quoted in the reference, for permission to reprint certain sections of Part One of Galvani's original work. For students with a special interest this volume with Professor Cohen's commentaries will be most valuable and rewarding.

CLASSIC 59 Art, History and the Crutch

SIGMUND EPSTEIN, M.D. (1880–1970)

The lame man has always been a source of popular interest; and a crutch never fails to challenge our attention. Pictures and the history of the spoken word establish the antiquity, ubiquity and continuity of the crutch as an aid to locomotion. Neither aborigine nor civilized man left any tangible evidence of such props, but many pictures survive. The artist through forty centuries has threaded an interesting chronicle with paint and other media; and so has woven a story of how the genus homo rose above the handicap of disease, trauma and deformity.

The Hebrew word for crutch is *mischeness*: the word for support is smuchos. Tradition has it therefore, that crutches were known in the days of Moses.

The Greeks had a word for an old man with a stoop; they had another for an old man with a staff. The Egyptians had a hieroglyph for each!

Larousse Illustré gives the derivation of the word *bequille*, crutch, as from *bec*: curvature or crook of the upper arm-piece; and *quille*, signifying leg or baton. It defines *bequille* as a stick surmounted by a little crosspiece, which the aged and crippled place under their armpits, or under their hands, to help them in walking.

The earliest known record of a crutch is a carving executed in 2830 B.C. on the entrance portal of Hirkouf's tomb. This Egyptian "capitalist-racketeer-caravan-conductor" (quotation from the stone-inscribed hieroglyphs) is represented as leaning on a crutch-like staff. Surmounting this staff is an axillary traverse, which Hirkouf steadies with his free right hand, while the left hand grasps the middle of the stick. (James Baikie, in *Egyptian Antiquities of the Nile Valley, 2830 to 2630 B.C.*, notes this as a staff. I think it is a crutch, because Hirkouf's right hand seems to grasp an axillary horizontal piece; and because locomotion would be made hazardous, without a cross-bar for his axilla to rest upon. We wonder if this adventurer were not injured in some encounter incident to policing the trackless sands. Maybe this account of his mishap was front-page news in the Sixth Dynasty!)

About this same time, we find recorded, however, examples of staffs and spears used as aids to locomotion. For example, there are several interesting wall-carvings in the caves on the isle of Elephantine, in the Nile. Here are represented two series of men: one, a group of corpulent men who represent a period of plenty; and another group of lean men, whose frail bodies indicate a period of famine. The fat type is traced leaning on a heavy cane; whereas the lean one depends on a slender knotted stick.

Twenty centuries later (about 800 B.C.) the earliest known case history of infantile

paralysis was recorded on a buriel stele of a priest of the Temple of Astarte in Memphis, Egypt. Doubtless, the use of a long ceremonial staff surmounted by a head of crystal or alabaster, enabled him to carry on his priestly duties. (Today, such a case showing a flexed, shortened and spindle-like leg, accompanied by a drop-foot, would necessitate the use of a brace or crutch, or both.)

Another crutch picture is a fragment of an Etruscan mirror, showing Philoctetus, the Homeric warrior, resting on a staff. A doctor is dressing his wounded heel. Menelaus as depicted in Daremberg derives support from a spear while his thigh is being dressed.

Cripples there must have been, during all the ages, whether recorded or unrecorded. What kind of mechanical aids were used in the early centuries just before and after Christ is a matter of conjecture and not mentioned in written history.

On a wall in Pompeii is a painting of Aeneas undergoing a thigh operation, leaning on a spear. There is a beautiful Arybal-los vase in the Peytel Collection: here is depicted the Athenian doctor's clinic, and a number of patients with wounds are grouped about the room; several of them are seen leaning on crook-like shepherd's staffs.

There can be no doubt that crutches, both cow-horn and the straight armrest type, were used during the fifth century in Greece, because graphically such scenes have been recorded on vases. Cow-horn crutches are a distinct advance over staffs, because their semicircular shape conforms more effectively to the chest. Other examples of crutches depicted likewise on ancient Greek vases show right-angled traverses, resembling the handles of shovels.

In this same era, in Etruria, was executed a bronze artificial leg, an imperishable historical memento, now in the Museum of the Royal College of Surgeons. These were times of war, and war being what it is, in any era, brings human wreckage as its sequel. There must have been other occasions at this time for the need of peg-legs and crutches: artists have not lacked cripples as models since man began to fight.

Little of historical or artistic value was recorded during the Dark Ages, but there appears an excellent drawing of two cripples, which was executed in 991 A.D., and found in the illuminated manuscript from the Codex of Echternach. The usual single-bar crutch supports one man who is standing upright, while a pair of crawling blocks is used by his crouching companion. And in the Museo de la Lonja Palma, Spain (unless destroyed by the ravages of civil war) there is a pre-Catalan painting, on a fragment of a retable of "St. Lucia giving away her Dowry." One recipient of the Saint's bounty is a man with his leg in a sling, suspended from his neck. This is a rare example of aid-in-locomotion, now obsolete. The supplicant leans on a crawling block, one quite similar to those seen today rolling down our avenues.

The Middle Ages, in contrast with the Dark Ages, offer a golden reservoir for our study of aids to the handicapped as recorded by the masters. And many powerful forces operated to make this period the treasure chest that it is. The introduction of artillery left in its wake staggering numbers of amputés and mutilated men. The ghastly practice of judicial torture and punishment also furnished its share. Unforgettable are the aftermaths of gangrene from ergotism and leprosy.

Most powerful was the force of man's reawakening interest in his fellow-beings and in religion. The immense patronage of the Church, encouraging artists to portray the saints and their miracles, has left its legacy in the great masterpieces that drew people to the Cathedrals. (In the early Middle Ages, before the introduction of engraving and printing, people made pilgrimages to the churches to behold these dramatic representations so well known to them.) Wha

an impression Orcagna's fresco "The Triumph of Death" must have made on those who flocked to Pisa to see it! How hopeless that discouraged group of lepers, leaning wearily on their crutches, must have seemed to them! And what a fine host Florence must have been to those who came to see Andrea del Pisa's bronze door at the Baptistery! One of the panels, "Healing of the Sick," features long and short crutches, in the hands of the cripples, seeking saintly intercession for their sicknesses and deformities. And we today can visit the Metropolitan Museum of Art and see Duccio's interpretation of Saint Lucia's beneficence to the cripples. In this lovely colored painting on wood can be noted an excellent example of the cow-horn pattern crutch. One surgeon drew a picture of a patient on crutches, the famous John of Arderne. His book, "De arte physicale de cirurgia," appeared in 1412. On the margin of his manuscript is sketched a man with flail-like legs, wearing a pair of substantial crutches.

Some painters at this time, such as Michael Pacher and Fra Angelico, used crutches as incidents of geometrical design. In the latter's fresco in the Vatican, "St. Lawrence Giving Alms," the lines of several long and short crutches on which the patients lean form an interesting contrast with both the background and the light colors of the saintly garments. The columns of the church carry the eye in a pleasing, effortless manner, to the staffs and crutches of the recipients of the dole.

The legend of the ever-popular Saint Martin was provocative of the animated interest of such noted artists as Hieronymus Bosch, Dürer, Droochsloot, El Greco, etc. Bosch portrayed such a fantastic picture of the Saint surrounded by crowds of deformed, crippled and weak-minded or simple-minded beggars, that many men thought that his mind was diseased or warped. In fact, cripples interested him so intently, that with his pencil he portrayed whole parades of them. These were done so accurately that we have no difficulty in identifying the long and short crutches, the little benches, the knee pads, the peg-legs and the skids, that unfortunates had to resort to.

Droochsloot (1616–60), in portraying St. Martin, painted groups of cripples as Bosch did, but he activated his theme by the introduction of a belligerent knot of citizens. He featured also a most passive type of handicap, the man in a bowl. Outstanding in a group of mendicants is a jolly fat man with a crutch, well able to bear his weight. A fat man is the crutch-maker's best customer. Droochsloot painted a "Beggar's Dance": a large group of male and female mendicants feasting at an inn; a lively collection of sticks! Droochsloot further achieved honor when he was elected Regent of the Hospital of St. Job in Utrecht, a practice which deserves commendation in any community.

Dirck Van Veen outdid Droochsloot, and packed into his canvas, "Need Makes Blood," an extraordinary measure of action, accented by the vicious use of peg-legs and crutches. In this spirited skirmish, one of the vanquished has lost most of his nether garments, in ferocious combat dominated by leg-rests and crutches used as weapons of offense. Dürer's woodcut of St. Martin is another magnificent example of the influence of the Church on art. In this delineation of the famous legend, Dürer shows a man whose crippled legs are strapped to a pair of skids.

Although Pieter Brueghel's work was not subsidized by the Church (he contracted to design many engravings for Cock, the publisher), we see evidences of strong religious thought in his canvasses and engravings. His pictures contain much to interest the physician: his portrayal of children on stilts at play, his delineations of the blind, his rendering of the maimed are only secondary in their appeal to the medical eye to the lovely display and handling of colors.

There is no more famous group of amputés than his rendering of four legless morons, now in the Louvre. This striking quartet, resting on heavy leg-rests and still heavier crutches, are evidently waiting in a monastery yard for a free meal from the prior. In his "Contest between Carnival and Lent," an excellent panorama of village life in the sixteenth century is depicted by many lively groups (some walk on crutches) engaged in various activities. Feasting at the tavern is contrasted with a procession of fasting worshippers just coming out of the church; some are dancing. The picture resembles a kaleidoscope.

A famous instance of fifteenth-century sculpture is Mino da Fiesole's "Altar-piece of Bishop of Salitarius," in Fiesole. A fine example of a cow-horn crutch is seen in the foreground.

Goya succeeds superbly in dramatizing the horrors of war and the tragedies of poverty and neglect. He deserves the palm, however, for a sepia drawing "'A Man Running"; for his picture illustrates the fastest scooting human on two flying crutches.

About the end of the sixteenth century, we note a change in the representation of the crippled subjects by the great masters. Human instead of religious interest dominates the scene. Commercial printing of newspapers and books encouraged the engravers and the masters of the woodcut, and suited the popular taste. And so we find diverting prospects such as Holbein's and Beham's highly amusing groups of decrepit oldsters: they seek rejuvenation in the magic healing waters of "Fountains of Youth." A senile procession comes to the spring in assorted wheelbarrows, hampers, stretchers, and on crutches. Interest is heightened by a Renaissance of "Nudist Dance" around a bonfire of discarded crutches, peglegs, etc. After taking the bath, they dash out transfigured, seeming to fulfill all their hopes of being reborn.

Rembrandt executed about thirty drawings and etchings that refer to peg-legs, crutches and walking-chairs. Most of these are individual studies, demonstrating in all a remarkable subjective interest of the artist in his topic.

Abraham Bosse, a French engraver of the seventeenth century, portrays two singing war cripples. One of them has a peg-leg. The scene is the interior of their cobbler shop where they are at work. This theme has a social service appeal, for it presents a solution of the modern problem of post-bellum reconstruction.

Jacques Callot's crutches struck a human note; he had a horde of imitators, and even the young girls painted copies of his etchings on silk, or outlined them in silk patchwork. Another of his etchings is "The Duel of the Cripples," wherein the referee is the man with the crutch.

THE CRUTCH AND MODERN ART

Today the artist strives for a different goal, and has a larger audience which reads books and illustrated magazines. They see his message in the newspapers, on bare walls and on billboards. Religious converts are no longer sought; instead, campaigns must produce results by raising money. The lessening of carelessness in industry and the urgent need of community chests are the driving forces inspiring many a masterpiece of real art today. Up to the Victorian Era, crutches with twin bars were absent from works of art. Daniel Vierge, the Spanish master of illustration, whose beautiful drawings illustrate many literary works of outstanding merit, drew the "Spanish Sharper," in which a pair of double-bar crutches make an effective feature. Frank Brangwyn's beautiful etching, "The Beggar Musician," shows a double-bar crutch that has been fastened together with rags and cords. Single-bar crutches are, however, the heavily accented note in George Scharf's excellent

portrait of an English amputé, "Drawn at Salisbury." C. E. Brock's accurate drawing of a beggar with a single-bar crutch, who is trying to wheedle a penny from "Mr. Hardheart" (1907), is a fine characterization of a sick, wizened, old man, as well as an overfed Lord Mayor, in doublet and hose. In the Carnegie Exhibition of 1931, a woodcut by Petritski depicts a double-bar crutch carried by an amputé. It is admirably executed and the title "Disabled" is fully descriptive of a group of four, cast up by the maelstrom of life.

For skilled handling of the single line, Forain's art is well known. His "Imploration" is a very good example of economy of the suggestive single stroke of the cutting tool. A father and mother with their child are kneeling at a shrine. A little crutch in the foreground speaks as a volume. Walter Ufer's "Don Pedro of Taos" shows a jolly fiddler wearing a twin-bar peg-leg crutch; he is followed by a group of children attracted by his playing like the Pied Piper of Hamelin.

THE CARTOONIST AND THE HUMBLE CRUTCH

A colored cartoon of Talleyrand appeared in 1802 satirizing his shifting alliances. It was entitled "The Man with Six Heads"; he was represented with a pattern or high shoe (he suffered from an old hip affection), holding a Bishop's crozier. As an epitome of Talleyrand's character it was timely and clever. Daily we see cartoons featuring crutches, what would the caricaturist do for drawing the "Dove of Peace" or "The Opposition Party," without the crutch?

THE CRUTCH IN CHURCH HISTORY

There is a popular legend of Pope Sixtus Quint and his crutches (date 1585) when he was elected. It is related that he entered the conclave on crutches "feigning great feebleness and the infirmities of old age," only to discard them upon his election. History hints that his intense and strenuous life for five years thereafter furnishes adequate proof that the tale of the sticks was an invention. Another solution to the riddle may be linked to a convalescence from a traumatic or inflammatory affection of the foot, hip or knee. "Upon his election to succeed Gregory XIII, the signs of infirmity vanished with surprising suddenness. He threw away his staff, lifted up his head, and made the place ring with his loud *Te Deum.*" An old man wears a crutch not for his senile state, per se; but for the painful and disabling conditions that flesh and bones of aging mortals are heirs to. Pope Pius will go down in history as having been carried in a sedan chair, incapacitated by vascular disease of the extremities.

RECENT INNOVATIONS

Before the eighteenth century, the comfort of a split-bar or double-bar crutch was neither known nor recorded by painters. The single stick, with an axillary traverse, had no hand rest (which permits a hand-grip in a comfortable position of supination). No other type was pictured by the artists for four thousand years. About 1800, the same made it possible to split the slender staff, to spread the two halves, and insert a cross-piece for the hand. For the axilla, a transverse wooden piece had made its appearance, while a more recent innovation was the axillary leather sling, fastened to the tops of the side bars. When these are fabricated in the best manner of the manufacturer, and of the best materials, they surely are a long step in advance of the heavy cylinders that medieval arms rested upon.

At the New York Public Library a recent and absorbing street display of rare old beggar prints was a huge success. They told realistically how the forgotten cripple of antiquity was helped to move about, with the aid of mechanical appliances and sup-

ports in his struggle through life. Passers-by stopped to study these pictured derelicts, an indication of their intense interest in art and history.

Thus it can be seen that the chronicle of the crutch was *painted*, not written.

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SIGMUND EPSTEIN

Dr. Sigmund Epstein (1880–1970) practiced orthopedics in New York City for a lifetime. He was graduated from Cornell School of Medicine in 1903, and died in retirement at the age of ninety. He was a cultivated gentleman with a pleasant interest in the arts and literature. During the latter part of his life he acquired a large collection of photographs of masterpieces from museums throughout the world and art books in which pictures of deformities, braces and crutches appeared. This paper was first presented at the New York Academy of Medicine to which his collection was given. It was published in the *Annals of Medical History*, a delightful publication which unfortunately ceased during the Great Depression and was never revised. The paper, in its own way, is a classic in its field.

CLASSIC 60 Hip Joint Involvement in Gaucher's Disease

ALBERT J. SCHEIN, M.D.* (1910–)
AND
ALVIN M. ARKIN, M.D.

Gaucher's disease was first described in 1882 by the man who gave his name to the condition. He thought it was a neoplasm. Subsequently, it was found to be a rare, familial disorder of lipoid metabolism, characterized by the deposition of kerasin in the reticulum cells of the reticulo-endothelial system. These cells take on a typical appearance, and are called Gaucher cells. The disease is largely, though not entirely, confined to Jewish patients. Symptoms occur most often in childhood and adolescence, but, because of its chronicity and slow progression, its victims may live a fairly normal life for many years. In several of the authors' cases, the diagnosis was not established until well on in adult life.

Any part of the reticulo-endothelial system may be involved, but the spleen, liver, lymph nodes, and bone marrow are most commonly affected. The bone changes were first described from the gross pathological viewpoint comparatively recently (1922) by Pick. In 1926, Cushing and Stout reported a woman, thirty-three years old, who complained of pain and stiffness of one hip. Roentgenograms showed marked collapse of the acetabulum and upper end of the femur. Bone sections, removed at operation, showed the typical infiltration of bone trabeculae by Gaucher cells. This was the first reported case with roentgenographic evidence of bone or joint involvement, and the only one in the entire literature on Gaucher's disease in which surgery was done in the hip. Several other patients with involvement of the long bones have had operations after a diagnosis of osteomyelitis.

Welt, Rosenthal, and Oppenheimer in 1929, and Reiss and Kato in 1932, discussed the bone lesions of this disease in detail, and reviewed the literature preceding their papers. In three out of the six cases reported by the former, hip-joint changes had occurred. The latter stressed the hip-joint changes in their cases and in others taken from the literature. Since 1932, additional cases with evidence of hip-joint involvement have been reported by Pachman; Melamed and Chester; Bloem, Groen, and Postma; de Lange; and Determann. In all, sixteen cases with roentgenographic evidence of hip-joint involvement have been reported in the literature.

It is the purpose of this paper to review and attempt to classify these bone changes as they involve the hip joint, and to add

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eight additional cases. All the skeletal changes are attributable to the infiltration and replacement of the bone trabeculae by kerasin-bearing, reticulum cells. These lesions appear on roentgenograms as translucent or more radiotransparent areas, and account for the characteristic mottling. The fusiform expansion of the lower femur with thinning of the cortex was first described by Welt, Rosenthal, and Oppenheimer as typical of Gaucher's disease.

Under the influence of weight-bearing, several changes, besides the infiltration and mottling, may appear. Collapse and aseptic necrosis of the femoral head with absorption of the acetabulum[3] may be noted. Infiltration and thickening of the neck of the femur with coxa vara formation have been described by several investigators. In children, the resemblance of this lesion to chronic osteomyelitis, tuberculous coxitis, and Legg-Perthes disease has been noted by Reiss and Kato. These observers also mention the occurrence of pathological fracture in the neck of the femur, as well as in other long bones. Late osteo-arthritic manifestations appear in the case reported by Determann.

The authors present eight cases of Gaucher's disease with various types of hip-joint involvement. At the Mount Sinai Hospital, on the ward services, from 1933 to 1941, the diagnosis of Gaucher's disease was verified in nineteen cases. All but one of the patients with hip lesions were taken from this group. The patient in Case 6 is from the practice of the late Seth Selig, M.D., and is the brother of the patient in Case 4. Eight out of twenty, or 40 per cent of the patients had hip lesions. This is second in frequency only to change in the lower femoral shaft, the latter occurring in about two-thirds of the cases. The authors' cases (as well as those from the literature) have been classified into the following groups:

A. *Hip Lesions in Children*

1. Lesions of the femoral head, usually suggesting Legg-Perthes disease or early tuberculous coxitis;

2. Lesions of the femoral neck with:

   a. Simple infiltrative roentgenographic changes,

   b. Pathological fracture of the neck,

   c. Coxa vara deformity, with broadening and irregularity of the epiphyseal line, suggesting epiphysiolysis, which might be secondary to simple infiltrative changes or pathological fractures of the neck.

B. *Hip Lesions in Adults*

1. Osteo-arthritic symptoms and signs, probably secondary to childhood lesions of any of the above types;

2. Roentgenographic evidence of similar changes in patients with Gaucher's disease, usually in young adults, but without any symptoms or signs pointing to the hip. It is likely that, in time, this group may develop symptoms of osteo-arthritis.

Although the onset is often associated with intermittent pain in various bones and joints, and low-grade fever, the diagnosis can be made only by recognizing the underlying Gaucher's disease, as well as the local condition. The presence of splenomegalia, hepatomegalia, secondary anaemia, often with slight leukopenia and thrombocytopenia, hemorrhages, and brown pigmentation of the skin, is of importance. Once the disease is suspected, it can nearly always be confirmed or ruled out by the relatively simple procedure of puncture of the sternal bone marrow. The pathologist can easily identify the large typical cells in the aspirated material. The finding of these cells confirms the diagnosis. Aspiration of the spleen and splenectomy are both unnecessary. Roentgenographic changes in the lower femora are also typical.

The disease in general, as well as its bone lesions, is chronic, lasting for many years. Symptoms may occur at intervals, but there are often free periods in spite of persistent pathology. Very little can be found in the literature about the therapy of skeletal manifestations of Gaucher's disease. For the orthopaedic aspect, the authors have treated their patients with some form of rest during periods of acute symptoms, and in children, for a prolonged period thereafter. Depending on the severity of the disease, simple bed rest, traction, or immobilization in a hip spica may be indicated. Especially in childhood, prolonged rest is considered indicated, as it is in coxa plana, to minimize deformity in what is apparently a vulnerable period of hip-joint growth. While the follow-up period is hardly adequate to prove the benefit of such immobilization, in Cases 1 and 3 definite healing appears to have taken place. In the former, regeneration of an approximately normal femoral head appears to be taking place as in Legg-Perthes disease, while in the latter, a pathological fracture healed with excellent restoration of bone structure, although with some coxa vara deformity. Both cases are still under treatment by rest, so that the final result is not yet evident.

It is known that the more the structure of a hip deviates from the normal, the more likely is the early onset of osteo-arthritis, which may ultimately become very severe. Once this had developed, disability is inevitable. Cushing and Stout have reported the only instance of surgical therapy in a Gaucher hip joint. This patient, a woman, thirty-three years old, had a resection of the femoral head and neck, and removal of six loose "sequestra" from the partly destroyed acetabular wall. In spite of her anaemia, she made an uneventful recovery from the operation, although there was no long follow-up. In at least one of the authors' cases surgery on the hip joint was seriously contemplated. Hematological study revealed leukopenia and thrombocytopenia. It was then thought that arthrodesis, which was the operation of choice, was unlikely to succeed and that hemorrhagic complications were likely. Apart from surgery, physiotherapy and roentgen therapy have proved ineffective. Rest in recumbency, with traction, has given at least temporary relief in adults and children alike.

REPORT OF CASES

A. *Hip Lesions in Children*

Case 1. M.D. (Hospital So. 447461), a German-Jewish girl, was 10 years of age when admitted to the Mount Sinai Hospital on October 18, 1939. She complained of pain in the left knee and hip of 6 weeks' duration. A similar attack had occurred one year before and was associated with low fever and a limp. It had been called "periostitis" in Germany where she then was, and she had recovered in two weeks.

Examination showed tenderness of the left knee, restriction of motion of the left hip in all directions, enlarged liver and spleen, and normal temperature.

A puncture of the sternal-bone marrow had been done in the Out-Patient Department, and Gaucher cells were found. Roentgenographic examination of the femora showed irregular areas of rarefaction in the medullary cavity of the left femur in its lower half, and a distinct tendency toward clubbing of the lower ends of both femora. There was a marked deformity of outline.

A sister also had a positive sternal marrow loaded with Gaucher cells, but showed no bone lesions either clinically or by roentgenogram.

The course of this case thus far has resembled very much Legg-Perthes disease of the hip. She improved rapidly with bed rest. A caliper brace was fitted to relieve weight-bearing as much as possible. Roentgenographic examination in September 1941 showed definite, though partial, restitution of the structure and appearance of the head. Some deformity of a coxa plana type persisted. She has been kept at partial or complete rest up to date in the Blythedale Home and Hospital for Convalescent Crippled Children. As relatively nor-

mal appearance of the head is noted, full weight-bearing will be allowed.

Case 2. M.S. (Hospital No. 448304), a German-Jewish girl was 10 years old when first seen at the Mount Sinai Hospital on November 25, 1939, with a complaint of pain in the left thigh on walking, of three months' duration. She was first seen at another hospital on October 1, 1938, for limp and pain in the right knee and thigh. Roentgenographic examination of the femora at that time was said to be negative, but splenomegalia had been noted. Symptoms subsided with bed rest. In a subsequent admission in April 1939, the diagnosis of Gaucher's disease had been established by splenic puncture, and splenectomy had been done.

On admission to Mount Sinai, tenderness and slight restriction of motion of the left hip was noted. Roentgenographic examination showed an infiltration with mottling of the upper portion of the left femoral head, like an atypical Legg-Perthes disease. An eosinophilia of 7 per cent was also noted.

Pain promptly disappeared with bed rest. A caliper brace was suggested, but before it could be obtained, recovery was so complete that it was omitted. Reexamination 4 months later revealed no further symptoms or signs related to the bones, and an excellent general condition. She then moved out of town so that further follow-up was impossible.

Case 3. E.K. (Hospital No. 472130), a Jewish boy had a series of admissions to the Mount Sinai Hospital, beginning in February 1938, at the age of 5. His presenting symptom was pain in the lower part of the right femur following a fall. Similar pain had previously been present without injury.

On admission, his temperature was elevated to 101°. There was some restriction of motion in the right knee and tenderness over the lower femur. An enlarged spleen and eosinophilia of 10 per cent were present, but the diagnosis was not made. Roentgenographic examination was negative. Prompt recovery occurred with bed rest.

He was readmitted in September 1938 for restudy. The liver and spleen were now both enlarged. A sternal puncture revealed typical Gaucher cells in the bone marrow. Roentgenographic examination of the skull and femora showed no changes. In December 1938, he developed a limp in his right lower extremity, with pain on walking, and with no known injury. Roentgenographic study at that time showed a pathological infraction of the neck of the right femur with coxa vara deformity. There was also medullary mottling at the lower ends of both femora. Symptoms of pain in the hip and both knees continued intermittently until he was readmitted in December 1940. At that time the only additional findings were an increased phosphatase, 37 King-Armstrong units, and a persistent eosinophilia. Roentgenograms showed some progression of the lesions of the bones.

In April 1941, he was again admitted for pain in the right hip and inability to walk, of one week's duration. There was again an elevated temperature (102°), marked spasm of the right-hip muscles, and tenderness over the anterior and lateral aspect of the joint. An inflammatory lesion was suspected in addition to Gaucher's disease. Roentgenographic examination showed marked coxa vara, but the epiphysis of the femoral head was undisturbed. Atrophy of the right pelvic bones was present. Traction was applied and brought prompt relief of pain. The temperature gradually became normal. He was discharged to the Blythedale Home and Hospital for Convalescent Crippled Children for a further period of rest and limited weight-bearing. While there, it was deemed advisable to apply a hip spica for further immobilization.

The final admission to Mount Sinai was in September 1941. Roentgenographic study at this time showed the same diffuse bone changes previously observed, and typical of Gaucher's disease. Persistent coxa vara was present, but there was no sign of the previous femoral neck infraction, and there was no epiphyseal change. Gradual mobilization and weight-bearing were then instituted.

B. *Hip Lesions in Adults*

Case 4. A.R. (Out-Patient No. 40-5471), a woman, 32-years-old, and a deaf mute, came to the dispensary complaining of pain in the left hip. There was a history of splenomegalia treated at another hospital. In May 1939, splenectomy had been done, and the pathological diagnosis of Gaucher's disease was made. Her hip symptoms were rather mild, and caused little interference with activity. A limp had been present since childhood, but the hip pain was said to be of a few months' duration. At the age of 10, she had had a plaster cast on the right hip for a period of 2½ years for "Legg-Perthes" disease.

She limped on the right lower extremity, and motions of the right hip were all somewhat restricted. There was no shortening, but 1 inch of atrophy of the right thigh was present.

Roentgenographic examination in September 1940 showed a mushroom deformity of the head of the right femur with coxa vara deformity. The femoral neck was shortened and widened. Both the femoral head and the acetabulum were irregular, and there was a marked coarsening of the trabecular structure in the upper end of both femora. Roentgenograms of the long bones showed areas of rarefaction up to 1⅗ centimeters in diameter in both shafts of the femora, tibiae, and humeri. There was general decalcification of all the bones, and clubbing of the lower ends of both femora. While the hip changes resembled osteoarthritis superimposed on an old condition of coxa plana, they were considered typical of Gaucher's disease in the bones.

Case 5. F.K. (Hospital No. 447741), a Jewish woman, was 32 years of age when first treated at the Mount Sinai Hospital in 1929. At that time she complained of pain in the left thigh of 4 years' duration, as well as of frequent nosebleeds.

Physical findings at that time included splenomegalia, bilateral pingueculae, and hepatomegalia. There was restriction of motion of the left hip and shortening of 1½ inches in the left lower extremity.

Roentgenographic examination revealed expansion of the lower portion of the shaft of the femora with thinning of the cortex. There was marked irregularity and absorption of the head and neck of the left femur.

Since that time, the patient has had more or less constant pain in the left hip, severe enough to cause much disability and to necessitate several hospital admissions. In March 1937, roentgenographic examination showed marked deformity of the left femoral head with mushrooming as well as widening of the femoral neck. The hip-joint space was narrowed, and there were definite osteoarthritic manifestations. Slight mottling of the neck and upper femoral shaft was present, as well as typical clubbing of the lower end of the femur. A flexion-adduction contracture gradually developed, with limitation of motion in all directions. The clinical picture resembled ordinary osteoarthritis. At various times physiotherapy, radiotherapy, and bed rest with weight traction were administered. Only the latter seemed to produce any benefit, and even then the pain tended to recur with undue activity. In 1937 also, the diagnosis was finally confirmed by puncture of the sternal bone marrow, which revealed the typical Gaucher cells.

Surgical arthrodesis of the hip was seriously considered, but the Hematology Department advised against this in view of the presence of thrombocytopenia and leukopenia, and the possibility of hemorrhagic complications. After this admission in 1937, a Thomas caliper tuber seat brace was applied and gave relief for a considerable period. In January 1941, the patient's activity was much restricted by pain, but she no longer required the brace. Further roentgenographic examinations showed little or no change in the condition of the hip.

Case 6. L.R. (Courtesy of the late Seth Selig, M.D.), male was first seen in 1939, at the age of 29. He is the brother of the patient in Case 4. He had had intermittent pain and swelling about the left knee for some years, with a rather persistent limp. In the year before, increased pain and limp in the left hip were present. At the first examination, there was tenderness over the lateral aspect of the left hip. A flexion contracture of the hip at 135° was present, with limited abduction, adduction, and rotation.

Roentgenograms showed a distortion of the left femoral head, which was elongated and flattened. The medial half was cystic, but the joint space and acetabulum were relatively normal. The diagnoses of old tuberculosis, old Legg-Perthes disease, or old slipped femoral epiphysis were suggested.

With no treatment but bed rest, the symptoms gradually subsided, leaving only slight limitation of extension, abduction, and rotation of the hip. Fusion of the hip had been considered elsewhere, but had been refused by the patient.

In October 1941, the patient returned for further examination. By this time, the authors were aware of the findings in his sister, Case 4, and recognized Gaucher's disease as the underlying cause of the hip lesion. The man was somewhat pallid, and his skin and mucous membranes were subicteric. The spleen was enlarged to four fingers below the costal margin. Further roentgenographic study of the lower femora showed the typical changes of Gaucher's disease, with clubbing, thinning of the cortex, and infiltration of the medulla. The hip joint presented the same appearance as before.

This is the only case not verified pathologically.

Case 7. F.R. (Hospital No. 417222). A Jewish girl was first admitted to the Mount Sinai Hospital in 1923, when she was 3½ years old. The presenting complaints were prominence of the abdomen, and epistaxis. An enlarged spleen and liver, and purpura were found. All roentgenographic findings were normal. A splenectomy was done, and the pathological diagnosis was Gaucher's disease.

Her next admission was in March 1934, when she compained of pain and swelling of the left knee of 7 years' duration. There was also occasional pain in the left hip. The left knee was enlarged by periarticular thickening, and widening of the upper end of the tibia and fibula. There was outward bowing of the leg at its upper end. Roentgenograms showed a transverse, pathological fracture of the left tibia two inches distal to the knee joint. In the hips, there was marked mushrooming of the femoral heads with coxa vara deformity on both sides. Areas of transparency and mottling were present in the lower ends of both femora. The leg deformity was corrected somewhat under anaesthesia, and the fracture was treated in a plaster cast. After prolonged plaster fixation, it gradually united with persistent bowing, union being firm only in May 1935.

Roentgenographic examination in December 1937 revealed the changes described previously. There was clubbing of the lower ends of the femora, and still marked flattening of the femoral heads with coxa vara deformity. No symptoms or signs of hip involvement were noted at this time nor have any developed since. At her last examination in 1941, this patient was asymptomatic, working, walked without limp, and had full range of motion in both hips. Slight persistent bowing of the left leg was still noticeable. In this girl, the hip involvement is so far of minor clinical importance. She is still young and future disability may develop.

Case 8. S.F. (Reported in detail by Melamed and Chester). In this Jewish male, symptoms of "arthritis," involving many joints, first developed in 1921, at the age of 12. Splenomegalia, failure to gain weight properly, and anaemia gradually appeared. In 1922, diagnosis of Gaucher's disease was made by splenic puncture. Four years later, nasal and oral hemorrhages took place, and splenectomy was performed. In 1928, there was a recurrence of joint pains. By 1930, spinal pain and deformity (gibbus) were marked, and there was a considerable decrease in the height of the trunk. Marked hepatic enlargement had occurred together with abdominal pressure symptoms. Collapse of several thoracic vertebrae were demonstrated in 1931.

On his final admission, he was poorly developed, anaemic, and had typical pinguecula. The lymph nodes in the neck, axilla, and groin were enlarged. A marked thoracic kyphosis with compensatory lumbar lordosis was present, as well as a huge liver. Generalized bone tenderness was present, but no definite symptoms or signs relating to specific joints were noted.

Blood studies showed a marked secondary anaemia. Biopsy of an axillary lymph node showed it to be full of Gaucher cells.

Roentgenographic study showed numerous collapsed vertebrae. The pelvis showed cystic changes in the innominate bones, specially near the acetabulum and bodies of the pubis. The femoral heads were flattened and irregularly mushroomed. Cystic changes were present throughout the heads and shafts with broadening of the latter. The lower ends of the femoral shafts showed the typical clubbing or bottle shape. Other less marked changes were present in the right fibula and tibia, as well as in the left radius and right humerus.

Postmortem examination showed the osseous type of Gaucher's disease. There was involvement of the lymph nodes, liver, spinal column, femora, pelvis, right humerus, left radius. Heterotopic bone-marrow formation was found in the liver.

In this patient, the hip changes were only incidental and gave rise to no symptoms or signs. It is likely that the extensive involvement of the bones resulted from the removal of the spleen in early life.

SUMMARY AND CONCLUSIONS

From a study of eight cases of Gaucher's disease with hip-joint involvement, classified on the basis of age group and roentgenograms, it appears that treatment by prolonged rest is indicated to minimize deformity in the patient in the younger age group.

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PHILLIPE C. E. GAUCHER

Phillipe C. E. Gaucher (1854–1918) a leading French physician at the turn of the century described the disease since named after him in 1882 but was not aware of possible bone involvement. Later Pick and Stout published pathologic material demonstrating bone lesions. Others followed and some cases involved hips.

In 1942 Albert J. Schein (1910–) now Professor of Orthopaedic Surgery at the Mt. Sinai Medical School, City University of New York, and his colleague Alvin M. Arkin (1912–1968) published the present paper in the *Journal of Bone and Joint Surgery* which established Gaucher's diseases as a specific and not too rare cause of hip disease. Probably its most important effect was to make us review our cases of Legg-Perthes disease in children and to differentiate those cases which were then discovered to be Gaucher's. Previously, in children, the similarities on x-ray were often deceiving.

CLASSIC 61 Cleavage of the Cutis

The Anatomy and Physiology of the Skin

Corresponding member of the Royal Academy of the Sciences.
Presented at the meeting of April 25, 1861.

PROFESSOR KARL LANGER (1819–1887)

Dupuytren observed in a paper published in 1836 "Injuries due to weapons of war", that a round tool that was stuck in the skin did not produce a round stab opening, but rather linear clefts. He made this observation on a young man who had tried to commit suicide and had stabbed himself three times in the direction of his heart. Were these stabs really made by a round tool, or were they made by a knife blade? This made it necessary to test the situation on bodies and the skin. Dupuytren found that stab injuries do take a different direction in different areas of the body and that they could be enlarged or narrowed, depending on which direction one is making the stab injury, lengthwise in line with the skin fibers or crosswise against them. Magenge also recognized the value of this observation and added more information on the direction of the fibers in the different areas of the body. He could not find a general law on the direction of the fibers, but encouraged other people to continue such studies. Finally, he pointed out the importance to the practicing surgeon of understanding these skin textures and reminded us of the influence of such tensions on the healing of skin injuries. These reports seemed to me to be sufficiently important that I decided to investigate further.

I assumed in the beginning that if I placed stab wounds as close together as possible in different areas of the body it might be possible to make a typographical picture of these tension lines for the whole skin surface as had been done on the distribution of human hair. These lines we shall see should give us some information not only on the texture but also on the elasticity of the skin and perhaps other useful information about the cutis. Having examined the results on a fairly large number of bodies of different age and condition I would like to present the results of my findings. I will limit myself to the cutis and its response to laceration.

The tools that I used in most of these experiments were nearly always a sharp pointed prong approximately two and one half centimeters long and having a base of approximately two millimeters. I also used prongs of larger dimension to find out what the difference, if any, would be using this bigger tool. I found that even the bigger prong, after penetrating through the skin to a full depth, always resulted in a linear wound. The prongs were kept sharp and lubricated by using oil, but they also had to be used in such a way that they would penetrate through the skin in a perpendicular fashion. If they hit bone shortly after en-

tering the skin further advance was made in a slanted direction. Tension on the tissues of the skin areas to be examined was avoided if possible, but was not always possible. The results were not influenced greatly by occasional exceptions. Only in those areas where the skin was very thin and when tension in the crosswise direction was applied to the skin area did we get a wound that was irregular in its surroundings. I have not observed a change in the pattern or the direction of these skin wounds on human bodies. When I examined the anterior portion of the upper thigh I found out that a change in the position of the hip joint, in other words, difference in tension of the skin, did not make any difference in the result in the appearance of the skin wound. For example, when the thigh was adducted the prong produced a narrow split but when it was abducted the same wound became more gaping, sometimes even circular: when the thigh was abducted still more the wounds assumed the same form of a narrow split. I also excised a piece of skin that had been injured lengthwise and used clasps to pull it apart transversely as much as I could. It was possible to produce a split in the skin that followed the direction of the pull, perpendicular to the initial original lengthwise cut of the skin. But without this artificial tension applied to the skin, even excised pieces of skin, always spit in the same manner, same fashion, same direction. In areas where the skin was really thin we used a blunt tip of a prong. Occasionally I produced a torn roundish wound opening whereas the sharpened prong in the neighborhood of this injury always produced a sharp split.

I chose thin skinned bodies for the first experiment but the fat bodies of deceased children gave us the most acceptable and most simple results. However, they may, as far as the skin direction is concerned, be different in some areas of the body from what we would find in an adult. When splitting preserved skin of old people, skin kept in alcohol, or even real leather, we still found the original direction of fibers. I also found that skin that has been swollen or saturated with acetic acid still let us produce the same kind of splits in the skin unless they were lacerated. Sometimes it was necessary to apply some tension to the skin or the initial injury would produce more gaping and roundish type of defects. I also examined some pieces of skin cut out of the body that had been changed into leather *after* having been given the same treatment by a sharp tool previously. And again I found that these splits were arranged in typical fashion as they kept their form. Looking at them under the microscope I found that they were lengthwise fibers that were arranged in layers. Two layers of longitudinal fibers were in line with the cut and one layer of cross fibers were cut by my tool. The incision was made with a sharp knife. If I made an incision with the same knife in a crosswise direction I found that nearly always all fibers were cut crosswise. The microscopic examination disclosed without doubt that the shape of the laceration depended upon the course of the fibers. The wounds are nothing but an enlargement and pushing away of the meshwork of these parallel fibers and the rhomboid arrangement of these fibers made it clear why the wound was either narrower or wider depending on whether, for example, a thigh had been adducted or abducted.

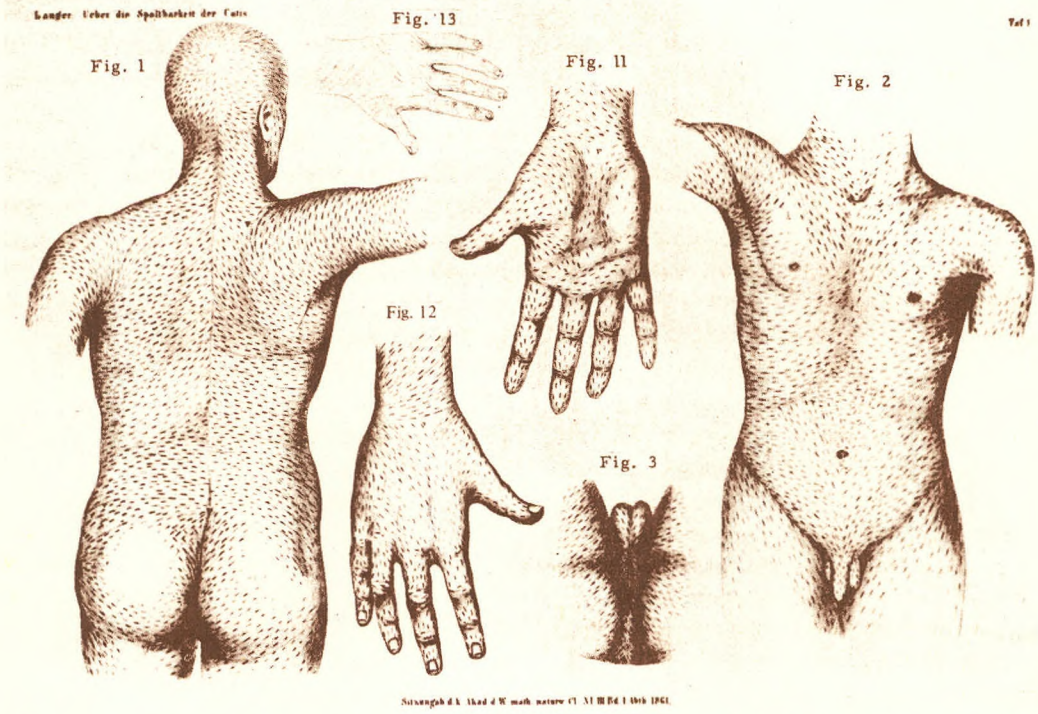
Now I found that this arrangement of fibers was not the same all over the body but in some areas these fibers are arranged differently. Using this sharp round tool I would not get gaping split wounds but a rather more triangular shaped injury and I found that the area of triangular injury usually happened at the extreme end of those areas where I had found longitudinal splits, for example, in the upper area of the scapula. It seemed that this triangle resulting from the tool is dependent upon how many

different directions longitudinal fibers come together in one particular area. In other words, the location of these triangular wounds is very definitely limited to certain areas of the body and it is possible to make a drawing in which definite irregularities are seen.

We can find these split wounds and on the other hand the triangular wounds and these drawings become so much more clear when the split wounds markings are connected. In certain areas of the body I constantly found the same direction of those splits, for example, over joints, also in the face and in the back and chest, but there were also other areas where I found variation, for example, the middle of the forearm, the lower legs, and the anterior abdominal wall. I found it of interest in this connection that these variations depended on the condition of the bodies at the time. Usually I found a very definite and constant pattern in very skinny individuals and more irregular patterns in suicidal individuals and deceased ones that died of chronic diseases. Of great importance were the variations found in newborns and embryos. I found that even if these embryos had been kept in alcohol for a length of time I could still find the same conditions but they were usually not as constant and usually somewhat different from those found in adults.

In the following description I refer fundamentally to those conditions found among adults and children. I refer to the drawings concerning the details. I have arranged descriptions of the torso generally in rows. Figures 1 and 2 on the left represent adults. The right side of Figures 1 and 2 represent a two-and-a-half-year-old boy. The linear split wounds form a belt around the rump and come in symmetrical lines from the back and the joint line to the middle. Those rows of cleavage lines are hardly ever in exactly a horizontal arrangement but they rather always begin a little higher in the back and end anterior a little bit lower. They are not of equal width all over and these lines could not be paralleled completely. So they converge on the small narrow part of the torso and diverge on those wide areas. But the manner in which they surround the torso can be seen very easily in Figure 1, left to right. The more simple conditions are found in the lower cheeks than in the lumbar area. Those rows are more horizontal but in other areas more descending, like a fan descending from the lower chest area to the abdominal area. In the area of the superior ribs they seem to be bent upward slightly more than in the lower ribs where they descend to the area of the pubis. Occasionally I also found rows of lines direct from the anterior superioiliac spine towards the umbilicus. In the middle of the abdomen quite frequently one finds a field of lines which interrupt those that come from the thigh and on the other hand one occasionally finds lines that come descendingly from the back in rows of fibers. Evidently in the middle and the upper abdominal area there are two mighty rows of fibers in the weave and in some areas one fiber string is closer to the surface than other areas. In this case one would find an area of triangular stab wound over a wider area in the abdominal area. Also in the area of the 9th rib cartilage one will find usually torn wound areas. In the inguinal area I have always found split wounds that were in the area of the inguinal canal. The linea alba sometimes produced slanted descending and transverse splits. These transverse splits are apt to be constant near the pubic bone and the same seems to be true in the neighborhood of xiphoid process.

In the area of an umbilical scar I have found the fibers arranged in a concentric way and spreading fanning out in line with fibers coming from the side of the back and the anterior chest. This is where I found a greater number of variations in the grouping of those splits. In the side of the torso between the ribs and the iliac bones I found



FIGS. 1 and 2. Diagrammatic representation of the manner in which anatomical lines encompass the torso: left side of torso represents adults; right side represents newborns. FIG. 3. Diagram of the anatomical lines of the anal area. FIGS. 11 and 12. Lines of the anatomy of the skin of the adult arm. FIG. 13. See legend for FIGS. 9 and 10.

constant transverse and descending fibers. The back of the torso situation is similar to the split wounds in the area of the neck. From the ligamenta nuchae superior of the posterior of the head down to the 7th vertebra we find lines that go forward to the anterior area of the neck. The upper lines go along the lower jaw to the mid-line forming acute angles. All these lines form a three sided triangle in the neck area.

The arrangements of the lines in the upper chest is peculiar. These rows of lines surround the original extremities or were perhaps moved over into them. In the area of the upper chest between the 1st and 8th thoracic vertebra the rows of lines go downward to the side of the chest cavity and then over the free edge of the latissimus dorsi into the axilla and turn around over the pectoralis major towards the anterior lateral chest wall in a similar way as the cutaneous nerves do. The anterior rows follow around the lower chest and in general terms the direction of the nerves. In the upper portions of the chest all these fibers go around the original extremity and in the areas where the lines come from the back of the head and those lines that go in the chest come together we usually find a small area of triangular stab injuries. In bodies of newborns, the borders of these two lines come together very suddenly without any area of irregular wounds.

In general, we find that in the back, those lines directed in a descending fashion near the upper dorsal spines lead to an area of irregular torn or wound opening. In the anterior chest area the stab wounds are arranged in a different fashion. In the chest area near the 4th and 5th rib cartilage and

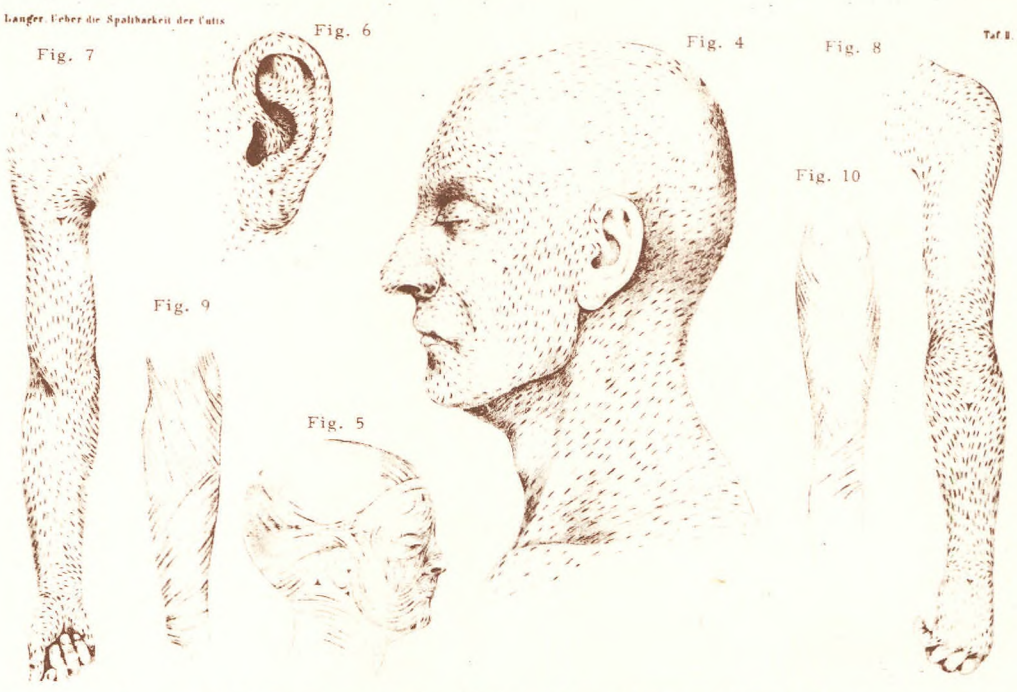


FIG. 4. Diagram of the anatomical lines in the skin of the adult head. FIG. 5. Diagram illustrating the irregularity of the anatomical lines of the newborn head. FIG. 6. Diagram showing newborn ear in detail. FIGS. 7 and 8. Diagram of anatomy of the thin skin of the adult arm. FIGS. 9 and 10. Anatomical lines of variations of arm and hand in detail.

area of the clavicle we have lines that descend towards the center. In the breast area they have more horizontal, and near the edge of the pectoralis they are more in a regular fashion. Just as in the umbilical area, we also have circular fibers near the area of the nipple. In the female the lines that cover the area of the breasts are the same as in the male except these lines are farther apart because they have to cover a larger area.

Just as in the upper chest and also in the area of the lower lumbar area we have a similar arrangement at the place where the lower extremity begins. Figures 1 and 2 on the left show the situation in adults and illustrate that the zone grows wider and broader and goes over the lateral portions of the gluteus and fans out over the trochanter mostly slanting downward toward the pubic area and to some extent towards the anterior and medial thigh area. The fibers that go into the thigh can be followed in adults and have gone to the middle area of the posterior thigh. Thus a portion of the fibers that come from the lumbar spine go down in a tortuous fashion over the hip.

From the tip of the coccyx there is a fan like spread of lines over the sacrum and up to the lower lumbar area meeting the horizontal fibers in the lumbar area at nearly a right angle. The more lateral fibers fan out toward the side over the gluteal and towards the lateral thigh. The curve of the gluteal area makes these fibers become more or less separated from each other. The trochanter is the radiation point from the gluteus maximus, thereby becoming three different rows together which are to some extent interwoven. This makes it most likely that we will find triangular stab wounds in this area. At the peripheral gluteal area we are more

likely to find regular split wounds. In cases of thin bodies I found the area of this type of interweaving much more limited and I could find even in the center of the gluteal convexity pure splits which usually were in a horizontal direction. In a very thin child two to two-and-one-half years of age I found the situation as illustrated in Figure 1 on the right, and the outstanding observation in newborns and children is that the fibers coming from the coccygeal area over and into the gluteal area are better defined but still the center of the gluteal muscle is usually ill defined. In the area of the anus the stab splits seemed to be arranged in a radial fashion but they are really slanted only in the mid-line. When pulling the anal area in a transverse fashion the spread in the perineal area will become more horizontal in a transverse fashion. When on the other hand the perineal is being stretched these fibers arrange in a circular fashion around the anus.

In the testical area tension will change the direction of fibers from horizontal to parallel formation. In the pubic area and in the area of the base of the penis these lines of stab wounds sometimes run horizontally and sometimes slantingly toward the inguinal area and towards the side of the scrotum. At the shaft of the penis they are longitudinal slightly sliding toward the side of the penis and the area of the glans. These rows are longitudinal but when putting some tension to them they can be moved into a circular direction. In the area of the glans of the penis they are nearly always directed towards the opening of the urethra. The arrangement of these lines in the area of the female genitals is similar to the arrangement of the scrotal area. Figure 4 shows an adult, Figure 5 shows a newborn and Figure 6 shows the newborn ear in detail. Bodies of newborns were more suited for this experiment because they made more irregular splits and the soft bones underneath did not pose a problem of pushing vertically into the skin. Especially in the newborn these fibers slant toward the ears and then divide near the mastoid in two directions. One group of fibers goes underneath the ear into the upper face area where the other group goes above the ear into the frontal area. From the frontal area it moves over the mandibular area and in a concavity it moves toward the lower lip. These two groups of lines evidently surround the ear and unite again near the mandibular edge. Near the mastoid and under the ear lobe we find irregular lines. On the lateral side of the mouth there develop new rows of splits which move to the side of the nose and in a fan fashion spread out to the bridge of the nose and more gradually towards the xygoma. Below the nasal fold under the upper lip we find short lines which spread toward the edge of the mouth. In the chin area one also finds separate fan-like arrangements of ascending fibers that are directed towards the edge of the lips on both sides of the face and edge of the chin.

Around the eyes we have a row of splits which are arranged following the fibers of the orbicularis muscle. The top of the head forms a center against which those rows converge from all directions. The longest rows are the ones which start in the area of the forehead. The shortest and easiest to find are those in the area of the occiput. The area of the flabella forms a fan, the base of which lies between the eyebrows and converge from the medial angle of the eyes towards the middle and go vertically up from the root of the nose towards the head between those two angles of the eyes. There is sometimes a short area where those folds go horizontally directly above the root of the nose. Over the forehead we find a border zone of horizontal folds which are interrupted many times by the ascending folds coming from the root of the nose. The lines in this area are not very definite, especially in adults. These folds sometimes run horizontally and sometimes in an ascending

fashion. Very often they are also regular. The situation is much more clear in a newborn, even using a smaller prong. I have always found the horizontal cleavage in infants to be very pure. Laterally and directly above the orbitus we find the horizontal arrangement again very clear, even in an adult. In the hairy portion of the anterior head we find the middle folds usually go towards the center. More laterally, we find more swirly folds with the mid-line; in the parietal area they are more slanted towards the top of the head. These folds are mostly irregular and near the xygoma they mix with those folds that go around the ears and become more irregular. In the upper portion of the occiput of adults, rows of folds directed towards the top of the head are usually very clear and well organized. Further down they mix with folds that are more horizontal and the lines become vague. Near the mastoid process and also on top of the head the lines are usually more irregular. In the facial area most folds follow the lines of the orbicularis muscles, especially around the eyes and lips. In the parotid area these folds descend laterally towards the cheek, the angle of the mouth, and the angle of the mandible. Over the edge of the mandible these rows descend toward the anterior neck. In the area of the xygoma where the folds mix we usually found irregular wounds. The bridge of the nose usually had folds that were directed in a fan-like fashion towards the tip of the nose. Near the tip of the nose the rows coming from both sides converge in acute angles. The angle of the mouth divides the folds that come from the periodontal area, the larger portion descends towards the chin and a smaller portion goes to the upper lip. Below the lower lip the same folds direct in a cove towards the lower lip. In the central area of the upper lip directly below the septum of the nose and also near the tip of the chin, we found frequent irregular wounds. The opening of the mouth has mostly regularly arranged folds. All of those rows of folds that come up the posterior neck and the occiput area correspond pretty much to the arrangement of the occiput and between these rows the ear is located. The area of the ear is mostly covered with irregular wounds except for the area of the meatus where we find a tunnel-shaped arrangement of these wounds.

Figures 7 and 8 show the thin adult arm; Figures 11 and 12 show the lines of anatomy of the adult hand; Figures 9, 10 and 13 provide more detailed variations of the arm and hand. In the shoulder area there are evidently circular contours which are arranged in a fashion that makes them seem to originate in the axillary fold and makes them ascend around the acromium and run against those rows that come from the upper chest area and over the acromium. These run against the rows that come from the lower posterior neck area. Near the scapula and also near the clavicular area they form a border with the above mentioned folds where we find undecided and irregular wounds. In the newborn these rows usually form some kind of belt that goes around the upper extremity, actually a series of belts which start over the deltoids and go down around the upper end of the elbow. These belts are of a spiral type of arrangement. They do not form irregular rings around the limb but move steadily down towards the elbow area. Some fibers coming from the chest and posterior neck area evidently go over into the upper extremity, but not in a direct fashion. This type of arrangement evidently is connected in some way with the stretching out of the lower extremity. These fibers become more extended when the person grows up. This is similar to findings in the gluteal area. On the upper arm we find on the lateral side long rows of slantingly descending split wounds that go over the biceps down to the elbow joint where they move toward the ulnar side and turn over the medial condyle towards the extensor side of the forearm. The folds that descend

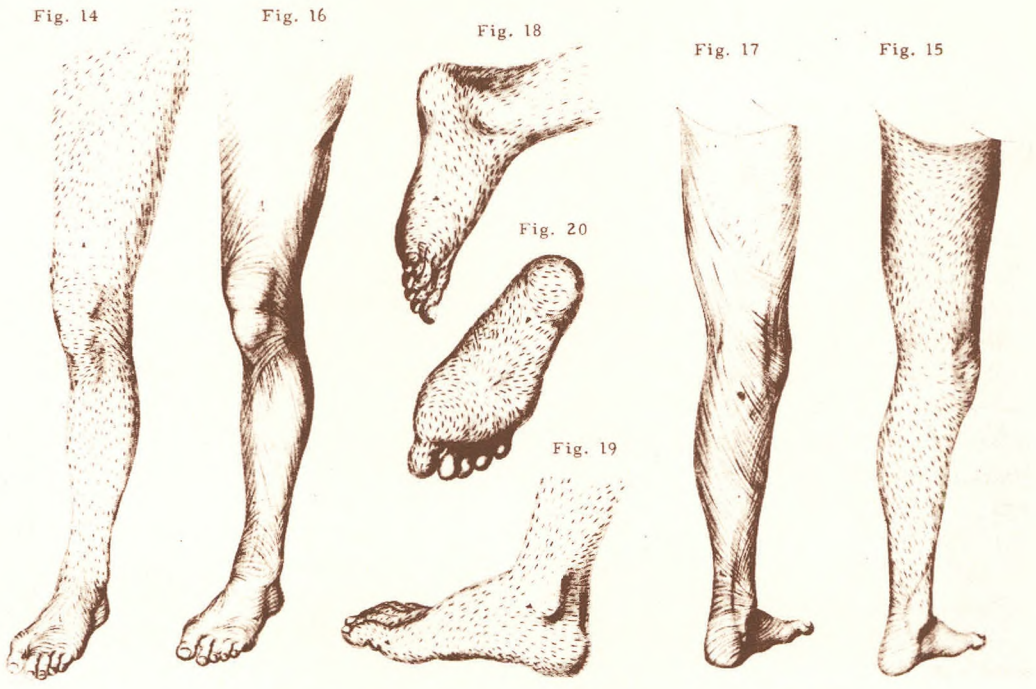
from the upper arm towards the forearm nearly form a figure 8 when coming from the upper arm and moving over the elbow area towards the forearm. In the forearm area I found two modifications in relatively simple situations, one in lean adults, and a more complicated arrangement in more muscular individuals who have died of acute diseases.

From the arrangements of these folds over the forearms we can come to the following conclusion with reasonable probability. Those fibers that start from the condyles of the elbow move over the dorsal side of the forearm to overlap in the form of a sling the fibers that come from the medial condyle and move over to the radial side. Other fibers coming from the lateral condyle move over to the ulnar side from which they pass over toward the back of the hand. In a modification we find a more confusing picture; rows that are usually not long interrupt the other folds that go against their direction. We do not have long rows of fibers in this kind of individual. All together fibers seem to make spirals around the forearm much sooner. In a second modification we have a much more frequent circling of the forearm by the fibers than we have found in previoulsy described types.

The investigation of the splits in the area of the hand posed difficulty because of the small area in which fibers go in multiple directions and are thus difficult to separate. Some observations were repeated; the lines consist of rows that originate at the base of the hand and the lateral edge of the midhand. Some had rows which were longitudinal but were interrupted in the area of the joints by transverse lines. On the volar side of the hand are deep folds and often the neighbor of these skin folds can be split in a direction that parallels the skin folds. Fibers on the back of the hand are arranged in the previously described manner of the lower extremity.

Figures 14, 15, 18, 19 and 20 deal with adults. Figures 16 and 17 show a variation in a three-year-old child in detail. In the inguinal area the folds we mentioned previously are divided by the Poupart's ligaments. The ones above the Poupart's ligaments descend towards the pubic area and those below Poupart's ligaments move slantingly over the anterior surface toward the medial area of the thigh and the more lateral they begin, the more slant they have. Under those that originate in the middle area of the anterior thigh, more follow the sartorius towards the medial condyle underneath. All of these rows move toward the posterior side of the thigh. On the lateral side the rows that originate from the trochanter move directly downwards to the knee and from there they move towards the posterior thigh surface. The two rows of folds interfere with each other in the area of the gluteal muscles. Here they form a field of irregular cleavage in the popliteal surface and are again interrupted by a transverse arrangement of fibers which move out in a fan over the medial condyle toward the extended leg underneath. On the extended side of the knee joint we find a situation similar to what we have already found over the elbow joint. Those fibers that originate in the upper thigh move towards the lateral side of the knee. Just above and including the patella area we find transverse and descending rows. We find a kind of a cap in which the fibers can be pushed together when the knee is straight and can be separated when the knee is bent. When the knee is folded in the back these fibers continue as in the elbow area by moving in a slanting way medially over the calf.

Again, as we found in the forearm, we observed a variation of thin individuals. The fold fibers or splits that were produced in the lower leg are spiral shaped as we found them to be in most individuals. The descent is more rapid but nevertheless the figure 8 type of arrangement of the folds is



FIGS. 14 and 15. Lines of the anatomy of the skin of the adult leg. FIGS. 16 and 17. Drawing of the details of the thin skin of the leg. FIG. 18. Superficial lines of anatomy of the skin of the medial section of the adult foot. Figs. 19 and 20. Skin lines of dorsal section of foot including sole of the adult.

seen here too. Again in the area of the ankles and the heels we find a system of transverse rows similar to the ones we found over the stretched side of the knee area. In the ankles we find an area of indefinite cleavage of these irregular wound areas. The typical finding is illustrated in Figure 14. The situation in the dorsal area of the foot is illustrated in Figure 19. Here we find constant rows of splits that are directed lengthwise and medially. More distally we find arches of rows that circle the area. In the hallux we find short rows that move over the back of the big toe. The sole of the foot has at least four different rows of folds, two starting on both sides of the heel and move forward distally and the other two starting at the ball of the toe and moving proximally. All four rows converge in the middle of the sole. At the medial edge of the foot and the area between the toes and the heel we also find a mixed formation where the folds move in one direction or the other. Irregular wounds appear throughout, most often near the heel and near the base of the small toe.

In the area of the pallet I found that when splits are arranged in curved rows going from side to side, they are parallel to each other and reach from one side to the other. The back of the tongue has rows of splits arranged slanted from lateral towards the center and there forming an angle with a median line. The male urethra and its lining can be split in a transversed direction. The vagina shows a particular type of cleavage.

In summary, from microscopic examination we have found that stab wounds always correspond with the direction of the arrangement of the fibers of the skin. Therefore we

can make the following statement: these fibers form loops which over the torso have shape, sometimes more horizontal and sometimes more slantingly, descending all over the body. The extremities are surrounded by these fibers in a figure 8 shaped fashion. These fibers are arranged in such a way that no musculature directly will overcome the tension of the skin fiber. All fibers in the areas of joints are either crosswise or slantingly arranged. Therefore, folds of the skin which have been caused by musculature indicate the direction of cleavage of the skin. This is not only valid for those folds near joints, but also folds over the face. The fibers are arranged in such a way that an increase in volume of that part of the body does not lead usually to any additional tension of these folds and fibers; but in some areas they are more separated, pushed apart from each other, when the volume of the extremity is increased. For the same reason the folds we see in people who have lost weight will correspond with the direction of their skin fibers. In the anterior chest area and the abdominal area these fibers in some places seem to be crisscrossed at more or less right angles so that these fiber bundles usually do not run uninterruptedly over the total body area but are rather interrupted by other fibers and replaced by new fibers that originate with the fascia underneath. It should be emphasized that these fiber bundles in several instances are stretched out over a considerable distance. Since the hairs of the cutis are interwoven with the arrangement of those fibers, we have to assume that there is a certain amount of agreement between the arrangement of those fibers and that of the position of the hair follicles.

I have made some observations on the cleavage of scar tissue, but I have only a few observations to record. I examined two deep round scars in a lower leg of a young man that developed after healing of a cornical ulcer. The diameters of these two ulcers were two hundred and three hundred millimeters respectively. I found in the lateral area of the scars and the center of the scars more irregular arranged wounds than splits.

KARL LANGER

Karl Langer (1819–1887), taught at the University of Vienna on the anatomy faculty. He contributed a number of papers in various areas of anatomy during his career. The one published here was an observational investigation which led to the concept of favorable lines of surgical incision in relation to subsequent wound healing.

CLASSIC 62 Fractures of the Neck of the Thigh Bone

SIR ASTLEY COOPER, BART., F.R.S., SURGEON TO THE KING (1768–1841)

I have stated it to be a general principle, that the neck of the thigh-bone, when it is broken within the capsular ligament, and attended with the usual characters of that fracture, viz. occurring in advanced age, a limb shortened from 1½ inches to 2½ inches, accompanied as it usually is by an everted knee and foot, such fracture does not unite by an ossific process, but by means of a ligamentous substance passing from the capsular to the reflected ligament, and from bone to bone.

Since the publication of the first edition of this work, I have had the curiosity to ascertain the number of specimens of un-united fractures of the Cervix Femoris, contained in the different collections of the United Kingdom, and I find them to be as follows:

In the Museum of St. Thomas's Hospital we have 7 specimens, 5 of which are human, and 2 are the result of experiments on animals.

Number of Specimens		
In St. Thomas's Collection	7	specimens
In the College of Surgeons	1	"
In St. Bartholomew's	6	"
At Dublin	12	"
In Mr. Langstaffe's of Basinghall-Street	6	"
In Mr. Bell and Mr. Shaw's	6	"
In Mr. Brooke's	2	"
In Dr. Monro's	2	"
Mr. Mayo's Collection	1	"
	43*	

The main principle upon which this want of union depends, I have endeavoured to shew, exists in the lessened nutrition of the head of the bone; from the bone, periosteum, and reflected ligament being torn through, and the ligamentum teres being the only source of supply of blood to the head of the bone which remains in the acetabulum, the

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* I intentionally exclude mentioning the numerous cases I have seen in the practice of my profession, in the living subject, of un-united fractures of this description.

arteries of the ligamentum teres are small, and do not appear to have the power of secreting ossific matter, as the head of the bone undergoes scarcely any change after the accident.

But the best proof of the difference of a fracture within, and 1 external to the ligament, is given in a preparation of Mr. Langstaffe's* in which a fracture has happened within the ligament, and another external to it, and whilst the latter is seen firmly united, the former has undergone no ossific change.

It is of great importance to determine if this want of union be a general rule or not. In the 43 cases which I have given, does the non-union depend upon the structure of the parts and seat of the accident, or on the surgeon's ignorance and inattention? It is my belief, that the permanent lameness, the crepitus, the shortened state of the limb, and its everted position, are not in the surgeon's power to prevent or control; but still, if he has the smallest doubt, either of the nature of the accident or its result, he should employ the means which may suggest themselves to his mind as holding out the hope of a successful issue.

There is scarcely any general rule to which some exception may not be found, and I have expressly stated in this work, that "It is possible the neck of the thigh-bone might be broken, without the strong sheath of its periosteum and reflected ligament on the neck of the bone which surround it, being torn; and that, under such circumstances, if they ever were to happen, ossific union might still proceed, but that in such a case, the usual shortening of the limb would not occur."*

Mr. Stanley, assistant-surgeon of St. Bartholomew's Hospital, has kindly shown me a bone, which conveys the idea that the neck of the femur had been broken and united; but it is curious, that the other neck of the thigh-bone, in the same subject, exhibited appearances nearly similar, only external to the ligament. I have in my possession, a fracture of the neck of the bone, and of the trochanter major, in which the periosteum and reflected ligament are not torn, and in which, if the patient had lived, I see no reason why it should not have united. If upon further investigation by Mr. Stanley, it should be found that in his case, the fracture of the neck of the thigh-bone within the capsule, had united, the cases would still remain 43 to 1 in favour of the general principle which I have stated. But in all cases in which a crepitus could be perceived at the joint by moving the thigh, if the leg be but little shortened, I should treat the patient as if the fracture were external to the ligament, although it be internal, as it will have the character of the external, and not that of the fracture within the ligament.

In examining the neck of the thigh bones in old and diseased persons, extraordinary and very unexpected changes will be found. It is very common to observe the neck of the bone in a great degree absorbed, and if a perpendicular section be made of such a bone, near to its cartilaginous surface, the head of the bone will form 1 portion, the trochanter another, and a portion of cartilage will unite them.

The head and neck of the bone are sometimes so much softened as to be incapable of being removed from the acetabulum without being broken. During the present winter this happened in each neck of the thigh-bone, in a subject in the Dissecting-room at St. Thomas's Hospital.

It often happens, that the neck of the thigh-bone is bent down so that the head nearly touches the shaft of the bone, giving it, to an inexperienced eye, the appearance of fracture.

* Of Mr. Langstaffe's professional zeal, good sense, and liberal conduct, it is impossible to speak in higher terms than he merits.

* I have however, seen cases of ligamentous union, even when the sheath remained whole.

When the neck of the thigh-bone of some persons is cut through, a line of solid bone will be seen proceeding from its shaft upwards, through the neck of the bone, having the character of a fracture united.

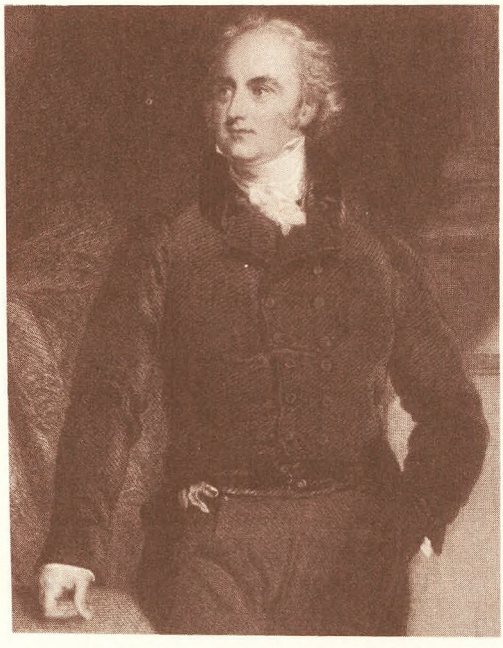
If the edge of the acetabulum be diseased, a projecting circle of bone will be often seen surrounding the neck of the thigh-bone, looking like an united fracture.

These circumstances must be first well inquired into before persons can form a clear judgment upon the subject of fractures, or they are constantly liable to mistake the effects of age and of disease for fractures of the bone.

I shall here take the liberty of subjoining the following letters, one from Mr. Stanley, assistant-surgeon, of St. Bartholomew's Hospital, and Demonstrator of Anatomy at that hospital; one from Dr. Monro, Professor of Anatomy at Edinburgh, and one from Mr. Colles, Professor of Anatomy and Surgery at Dublin, as each of them is interesting as regards the facts upon this subject.

REFERENCE

Cooper, A. P.: A Treatise on Dislocations and on Fractures of the Joints, 2nd ed. London, Longman, Hurst, 1823; pp. 570-576.



SIR ASTLEY PASTON COOPER

Sir Astley Paston Cooper (1768–1841) was the leading surgeon of London in his day. He was probably John Hunter's most prominent pupil and Guy's Hospital's most popular personage (see Vol. 42, 1965 for his biographical note). Although Paré described fractures of the hip his observations other than diagnostic were not contributive. Cooper not only described the fracture but added the classic discussion of its major problem, the circulation of the femoral head and the circumstance of what subsequently became known as its vascular necrosis.

With subsequent editions of his long lasting book, *A Treatise on Dislocations and Fractures*, Cooper would add notes from his very popular lectures at Guy's. This classic is from the supplementary pages of his second edition of 1823.

CLASSIC 63 De Rachitide Sive Morbu Puerili, Qui Vulgo the Rickets Dicitur

FRANCIS GLISSON, M.D. (1597–1677)

Now that we may accommodate these things to the present business, if the Bones aforesaid be more plentifully nourished on one side and therefore do grow out more on that than the opposite side, there is a necessity, that that must grow crooked. For here the over plentifull nutrition of that side has the same power after the same manner to bow the Bones, as the interposed wedge have to bow the Pillar, save that the wedge is fastened only in some places of the side of the Pillar, and the over plentifull nutrition of the side of the Bone, is commonly equally made, according to the whole length thereof. For the aliment received into the Bone, in what part is obstructed; and like the wedge thrust into the Pillar it extends it into an augmented length, whereupon the Bone must needs be bowed towards the side which is not lengthened in an equal degree with the other. Moreover, if the production of one side of the Pillar happen only in one or two places thereof, and not in many, as in the third figure, then so much the nearer the inflexion of it approaches to the figure of a part of a Circle or a Bow. But if the said side according to the total longitude thereof, should be equally lengthened beyond the opposite side doubtless it would be bended towards the opposite side, and would exactly resemble a piece of a Circle or Bow without any Angles; just after the same manner arise the bending of the Bones in this affect: namely, from the greater lengthening of the side most nourished; for feeling that the lengthening happens by the received aliment, according to all the parts of that side an Angular figure cannot be expected or one compounded of many straight ones angularly convexed, but a crooked one like a Bow, wherein the convex part is constituted by the side, plentifully nourished and the concave or hollow part by the side, which is sparingly nourished. But when it happened that some part of the convex side of a crooked Bone is disproportionately nourished, in respect to the opposite side, without all doubt the convex Bone will stick out more on that part than the rest: and so from the inequality of the nutrition, we have given a reason of the crookedness of the Bones in this affect. We will add for a higher confirmation of this matter, an observation raised from the cure of this crookedness of the Bones. The Quacks of our Country are wont to rub daily the hollow, not the convex side of the Bones, and that rubbing, say they, does very much conduce to the cure, but this does rather hinder it. But it is certain, that rubbing does powerfully summon the nutritive juice out of the Bloody mass into the part so rubbed. Therefore if at any time you rub the hollow part which is insuffi-



FIG. 1. This illustration has traditionally been considered Glisson's portrait.

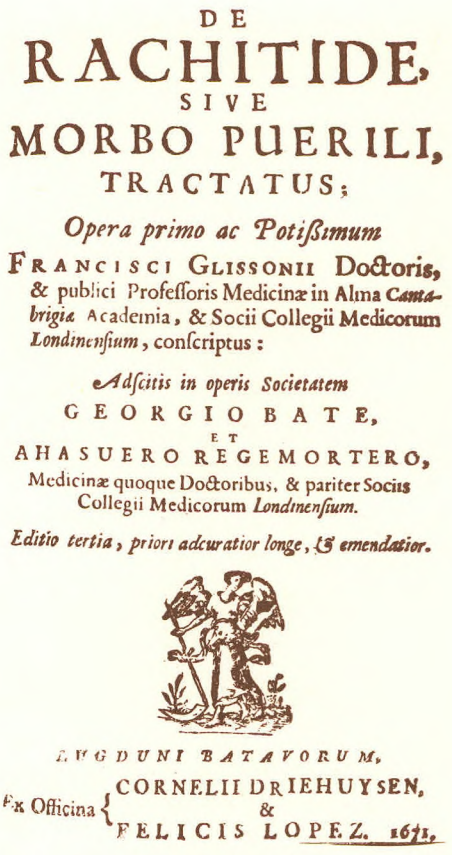
ciently nourished, it is no wonder if it do good, seeing that thereby the aliment is more plentifully allured, and that heat of the part is also excited and augmented; neither on the one side is the Gibbous part of the Bone being hurt by the rubbing, to be wondered at, because by that means the aliment is attached to that part which was before superabundantly nourished: besides the Ointments, which may cherish the inherent heat, and strengthen the nutritive faculties after the rubbing, do most good when they are applyed to the hollow part of the Bone; rising up of the Bones is usually fitted with desired success; chiefly indeed for this reason, because the capillary Arteries which convey the Blood or nutritive juice to that side of the Bone, are bound up by such as a ligature and thereupon the nutriment is lessened. And these things shall suffice concerning the crookedness of the Bone in this affect.

Moreover, to this Article we apportunely add the inflexion of some of the Joints, as of the Knees and Ankles which happen very frequent in this Disease, sometimes being made inwardly, sometimes outwardly. And this bending also seems to be not unfitly referred to the inequality of nutrition. For if it happen by unequal nutrition that one side of the Shank-Bone be so lengthened more than the other; suppose outwardly, that it does somewhat lift up the outward part of the Epiphysis of the Shank-Bone above the inward part, the joint in the Knee must needs stand outwardly bent; and on the contrary, if the inward part be lifted up, and the outward depressed the same joint must needs stand inwardly bent. . . .

The same thing likewise may happen in the Ankle-Bones and the Turning joints of the Back, if the Bones fastened to the Joint be higher on one side than on the other. But in the Ankles, because there bends the Shin-Bone, the lesser Bone of the Leg is also fastened through the joint, it may so fall out, that the lesser Bone below may stand out further than the Shin-Bone, and so bend outwardly the joint of the Ankle: and on the contrary, if it happen that the Shin-Bone be longer than the lesser bone, the joint must needs be inwardly bent. Although we confess that such an inequality of lengths between the Shin-Bone and the lesser bone in the Leg does not so often happen.

Moreover, we suppose that the preternatural bending of the Spine does rarely happen from the unequal altitude of the sides of the turning joints of the Bones, but more often from another cause which we will now prosecute. We have already said, that the Spine is somewhat weak in this affect and that Children afflicted with this

)isease are unapt not only in motion, but lso to stand upon their feet, yes, and to aise their backs by reason of the weakness)f the Spine. Therefore whensoever their 3odies are raised, they seek somewhat to est upon, and they suffer their Spines to be)owed, sometimes forwards, sometimes to he right hand, and sometimes to the left; vhereby the burden of their Body may be ested upon something that stands near hem. Hereupon it many times happens, that he Ligaments of the turning Joints of the)pine is that part which is most commonly)ending out are loosened and lengthened, nd on the opposite side they are contracted; o that in tract of time the Spine cannot be rected according to the straight and natu- al Figure. And truly in this case we cannot xcuse the Nurses indiligence or negligence,)ecause they do not observe with a sufficient ttentiveness, to which part the Children vhich they suckle are most prone to bend heir Bodies, that by that means they may ndeavor to bend them to the opposite part. n like manner also when Nurses without lue regard and care do too soon commit veak Children to the use of their feet, it nay happen, that when the regular motion)f the Muscles are too weak to bear the 3ody, Children may suffer either their Knee)r Ankles to be bowed to one side; where- upon the Ligaments of the Joints are ex- ended either on the inner or outer side, nd by consequences the Ligaments on the ontrary side are contracted, whereupon the oint must needs be bended either inwardly)r outwardly, therefore; although we have lcnied above, that the crookedness of the)ones depend thereupon, yet we grant, that he bending Joints may happen in weak Children by the negligence of the Nurses. Ve grant moreover, that the bones which vould otherwise have been straight may be rooked by an unskillful swaddling; yet that his cause does happen exceeding rarely in his affect, we are somewhat confident, as we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RACHITIDE,
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& publici Profeſſoris Medicinæ in Alma *Cantabrigiæ* Academia, & Socii Collegii Medicorum *Londinenſium*, conſcriptus:
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GEORGIO BATE,
ET
AHASUERO REGEMORTERO,
Medicinæ quoque Doctoribus, & pariter Socius Collegii Medicorum *Londinenſium*.
Editio tertia, priori accuratior longe, & emendatior.

LUGDUNI BATAVORUM,
Ex Officina { CORNELII DRIEHUYSEN, & FELICIS LOPEZ. 1672.

FIG. 2. Title page of 1672 edition of Glisson's work.

have showed already more at large. Now we proceed to the pointedness and narrowness of the best in this affect.

We observe this pointedness and narrowness of the breast does not appear presently at the beginning of this affect, but that it succeeds upon the confirmation of the Disease and is by degrees intended till by the perseverance of the Disease it becomes evident and conspicuous, when the breast forwards resembles the breast of a Hen or the Keel of a Ship. This vitiated Figure of the Breast which otherwise should be broad according to Nature, and not straightened at the sides and even not pointed forwards, we reduce to four causes. . . . The three former whereof we confess do contribute little efficacy to this matter, but the fourth

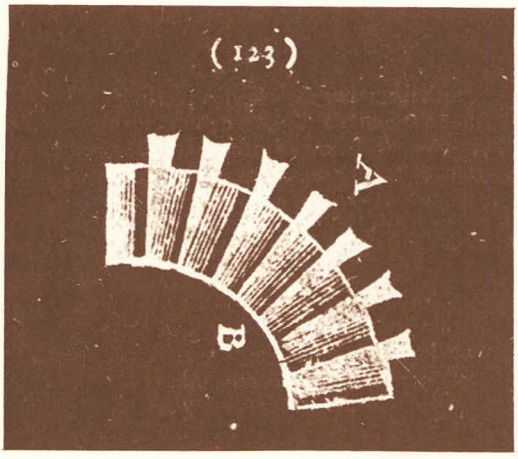


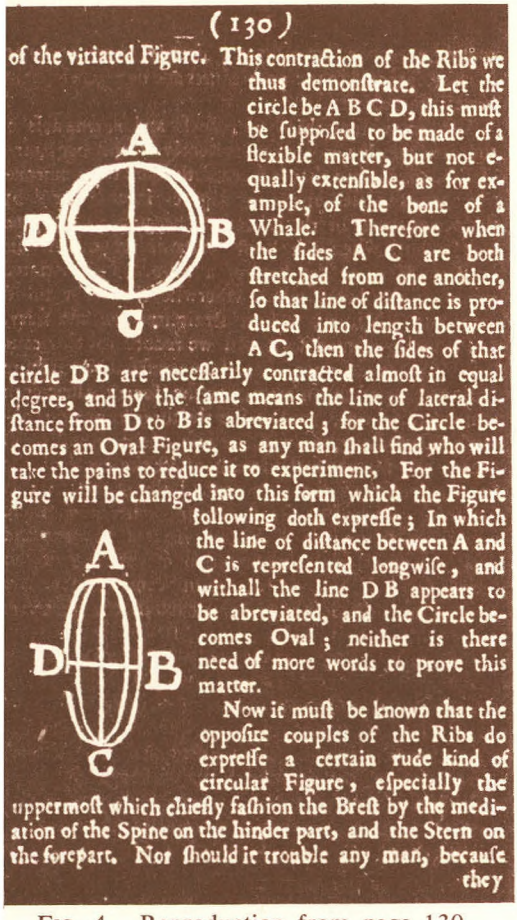
FIG. 3. Reproduction from page 123.

other part of the vitiated Figure. This contraction of the Ribs we thus demonstrate (Fig. 3). Let the circle be A B C D, this must be supposed to be made of a flexible matter, but not equally extensible, as for example, the bone of a Whale. Therefore when the sides of A C are both stretched from one another so that line of distance is produced into length between A C, then the sides of that Circle D B are necessarily contracted almost in equal degree, and by the same means the line of lateral distance from D to B is abbreviated; for the Circle will become an oval Figure, as any man shall find who will take the pains to reduce it to experiment. For the Figure will be changed into this form which the Figure following does express (Fig. 4). In which alone does almost all the work. Yet because the three former do contribute something we will likewise recite them here in order. Be this the first. In this affect the Bone of the Stern by reason of the augmented bulk of the Liver is somewhat elevated or thrust forward, whereupon there happened some part of the said vitiated Figure and moreover from the elevation of the Bone of the Stern there happens a certain contraction of the Ribs towards the Spine, and this causes the the line of distance between A and C is represented longwise, and withall the D B appears to be abbreviated, and the Circle becomes Oval; neither is there need of more words to prove this matter.

Now it must be known that the opposite couples of the Ribs do express a certain rude kind of circular Figure, especially the uppermost which chiefly fashion the Breast by the mediation of the Spine on the hinder part, and the Stern on the forepart. Nor should it trouble any man, because they will not make an exact perfect Circle, seeing that our demonstration is as effectual in a circular Figure how imperfect soever, as in the most exquisite and perfect; provided that there be a coherence among all the parts, that they are not distorted, that they be flexible, but not easily extensible; which conditions are sufficiently conspicious in the Figure of the Ribs even proposed to view. Therefore if in this affect the bone of the Stern be somewhat elevated forwards, that it may yield room to the augmented bulk of the Liver, the ribs towards the Spine must needs be drawn in nearer to one another, whereupon the breast must unavoidably be laterally straightened, the latitude of it being lessened.

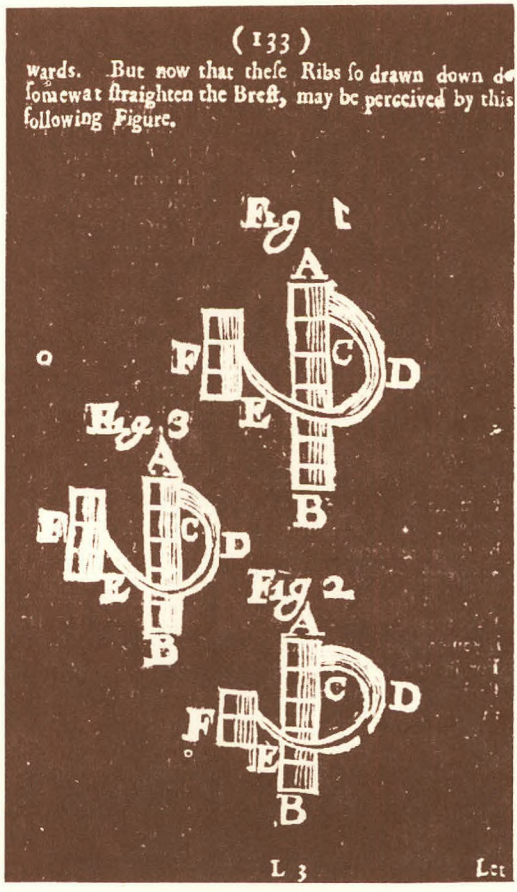
Some may say, If the rising of the Bone of the Stern did conduce anything to the pointed Figure of the Breast, it would chiefly effect that about the inferior Ribs, seeing that this elevation of the Stern does begin at the lower part; but it is manifestly known to fall out otherwise: for the narrowness of the Breast happens chiefly about the armpits, and afterwards beneath the Channel Bones; but the lower Ribs seem to be enlarged about the sides rather than straightened.

We answer, That the five lower ribs are not articulated with the Stern, neither do they make a perfect Circle; and therefore in no wise do they relate to the propounded demonstration; but the stretching of them depends upon another cause, namely the


(130)
of the vitiated Figure. This contraction of the Ribs we thus demonſtrate. Let the circle be A B C D, this muſt be ſuppoſed to be made of a flexible matter, but not equally extenſible, as for example, of the bone of a Whale. Therefore when the ſides A C are both ſtretched from one another, ſo that line of diſtance is produced into length between A C, then the ſides of that circle D B are neceſſarily contracted almoſt in equal degree, and by the ſame means the line of lateral diſtance from D to B is abreviated; for the Circle becomes an Oval Figure, as any man ſhall find who will take the pains to reduce it to experiment. For the Figure will be changed into this form which the Figure following doth expreſſe; In which the line of diſtance between A and C is repreſented longwiſe, and withall the line D B appears to be abreviated, and the Circle becomes Oval; neither is there need of more words to prove this matter.

Now it muſt be known that the oppoſite couples of the Ribs do expreſſe a certain rude kind of circular Figure, eſpecially the uppermoſt which chiefly faſhion the Breſt by the mediation of the Spine on the hinder part, and the Stern on the forepart. Nor ſhould it trouble any man, becauſe they

FIG. 4. Reproduction from page 130.


(133)
wards. But now that theſe Ribs ſo drawn down do ſomewat ſtraighten the Breſt, may be perceived by this following Figure.

L 3 Let

FIG. 5. Reproduction from page 133.

fullness of the Hypochondriacal parts. Let it likewise be noted, that we assign not this for the chief cause of the vitiated Figure, yes, we suppose that it confers very little towards it. And so we proceed to the second cause of this vitiated Figure, which we also conceive to be a very slight one.

In this affect the Hypochondriacal parts are almost perpetually observed to be full and stretched, namely, both in respect of the greatness of the Liver, and also because all the other bowels almost which are contained in the bottom of the belly are sufficiently large, seeing that as has been said, the first essence of the Disease is not rooted in them. And lastly, because of the Guts and the Ventricle are usually more or less distended with wind. But now from that fullness and extension of the Hypochondriacal parts we may justly collect that in this affect the Ribs are drawn downwards a little more than is expedient. For the greatest extension is here observed in the oblique Muscles but are extended beneath the Hypochondriacal parts. Now the Muscle obliquely descending has toothed heads fastened to the fifth, seventh, eighth and ninth Ribs, and the part of the broad tendon also obliquely ascending is adjoyning to the gristles of the ninth, tenth and eleventh Ribs. Wherefore seeing that the said Muscles are almost perpetually too much extended in this affect, they must needs in some manner draw the said Ribs

downwards, and seeing all the Ribs are firmly fastened together by the intercostal Muscles, it happens that in this affect all the Ribs are somewhat drawn downwards. But now that these Ribs so drawn down do somewhat straighten the Breast, may be perceived by this following Figure (Fig. 5). Let A B be the back-bone, C D E the ribs, F the bones of the Stern. We suppose that every one see here in the Skeleton, that the ribs are not conjoyned with the Spine according to the straight Angle, but that the Angle beneath the rib is somewhat less than the straight Angle: So that the rib be drawn upwards, the Articulation of it approaches nearer to a straight line. We suppose also, that the circulation of the ribs whether with the Spine or with the Stern abideth firm, and does not draw upwards (least any man should err) save only the middle parts of the rib between the said Articulations. We say therefore on the contrary by how much the more downwards the rib is drawn, so much the more acute is the Angle with the Spine, which it then makes: Wherefore that part of the rib furtherest distance from the back-bone A B C; (namely, D in each of the Figures) as being thrown downwards, it contributes a more acute Angle with the Spine, so is it also less distance from the Spine than it was before, and renders the broadness of the breast more narrow. For the sides of the breast were then indeed most broad: when the ribs are more erected upon the Spine, according to a straight line. For that part of the rib D will be then furtherest distance from the back-bone A B, and you may soon perceive if you compare the first and second Figure with the third. For in the third Figure the rib is exprest erect in a straight line with the back-bone, and then that part of the rib D is sensibly further distant from the back-bone A B, than it is in the first or second Figure, as he that will examine them, shall quickly apprehend: but in the second Figure, the rib with the Spine is supposed to make a more acute Angle, and in proportion that part of it D (as you may perceive) is less distant from the Spine than the same part D in the same Figure, whose Angle is supposed to be less acute; and yet that is much less distant from the Spine, than in the third Figure, whose Articulation is erected to a straight Angle. We infer therefore, that the ribs when they are drawn upwards, do amplify the breast sidewise, but when they are drawn downwards, then they straighten the breasts on the side.

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Francis Glisson (1597–1677), Professor of Physics at Cambridge, President of the Royal College of Physicians, was among that outstanding group of scientifically oriented clinicians who by most definitions created modern medicine in the 17th century. His studies in pathologic anatomy are noted by pseudonyms in various systems of the body, but most important was his book on *The Rickets.*[1] This in fact is a monograph on the biomechanics of its deformities, the most complete study of the pathologic anatomy of scoliosis yet written. It also included a warning not to confuse it with scurvy, (forgotten until the 19th century), chapters on methods of correction, including Glisson's cervical halter and preventative postural control. The disease, of course, had been known since the first century, but not until Glisson and his co-authors put together this classic was any serious study available. This extract is from the 13th chapter of the 3rd edition (Rare Book Room, New York Academy Medical Library).

CLASSIC 64

Des moyens prosthetiques destinés a obtenir la reparation de parties osseuses

(On Prosthetic Methods Intended to Repair Bone Fragments)

JULES EMILE PEAN, M.D. (1830–1898)

In recent years, surgeons have endeavored to find prosthetic methods for inducing repair and cicatrization of rigid parts of the organism by unquestionably ingenious methods. It is sufficient to observe with what facility one can maintain resected bones of the extremities or those fractured by accident or surgical intervention, to see all the advantages which one can derive by external means such as aluminum plates and screws applied to each side of the bone, by twisted silver wires passed across their lamina comparta or the diploe. One will find similar examples in our practice reading clinical volumes in which are published the observations of patients which we have treated at the hospital of St. Louis. Like Ollier and several of his colleagues at Lyon, we have succeeded in replacing the bone structure of the nose by thin and fenestrated plates of platinum, and the results have been satisfactory in several patients in whom the bridge of the nose could not have been otherwise supported, as indicated by the following observation.

(Case report of a 36-year-old mechanic operated on in 1892 replacing the necrotic syphilitic bridge of the nose with platinum plate, Figure 2.)

Formerly, following the loss of bone substance we could, by means of similar metal plates, prevent the skin attaching itself to the underlying organs, irremediably depressed; the effect is important in visible areas like the face, especially in children and young ladies. In such a case, the small artificial frame could be removed after a certain time if it were not tolerated, when the loss of substance has been replaced by the regrowth of adjacent tissues as one can see in the following example:

(Case report of a 4-year-old girl with tuberculosis caries of the malar bone and the lower half of the orbit. A fenestrated aluminum plate was inserted [Fig. 3] after proper debridement, and the skin sutured over it. As tissue developed in the area the plate was removed.)

We will not discuss it further except to note the prosthesis used in maxillary bone and chiefly the lower maxillary which gave such good results in fractures and loss of substance of that bone. We wish particularly to stress today the value of prosthetic apparatus more complicated, extolled by Glück for the past few years, its worth wrongly or rightly denied by most surgeons, who have stated that it would be hardly possible to utilize these mechanisms in the course of extensive resections of the skeletal structures of the limbs.

A year ago in the case of a patient brought to the International Hospital almost dying with tuberculosis of the humerus including the

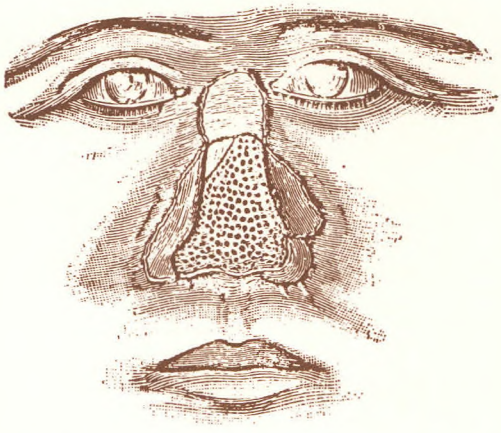


FIG. 2. Replacement of necrotic syphilitic bridge of the nose with a platinum plate.

shoulder joint, complicated by a vast abscess under the muscles and of difficulties so severe that we bluntly thought there was nothing else to do but a disarticulation; we found ourselves embarrassed by his firm refusal. The extent of the disease was such that the joint and the humerus seemed as one; a resection extensive enough did not seem possible to effect a satisfactory functional result. At that point we thought of a prosthesis to measure the extent of the damage and to be able to remove all the diseased parts, to manage all the sound parts, we made a vertical incision through the anterior aspect of the arm crossing the acromion and descending vertically to the junction of middle and lower third of the arm, passing the sinus of a previous incision to incise an abscess. This incision involved the skin, the subcutaneous tissue, and penetrating the intermuscular space which separates the deltoid from the biceps and exposed the anterior face of the bone and the scapulo-humeral joint, released considerable fetid pus and detritus.



FIG. 3. Four-year-old girl with tuberculous caries of the malar bone and the lower half of the orbit.

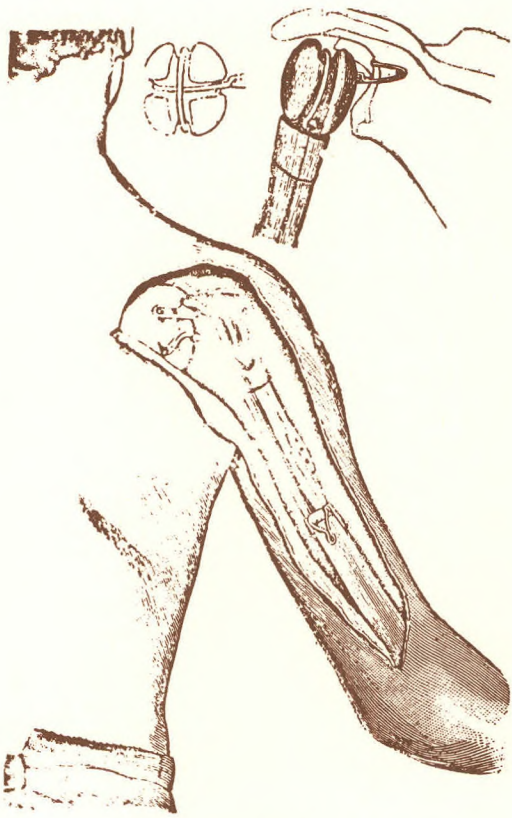
The vessels being clamped and the edges of the wound was retracted the periosteum was opened with the raspitory, the entire length of the diseased bone from the joint to the mid portion of the bone. Opening the capsule shows the joint filled with pus, the head of the humerus hypertrophied, destroyed in part, and the synovium lined by thick fungiform tissue which extends to the glenoid cavity. The glenoid cavity was altered but slightly except in a few areas where the cartilage is lightly rarified. Around the joint and the periosteum of the upper end of the humerus, the many centers of submuscular supperation are lined similarly by luxuriant fungiform tissue. All of this is removed by scraping with a curette then we removed the superior extremity of the humerus with the aid of our forceps and gouges, and seeing that the osseous tissue is infiltrated with yellowish and softened tubercles, we continue to remove the bone from top to where we meet healthy bone. The superior part of the humerus is thereby removed. The synovium is dissected and removed, nothing remains of the joint structure but the glenoid cavity, the fibrous capsule and the periosteum in the form of a sleeve in all the places where it had not been destroyed.

Fortunately the loss of substance was great enough so that one could widely explore a large part of the infected area, an incision could be made through the posterior aspect of the joint to excavate the pus and scrape the lining of an abscess which extended under the deep surface of the deltoid and dorsal musculature toward the spine of the scapula.

Resection of bone was very important because scars of the wound and the movement of the limb were not compromised. We therefore decided to use a device constructed according to the designs of Glück: we first consulted M. Mathieu, our skillful mechanic, to make an interarticular artificial joint at the

end of a stem long enough to fill the loss of substance of the humerus, with the joint part able to reach the glenoid cavity with a surface permitting full movement. He was able to give us one of Glück's pieces. This device was too weak, made of ivory, a substance too easily resorbable, with an articulation too little movable. We then asked Dr. Michaels, who had been clever enough to construct an ingenious apparatus intended to replace the 3 maxillary bones in a patient we presented to the Academy January 14, 1890, whether he would work with us to design a prosthetic device made of an unalterable material and capable of lending itself to an artificial joint with all its motions (Figs. 4 and 5). This mechanism, a model of which we are presenting today to the Academy, was constructed by him with a speed and facility worthy of commendation. In the construction of this piece, of which the illustration is attached, the hardened rubber and irridescent platinum are the sole materials incorporated. To render the rubber stable in contact with tissue fluids, the pieces of which it was formed were boiled for 24 hours in paraffin. When the prosthesis had been solidly fixed to ensure its stability, the periosteum and articular capsule were attached around it. Catgut sutures closed the shaft within a sort of periosteal case. The wound was then closed with interrupted horsehair sutures. A rubber tube was sutured in place posteriorly to assure drainage of fluids by gravity. A soft iodoform dressing, lightly compressive, kept the arm and shoulder immobilized.

It was feared that a mechanism so complex would not be tolerated by tissues which had already been the seat of serious disorders, and had not yet recovered from an acute inflammation, aggravating the chronic inflammation which put the days of our patient in danger. Nothing happened. At the end of a few days not only was he relieved, but his fever subsided, his appetite increased with his physical strength, he raised himself and could walk about the ward 12 days after operation, and on the twentieth day, he visited his family for a day on the outskirts of Paris. Finally, since the operation he had gained 35 pounds, and his health would have been excellent had he not been troubled by several recurrences of a small localized abscess which reformed above the epicondyle. We had to open this small abscess on 4 different occasions. It had attacked the lining in several days but in spite of all the care which we gave, and



FIGS. 4 and 5. Artificial joint made of hardened rubber and platinum.

the repeated injections attempted: phenol, chloral, oxygenated water, potassium permanganate, camphorated naphthol, etc., we could not dry the fistula completely. Such is the case history which we submit.

Is it of a nature to make one believe, as Glück has said, that foreign bodies as large as those which we have used can definitively replace so considerable loss of skeletal substance? We may respond in the affirmative after seeing the actually surprising result obtained in this patient, if it were not for the occasional recurrence of a small abscess 12 months after the operation. It is true that from this point of view one cannot accuse the prosthesis exclusively, since we daily see small abscesses following simple excision of bone in tuberculosis that fistulae are produced attesting to the fact that the local

involvement of the diaphysis was not completely removed. At the least it is remarkable to see that, several weeks after the operation, the patient had regained his health, that the old foci had disappeared, that he had recovered movement in the joint, that he could use the extremity for most of the usual needs of his life. To those who consider that in a similar case, it would have been preferable to immediately disarticulate at the shoulder at the moment the patient presented himself to us, we reply first that it is entirely the opposite; that his state of weakness at that time was such that he would have probably succumbed to so serious an operation as the complete amputation of a limb. Secondly, if the resection as extensive as that which we performed would not have been followed by recovery and would not have allowed the patient to use the extremity, the disarticulation would have become practical and with less danger today.

Concluding the preceding observations:

1. It is possible to replace an important part of the skeleton and even an enarthrodial joint;

2. That this device to be well tolerated, should be not only aseptic, but made of nonresorbable material;

3. That it is tolerated by the organism when one takes the required precautions;

4. It permits one to substitute for an immediate disarticulation when the patient refuses such intervention;

5. Large resections have the advantage of preventing the destruction of the soft parts;

6. Finally that they can be provided with a mechanism permitting the joints to preserve their movement.

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JULES EMILE PEAN

Jules Emile Pean (1830–1898) was one of the leading surgeons of Paris during the latter half of the 19th century. Among his credits was the invention of the haemostat, the first gastrectomy for carcinoma and the introduction of the American ovariectomy into continental Europe. The present paper describes the first attempt at articular prosthesis with metal. Before this, as he notes, Glück and others had tried ivory and animal bone, all of which were quickly absorbed. Pean not only used metal but recognizing the corrosive qualities of steel, iron and other metals, used platinum as least affected by tissue fluids. The concept was good, but of course, not until the classic work of Venable and Struck in 1938 did the non-electrolitic quality of vitallium and certain steel alloys raise the standard of success for all metal implantations.

Pean was associated with the Hospital St. Louis for most of his career. Later in life he founded his own hospital, the International. After his death it was renamed the Hospital Péan.

CLASSIC 65 Arthroplasty of the Hip: A New Operation

JOHN CHARNLEY, M.B., B.Sc. MANC., F.R.C.S. (1911–)

In considering how arthroplasty of the hip can be improved, two facts stand out: 1. After replacement of the head of the femur by a spherical surface of inert material, the failures are essentially *long-term*. At first the patient may notice no difference between the artificial head and the living one which preceded it. Our problem is to make this temporary success permanent. 2. Objectives must be reasonable. Neither surgeons nor engineers will ever make an artificial hip-joint which will last 30 years and at some time in this period enable the patient to play football.

DEDUCTIONS FROM PAST EXPERIENCES

The methods from which we have learned most are those of Smith-Petersen and Judet.

The *Smith-Petersen method*[5] was a refinement of the oldest of all forms of arthroplasty, in which a membrane, or some kind of tissue, is interposed between the head of the femur and its socket. A metal cup, loose-fitting and polished, was placed between the femoral head and the acetabulum, after the femoral head had been reduced in size and the acetabulum had been enlarged by removal of the eburnated lining. The polished hemispherical surfaces of this metal cup induced changes in the fibrous tissue on the exposed surfaces of cancellous bone, which were transformed into a form of articular cartilage.

Smith-Petersen repeatedly emphasized that the moving parts should be made to fit loosely together; in no sense, therefore, could the mechanical arrangement at the finish of this operation be regarded as a mechanically stable ball-and-socket joint. The femoral head inside the cup is capable of slight displacement, and the cup also is capable of displacement inside the socket. In course of time the spaces between the cup and the femoral head and the cup and the acetabulum becomes filled with fibro-cartilaginous material and the hip can thus become stable; but unfortunately the peri-articular soft tissues often become thick and stiff, and mobility is lost.

In the *Judet operation*[4] the head of the femur is replaced by a prosthesis bearing a polished hemispherical surface. In the original Judet operation the prosthesis was like a gigantic tintack with a hemispherical head and it was fixed to the femur by driving the spike down the center of the stump of the femoral neck. The joint formed by this procedure was much more stable than that formed by the Smith-Petersen procedure, because a prosthesis was chosen which was a close fit in the acetabulum. Very soon afterwards many patients could perform circumduction of the hip under full muscle control, against the force of gravity and without pain.

The capacity of the living organism to react favorably to sound mechanical design,

and its capacity to reveal incipient mechanical failure by deterioration of function, even before the appearance of frank pain, is a fundamental guide in developing any arthroplasty.

JOINT LUBRICATION

The starting-point of the present research was the well-known observation that after the Judet operation the hip sometimes squeaks. This does not last more than a few weeks and the final result is neither better nor worse than in cases without a squeak. In our experience the squeaks have occurred in the hips of osteoarthritics, but never when the acetabulum was lined with normal articular cartilage as in the treatment of subcapital fractures of the neck of the femur.

A squeak indicates that frictional resistance to sliding is so high that the surfaces are seizing together. Hence it seemed likely that the plastic of the original Judet prosthesis had adverse frictional properties when sliding against the bare bone encountered in an osteoarthritic acetabulum. It seemed possible, too, that the cessation of squeaking might be a sign not of improved lubrication but of loosening of the attachment of the prosthesis to the neck of the femur. In these circumstances the head of the prosthesis would be stationary in the acetabulum and all movement would be taking place between the femoral neck and the stem or spike by which it was originally attached to the bone. Clearly, the mechanical bond between the prosthesis and the neck of the femur could be broken by a twisting strain, or torque, resulting from high frictional resistance to the turning of the prosthesis in the acetabulum. If there were no such frictional resistance, the mechanical attachment to the femoral neck would be spared any such strains.

Laboratory Experiments

I could find only two references to measurements of the coefficient of friction of normal animal joints,[2, 3] and my own experiments closely confirmed the figure of $\mu = 0{\cdot}02$ reported by Jones, with the possibility that in certain conditions μ might be much less than this. For a skate sliding on ice, μ has been estimated at 0·03, which indicates that an animal joint is rather more slippery than ice. Engineering science knows no way of approaching such low figures for μ in a "plain" bearing when the application concerns reciprocating motion, at slow speeds, and under heavy loads. Nature has solved completely the most difficult set of lubricating conditions which ever face the engineer.

These investigations on lubrication[1] suggested that synovial fluid is not an essential lubricant but rather a product of the activity of joints—a view taken for granted by Sir Arthur Keith in 1919. Emphasis was transferred from the synovial fluid to the properties of articular cartilage, and attention was drawn to the engineering concept of "boundary lubrication" between dry solid surfaces, or between solid surfaces separated by a film of fluid too thin to behave as a fluid. A boundary lubricant reduces friction by entering into physicochemical combination with the surfaces, and diminishes the free molecular attraction which may seize the surfaces together. Hence there must be a physicochemical affinity between the lubricant and the solid material of the rubbing surfaces; the lubricant is effective only with certain combinations of solids. Even if synovial fluid is a lubricant in an animal joint, it will not necessarily lubricate a prosthesis.

This was confirmed by experiment on the effect of ox synovial fluid on the frictional resistance between steel and bone and between 'Perspex' and bone. The coefficient of friction for plastic and steel against bone, moistened with ox synovial fluid, was high ($\mu = 0{\cdot}4$). On the other hand, when the plastic or steel was tested against normal articular cartilage, the frictional resistance

was almost as low as in a normal joint (μ = 0·02).

PROSTHESIS AND SOCKET

These investigations indicated that to give an artificial hip-joint the same kind of slipperiness as a natural joint, we should need a substance with a low coefficient of friction which at the same time could be tolerated in body tissues. For this purpose I chose polytetrafluorethylene–a plastic which looks not unlike articular cartilage (being white and semitranslucent, and capable of being cut with a knife) and is chemically the most inert plastic so far discovered.

The first idea was to use this low-friction material as "synthetic articular cartilage". I lined the eburnated acetabulum of the arthritic hip-joint with a thin shell of polytetrafluorethylene and covered the reshaped head of the femur with a hollow cup of the same material firmly pressed into position. The absolute relief of pain, and the range of active movement under muscular control, were impressive in the first 3 months; but the most conservative feature of this design was its undoing. Adhering to the conservative principle which Smith-Petersen called "conservation of stock" I had retained the femoral head and refashioned it as a spigot on which to press the inner plastic sphere; but this resulted in ischemic necrosis of the bone inside the inner sphere. As soon as the early good function started to fail, radiological examination always indicated that the head of the femur was necrotic and was becoming loose inside the inner sphere. The poor results of this kind of prosthesis thus resembled the poor results of the Smith-Petersen cup.

Cementing the Prosthesis to the Femur

My next step was to replace the head of the femur with a metallic prosthesis in combination with a low-friction plastic socket. I had for some time been interested in improving the mechanical bond between prosthesis and bone, by using a cement to transfer the weight of the body from the metallic stem of the prosthesis uniformly to the cancellous bone of the interior of the neck and upper end of the femur (Charnley 1960). My object was to get over the defect of the Moore and Thompson types of prosthesis, which is that they have no resistance against stresses tending to twist them in the medullary cavity on its long axis. (Twisting forces of this kind will in particular be experienced when a patient is rising from a sitting position with the femoral shafts horizontal.)

In 3 patients in whom the arthroplasty was reexplored, because of mechanical defects in the socket, I found that the cemented prosthesis had remained absolutely rigid in the femur after taking the full weight of the body during 10 or 11 months. Furthermore, experience of over two years, with more than 100 patients, lead me to believe that, as regards infection, this technic is safer than the original one. Infection of an arthroplasty will probably start with multiplication of bacteria in blood-clot within the cavity of the joint. If the prosthesis is loose in the medulla, the infection will be pumped into the medullary canal at every muscular movement. But where the prosthesis is cemented in position I imagine that the joint might contain pus, and the stump of the femoral neck might be bathed in pus, without any spread of infection to the medullary canal.

Design of the Socket

Though the results of using the arrangement previously mentioned were gratifying, it was pointed out to me that the best engineering practice would be to use the smallest diameter of ball which would cope with the expected load. Up to then I had used a standard Moore prosthesis with a ball 1⅝ inches in diameter, believing that polytetrafluorethylene, being a relatively soft material, would wear longer if the load per unit area of bearing surface were the smallest possible. The recommendation of my en-

gineering colleagues enabled me to make a big improvement in the anchorage of the plastic socket in the bony acetabulum. Resistance to movement of the head in the socket is greatly reduced by reducing the radius of the ball and therefore reducing the "moment" of the frictional force. If at the same time the radius of the exterior of the polytetrafluorethylene socket is made as large as possible, the "moment" of the frictional force between socket and bone will be increased, and this will lessen any tendency for the socket to rotate against the bone. The small remaining shearing force can be resisted easily by the fibrous tissue occupying the deep irregularities on the outer surface of the socket.

PRESENT OPERATION

The operation is performed through a lateral exposure by elevating the great trochanter. At the end of the operation the trochanter is reattached to the outer surface of the femur in order to enhance the leverage of the abductor muscles. Though this delays rehabilitation, it is of paramount importance in preventing adduction, external rotation, and dislocation.

When the head of the femur has been resected, the acetabulum is deepened and then reamed with special tools to an exact diameter for receiving the polytetrafluorethylene socket. To enhance the precision of the reaming, the sequence of tools all operate on a ½ inch pilot hole which is made in the center of the floor of the acetabulum, the exact center being found by a self-centering device. The polytetrafluorethylene socket carries a spigot ½ inches in diameter which engages with the pilot hole and ensures correct orientation. The socket is hammered into the acetabulum with a punch, its external surface being deeply serrated to receive the ingrowth of fibrous tissue or bone.

The prosthesis carries a head which at present is no more than ⅞ inch in diameter. Several lengths of neck are available, so that during the operation the one which best suits the depth of the socket can be chosen.

After a trial reduction has shown that everything is satisfactory, the prosthesis is cemented in position and the great trochanter is reattached with wire. The patient is splinted with the leg in abduction for 3 weeks, and is allowed to take full weight on the hip 5 weeks after the operation. Recent experiences suggest that plaster is not essential.

RESULTS SO FAR

Though my experience of using polytetrafluorethylene for arthroplasty of the hip extends over 3 years, the technic in its present form has been in use only since January, 1960. Since then 97 hips have been operated on. There have been no deaths, except a coronary occlusion 6 weeks after operation, and the only serious complication encountered has been deep venous thrombosis.

While the long-term results are still awaited, the method has been restricted to cases of gross disablement by (1) rheumatoid arthritis, (2) severe osteoarthritis in patients over 65, and occasionally (3) bilateral arthritis in middle age. The only disappointing results have been in very difficult "salvage" cases where the absence of normal structures made it impossible to carry out a technically sound procedure. With 1 exception, the only cases of infection have been those in which there have been previous attempts at arthroplasty by other methods.

On removal of the splints, after 3 weeks, most patients can execute a "straight-leg raise" and have no pain or spasm on passive movement. After a week out of plaster, they have recovered the pre-operative range of movement. If the hip has previously been very stiff the final range may be no greater than 30°, but it will be painless and under muscular control. The average stay in hospital is 8 weeks, and before they go home most patients can walk the length of the ward without sticks and with only a slight limp.

As regards wear and tear of the socket, working against the metal head of the prosthesis, close scrutiny of the radiographs of patients who have been transmitting the full weight of the body through this implant for

10 months has shown negligible wear. The stresses imposed on the hip-joints of patients disabled by arthritis are only a fraction of those borne by the hip-joints of normal subjects or athletes; but even if the method should prove unsuitable for robust patients in middle life, it may have a permanent place in the treatment of the rheumatoid and the elderly, for whom it is particularly suitable, because it requires almost no rehabilitation. Even in the early stages there is no pain on movement, and the procedure is therefore appropriate for subjects with the poor muscles and relatively feeble morale which so often accompany long-continued ill-health or old age.

ACKNOWLEDGMENT

I am indebted to the Manchester Regional Hospital Board, which has established at Wrightington the center for the surgery of the hip-joint at which the clinical work described in this paper has been done. In the general ideas behind this project I have been supported by interest shown by Sir Harry Platt, Prof. J. H. Kellgren, and Prof. J. Diamond. The research committee of the Manchester Regional Hospital Board has built and equipped a research workshop in the hospital and has provided the salary for a fitter and turner who will make the surgical implants. With advice from the university department of engineering, we hope to build test "rigs" and other devices for submitting different types of implant to trials of wear.

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JOHN CHARNLEY

John Charnley (1911–) C.B.E., F.R.C.S., Professor of Orthopedic Surgery, University of Manchester, Director, Center for Hip Surgery, Wrightington Hospital, was the effective innovator of the arthroplastic procedure known in English medical writings as total hip replacement. There is of course a century and a half of joint reconstructive surgery behind this. Charnley's principal contributions must be considered the efficient development of a self-curing acrylic cement to anchor both the femoral replacement and the acetabular acrylic or metal socket. This 1961 report in the *Lancet* was suggested by John Charnley in a personal communication to me as among his most important early contributions to total hip replacement.

CLASSIC 66 Joint Debridement: Surgical Treatment of Degenerative Arthritis

PAUL B. MAGNUSON, M.D., F.A.C.S. (1884–1968)

It has been assumed in general by the medical profession that a joint damaged as a result of any form of arthritis is beyond help, except by the eradication of any possible foci of infection which might be found or the elimination of chemical disturbances of metabolism. Certainly chemical upsets can be a contributing cause to the degenerative forms of arthritits,[1] as can also be foci of infection. There can be no doubt, however, that it occurs most frequently in joints which are subject to often-repeated small trauma. Bauer and Bennett[2] believe that "degenerative arthritis is the result of the wear and tear of increasing age and repeated trauma which may be caused in a variety of ways and that it is not the result of an inflammatory process, metabolic disturbance, or endocrine dysfunction." Their studies tend to prove that trauma certainly has a definite effect on the production and continuance of cartilage degeneration. Key[3] notes that several types of reaction in cartilage may result from the same type of injury, and calls attention to the fact that, in his experimental work, "if two joints be subjected to practically identical operative procedures, one may return to a practically normal condition and the defect may be healed by a cartilage which approaches the normal articular cartilage, and there may be no reaction in the bone or joint except the deposition of a very small amount of subperiosteal bone on the sides of the joint; while in the other joint a condition resembling severe hypertrophic arthritis may develop. In some cases animals developed a rather marked degree of arthritis in one knee, while the other knee which had been subjected to a practically identical operative procedure developed almost no arthritis at all."

Our own experimental work, performed by Dr. O. H. Horrall and myself, to be reported at a later date, did show, however, a few constant characteristics of cartilage injury and healing. These are mentioned briefly here because the reactions correspond very closely to the pathological conditions found in various joints at the operating table in certain types of arthritis, which we considered due primarily to trauma, or trauma plus infection or toxemia which, added into a total, means the wear and tear of life. The trauma is often found in disalinement, overweight, or primary injury, and these in some cases may be the sole cause.

We have opened and inspected a total of 83 joints in 72 patients suffering from various forms of arthritis, and it is from the experience gained in this series that this report is made. We consider in this paper, however, only one phase of the surgery of arthritis, and that is the reaction of cartilage in so called degenerative arthritis, and what may be accomplished by the removal of what,

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in our opinion, is one of the major causes of prolongation of symptoms and disability in these patients. In my opinion, often-repeated small trauma is the major cause in this form of arthritis, and this is based on our experimental work and the observation of joints at the operating table.

The spectacular results that have been obtained by removal of rough and irritating material indicates that after the roughness has started it automatically continues and becomes progressively worse as a result of this constantly increasing trauma caused by motion and weight-bearing.

In our experiments performed on dogs there were certain consistent reactions to trauma of cartilage which were very definite. First, cartilage which has been cut or broken away from its surroundings has no tendency to heal in from the sides as do epithelial surfaces. Therefore it would seem that cartilage once fractured would leave a permanent defect and rough spot. A cork-borer driven through the cartilage and underlying bone and a plug of bone and cartilage being removed, the underlying bone curetted out, and the plug countersunk below the level of the surrounding normal cartilage, the bone will heal entirely and be revascularized, while the defect will be obliterated completely in the course of 90 to 120 days. However, the outline of the cartilage defect will remain. Although the cartilage which is countersunk below the level of the surrounding areas may build up to the level of the surrounding surface and be thicker from matrix to surface than the surrounding cartilage, the defect made by the cut through the cartilage cells will not heal laterally, and remains indefinitely as a cut or fissure.

The growth of cartilage takes place in straight columns from the matrix toward the surface, not laterally as does epithelium. If hyaline cartilage be stripped up from the surface parallel with the matrix, within a few weeks its character has changed from hyaline cartilage to fibrocartilage, which acts as stringy bands between the joint surfaces and consequently it becomes a mechanical irritant. If the cartilage has been traumatized beneath this area there is condensation of cartilage cells and nuclei which stain poorly. The columnar appearance of the cartilage cells disappears and eventually this surface becomes rough and granular and continues the irritation of the joint on motion because of the degenerated rough substance within the joint.

If an incision is made perpendicularly through the cartilage into the bone and then beneath the surface of the cartilage a Y-cut is brought out practically parallel to the matrix, so that the outer surface of the cartilage is cut off from the matrix lying beneath, the cartilage cells distal to this horizontal incision show condensation of nuclei, with poor staining as far back as the cut extends, and this area ultimately degenerates into fibrocartilage and everts into the joint, forming a rough area. This same degeneration is seen whenever there is interference with the nourishment of cartilage cells, and occurs regularly and consistently if the matrix is damaged or its source of supply is cut off. However, if the cartilage is completely gouged out, including the matrix and into the underlying bone, leaving a cup-shaped area, there is no tendency toward regeneration. The defect is filled in somewhat by fibrous tissue; the margins of cartilage on each side of the defect, if not injured, will retain their normal hyaline character, but if injured will degenerate into fibrocartilage or fibrous tissue and form rough areas around the margin of the defect. The gouged out area does not act as an irritant, apparently, because the cartilage on the opposing surface of the joint seems to give no evidence of irritation, but where the opposing surface comes in contact with the rough areas along the edge of the defect there is roughening of the cartilage and gradual degeneration.

The production of these injuries to cartilage, however, did not result in the occurrence of typical findings of degenerative arthritis. There was no building up of periosteal bone around the edges of the joints. The reaction was confined entirely to the cartilage and was apparently local.

Many other experiments were tried to produce the joint pathology so often seen in the human. These included the injection of irritating chemicals, injection of bacterial toxins, severe trauma to cartilage over a wide surface of the joint, and the introduction of foreign bodies. So far as we were able to determine all these things were irritating factors and produced in some cases pain or joint irritation, but did not produce proliferation of bone and broader degeneration of cartilage in areas other than those immediately involved. We were able to produce the typical picture of degenerative arthritis in only one way, and that was by allowing the animal to subject the joint to often-repeated slight trauma. This was done by cutting away the medial and crucial ligaments of the knee and allowing the animal free range of exercise. Those dogs, which were kept in the confinement of the ordinary cage, did not show proliferation of bone or degeneration of cartilage in the experimental joint. It was only by permitting free exercise in ample space which allowed the unstable joint to sustain cross strain constantly, that the exostoses around the edge of the joint appeared. In animals so treated there was deposition of subperiosteal bone around the edge of the joint, which began to appear in about 3 months and in from 6 to 9 months produced typical exostoses such as are seen in hypertrophic or degenerative types of arthritis. These exostoses appeared before any considerable amount of degeneration of cartilage was observed on the surface of the joint, even on the weight-bearing surfaces where one would naturally assume that most of the trauma occurred in walking and running.

The cause of the proliferation of bone around the edges of these joints which are constantly traumatized is unknown, and has remained unexplained by all the authors on this subject, and is still unexplained as far as I am concerned. It would seem to be an effort to throw up an abutment and limit the motion of the joint, because it occurs most frequently on the lateral margin, which would have a tendency to widen and flatten the joint in order to produce more stability. It is the blocking and irritation of the joint caused by these exostoses that, in the human, not infrequently makes it impossible to extend the joint fully, and in my opinion this is one of the causes of prolonging and aggravating the already existing symptoms. When motion of the joint is limited, the patient continues to make it function as much as possible, in an abnormal position which throws further cross strain on the joint and continues the pain and aggravates the disability purely by mechanical irritation.

It was on this theory that the procedure to be described was developed. There have been 83 patients operated on for various types of arthritis, 62 of whom have had the degenerative or hypertrophic form of arthritis. Sixty of the 62 have made a complete recovery from their symptoms.* In this report there are considered only cases of the degenerative form which has been commonly called hypertrophic arthritis. It is difficult to say which of them had contributing causes. In 7 cases infections were found and eliminated prior to operation. In 4 there was evidence of chemical or metabolic disturbance, and in 51 there were no findings except those locally in the joint. In all cases operation was performed because other forms of treatment did not give relief — heat, counterirritation, rest with

* In the 2 cases which are classed as unsuccessful the patients were not cooperative in straightening the joint or taking their exercises. Neither case remained in the hospital nor under my immediate control, and the flexion deformity occurred because of incomplete after-treatment.

traction, stimulation of metabolism, change in diet, and the like, had all been tried. Therefore, with the idea that the mechanical roughness of the joint was the primary factor in continuance of the symptoms and disability, operation was performed. We believed that the roughness within the joint was responsible for the gradual building up of joint obstruction in the form of rough surfaces and exostoses around the margin and that the synovial membrane was not in any way responsible for the symptoms or the continuance of the symptoms.

The pathological process found in the cases which were proved to have possible infectious or toxic conditions did not differ from that found in those which were believed to be purely traumatic in origin. In 12 cases the procedure to be described has been done on two corresponding joints in the same patient, and in this group the joints have remained free from symptoms to this date. At this date the time since operation varies from 16 years to 6 months, which would indicate that the symptoms do not return after the removal of what is believed to be the aggravating cause, namely, roughness within the joint.

There are two forms of degenerative change encountered. One is a surface roughening of hyaline cartilage beneath which, in the earlier stages, is found normal hyaline cartilage. This degeneration starts apparently from the surface and progresses toward the matrix. In the earlier stages this rough surface can be removed, leaving a layer of normal hyaline cartilage covering the ends of the bone. The defect will be filled by growth of the cartilage cells and a smooth normal joint will remain. The regeneration of normal cartilage depends upon the integrity of the matrix and the viability of the cells underlying the degenerated area. If the whole thickness of cartilage has not been involved one may expect to restore practically a normal joint. If the degeneration has progressed down to the matrix, the surface of the joint will be covered by fibrocartilage after the degenerated hyaline cartilage has been removed, but this seems to serve as quite a useful friction-preventing covering for the underlying bone, much as does the fibrous tissue which forms around the ends of old ununited fragments in a fracture.

Another type of degeneration apparently starts at the matrix and works in the opposite direction. On the surface of an apparently normal area there will be seen a little blister, sometimes so insignificant that unless the light falls obliquely, the eye will not catch it, although the moist gloved finger may feel a slight elevation of the surface. If a horizontal slice is removed from the surface, including this blister at about the center, there will be found beneath the surface a degenerated area with normal hyaline cartilage surrounding it. Usually there is a little discoloration at one side with indication of a fissure or breakdown of cartilage like the handle of a dipper extending from the end. This area, when sectioned for microscopic examination, shows small, poorly-staining, irregular layers of hyaline cartilage with condensation of nuclei, fibrous tissue irregularly interspaced, and a mucoid material filling some of the spaces. In the same joint other areas are found which are apparently a continuation and advancement of the same process. Fissures are seen in the surface of the joint surrounded by irregular, roughened, mottled and loose cartilage. Stringy fibrous degeneration with yellowish discoloration is noted in some areas, with tendrils of fibrous tissue attached at their base to the degenerated cartilage, and these areas are surrounded by perfectly normal hyaline cartilage, the degeneration near the rough area gradually fading into normal hyaline cells. The handle of a scalpel may be dropped into a fissure in the center of this degenerated area, and it will be noted that the edges overhang and the degeneration widens as it approaches the matrix, being somewhat pyramidal in shape. Underlying the fissure no normal cartilage cells are found.

The fissure extends completely through to the bone.

The cause or causes of these two types of degeneration are unknown. Further experimental work is in progress in an effort to determine the causative factors. Apparently when either type progresses to a sufficient degree the entire joint becomes eroded, and the finale is the same in both types, although progress is most rapid on the weight-bearing surfaces. At least in the earlier stages, it is practically always confined to weight-bearing or most frequently traumatized surfaces: in the elbow, the upper end of the ulna, the olecranon; in the hip, the upper end of the femur, the head; in the knee, the lower end of the femur; and in the ankle, the lower end of the tibia. The greatest degeneration is noted over the areas which receive the greatest trauma in performing the function of the joint. If there is disalinement of the joint as a result of fracture or faulty growth, the degenerated areas are most frequently found on the side of the joint where the greatest pressure occurs. In this series of cases there are 11 hips, 8 elbows, 41 knees and 2 ankles.

The hip. I am at a loss to explain why the greatest degeneration occurs at the head of the femur on the weight-bearing surface instead of within the acetabulum, but uniformly we have found the cartilage much more roughened and degenerated on the head of the femur than in the acetabulum. The exostoses appear around the head and extend down into the neck. Exostoses develop also around the acetabulum as the condition progresses, and the acetabular lip in some cases becomes calcified, deepening the socket and taking a firm grip of the usually broadened head, which limits abduction, rotation, and extension. In these cases will be found an adduction-flexion deformity which is more or less fixed. The exostoses around the head usually extend down onto the neck and thicken it, and in the X-ray film it gives the appearance of a shortened neck. This type is found frequently in Perthes' disease which has been arrested in youth, or in slipped epiphysis which has healed and borne weight for a number of years. The thorough removal of the overhanging acetabular lip and the removal of the edges of the broadened head and the exostoses extending down onto the neck will allow the leg to be brought into abduction. At the time of operation the head can be rotated out of the acetabulum sufficiently by adduction and internal and external rotation to remove the roughened cartilage of the weight-bearing surface. Occasionally small foreign bodies will be found, either free or attached to a pedicle lying along the edge of the joint, which are sucked into the joint on certain movements and give acute pain and locking, as they do in any other joint. Although we have found these bodies in three hips, there was no evidence of them in the X-ray films, which were of good diagnostic quality. The X-ray films were examined subsequent to operation when it was known where the foreign bodies were located, and even then they could not be seen.

The elbow. In the elbow the mechanics of weight-bearing are reversed and, except in pugilists who traumatize their elbows severely in their occupation, we have found most of the degeneration on the articular surface of the ulna, particularly around the proximal two-thirds of the joint surface of the olecranon, with exostoses around the posterior edges of the lower end of the humerus where it comes in contact with the olecranon.

In the exposure of the elbow it has been found that cutting the olecranon off, well down toward the joint, directing the chisel toward the lower and somewhat anterior surface of the humerus, which removes the upper end of the ulna completely so that it can be reflected backward and upward, gives the best exposure. If the anterior two-thirds or three-fourths of the ulnar articulation is left in contact with the lower end of the humerus, it is difficult to inspect the lower end of this bone far enough anteriorly to be sure the exostoses and joint surfaces are properly cleared off. The olecranon, therefore,

has attached to it about 50 per cent of the articulating surface of the upper end of the ulna, and when it is replaced it fits around anteriorly, serving as a grip on the lower end of the humerus, and this fragment of the upper end of the ulna is not as easily displaced as when the olecranon is taken off as such. In one patient, an enthusiastic bowler, the cartilage had entirely degenerated in a strip completely across the olecranon from side to side, and there was a fine sharp edge along both sides of the olecranon, extending down to the ulna, which was actually sawing the synovial membrane. The patient had intermittent swelling and locking of the joint, not acutely as in a foreign body, but coming on over a period of an hour or so after the attack occurred. Blood was found in the joint and the synovial membrane was lacerated on both sides. The patient made a complete recovery after the removal of the rough cartilage and the sharp edges along the sides of the olecranon.

The knee. Inasmuch as knees have been the joints most frequently affected, the operative procedure is described in detail. It has been our experience that if this procedure is carried out in other joints the results will be the same, provided the cases are carefully selected.

A medial parapatellar incision is made from the medial edge of the attachment of the patellar tendon at the tibia to about 3 inches above the patella, the medial half of the quadriceps being cut from its patellar attachment and split longitudinally. The patella is retracted laterally as the knee is flexed, thus exposing the entire anterior and inferior surface of the lower end of the femur and part of the upper surface of the tibia. The joint surfaces are well exposed, as is the articular surface of the patella. A sharp, thin bladed chisel is used to remove the exostoses from both condyles with the edge of the synovial membrane attached. In some cases the synovial membrane is slightly overhanging but not adherent to the joint surfaces, as is found in the atrophic form of arthritis. The cartilage on the condyles is then shaved. Care must be taken not to leave any transverse ridges. If ridges are left they should be longitudinal so they will act as tracks on which the opposite side of the joint can glide, and not as obstructions in the plane of motion. All degenerated cartilage is removed down to bare bone. In old cases the patella is found to be widened, the cartilage very thin, yellowish and granular on both the lower end of the femur and the articular surface of the patella. The patella must be narrowed so that it will slide between the condyles without obstruction, and narrowing, sometimes as much as 50 per cent, will make a useful joint. In this illustration the patella is cut off square to emphasize the amount of lateral margin remaining. These sharp corners, of course, are removed before the joint is closed, as are also the sharp edges which in themselves would act as irritants.

The fibrous degeneration is seen most plainly in the earlier stages of the disease. This fibrous degeneration is completely cut away, leaving all the healthy cartilage possible, but allowing no rough surfaces to come in contact. In the earlier stages the joint margins are not found to be inflamed as they may be in the later stages. They are covered with thin fibrocartilage and hyaline cartilage, and have a pinkish blush without the extremely engorged appearance of the later cases.

The upper end of the tibia is explored and if any rough cartilage exists it is removed. The menisci are examined and removed if they are degenerated. This has not been found in most instances, but in three joints rather sharp exostoses were found extending from the upper end of the tibia, which protruded upward and impinged against the condyles of the femur when the knee came into full extension.

When all roughness has been removed from the surface of the condyles, the margins of the condyles and the articular surface of the patella and upper end of the tibia, the operation is complete, and not until that time is it complete. The success of the procedure de-

pends on the complete removal of all mechanical irritants from the joints. No halfway procedure will give a satisfactory result, in my experience.

The synovia is sutured, plain No. 00 catgut interrupted sutures being used. The ligament is sutured in the same manner, and the skin with continuous dermal sutures. Pressure dressings are applied, two laparotomy pads on the flexor surface and two on the extensor surface, with a non-rubber elastic bandage applied snugly over them. This is reinforced by another laparotomy pad over the same area and a firm gauze bandage over all. Buck's extension below the knee, to which 6 to 8 pounds of weight is applied when the patient is returned to bed, sometimes adds to his comfort for the first few days. The first compression is removed in 36 hours, the second in 72 hours, and comparatively little swelling is found within the joint.

In operation on other joints similar compression is used, put on in a way to maintain strong pressure without interfering with circulation.

AFTER-TREATMENT

Motion is started on the fourth day. Muscle exercise is of prime importance. The patient should be required to use the muscles both in flexion and extension and it has been found helpful to synchronize the use of the muscles on both extremities, moving the unaffected limb at the same time that effort is made to move the affected one. This must be done regularly and consistently. Assisted motion is very slow and steady. In the knee it has been our custom to build the flexion up by inserting laparotomy pads one at a time between the mattress and the flexor surface of the joint; up to 45 degrees during the first week after motion is started, gradually increasing each day. Pads are inserted for one hour and removed during the next, always one at a time.

If it is a weight-bearing joint, the patient is put on his feet on the eighth to tenth day following operation. Prior to this it should be possible for the patient to completely straighten the knee or hip. Too much importance cannot be attached to this point. No pain is caused if the weight falls in the right line, but if there is slight flexion of the joint the soft tissues surrounding the joint, which are painful and tender, will be strained, the patient will have acute pain and will not rest weight on the joint because of fear of pain, once it has occurred. It has been my custom to assist the patient out of bed and while he is sitting on the edge of the bed, or leaning against it, get the joints in proper weight-bearing line. I then stand behind the patient, supporting the elbows and forearms on my arms and forearms. The patient is requested to hold his chest up, tail in, knees back and hips straight. It is easier to do this standing behind the patient, supporting him strongly, than to stand in front of him or allow him to use crutches, under which circumstances he always has a tendency to bend forward. If the patient is straight, his joints are in proper weight-bearing line and he will not have pain.

The first day's lesson is in standing only. He is assisted into bed without causing pain. On the second day, in the same position and with the same support, he is encouraged to take two or three steps, the surgeon being sure that the patient does not lean forward as he would were he using crutches or being supported from in front. He walks with the knees stiff and the hips stiff until he finds he can bear weight confidently and then each day with trained assistants or, preferably, the surgeon himself acting as support and instructor, the patient begins to walk. He is never allowed to limp, moves one foot forward evenly with the other. The assistant stands back of him, supporting his weight and insisting that the body move forward smoothly and evenly as in normal walking. These patients are never given crutches, but are allowed to use two canes, with the upper end of the cane and the hand held firmly against the thigh, chest up, hips straight, knees back, tail in. The lessons are given each day until the patient has confidence that he can bear weight, and

he will have no pain when he does bear weight.

It is a good plan before the patient begins the walking exercises to have assisted motion while in bed. In the case of the knee, the patient may sit on the side of the bed with the leg hanging over the side, the heel supported in the palm of the surgeon's hand, and be instructed carefully in muscle contraction and relaxation, so that he may see the knee move under his own power and see the muscles work. In the case of the hip, a sling is put under the knee and a rope attached to this sling is run up over a pulley on a frame and terminates in a handle which the patient can grasp and give himself assisted motion. It is important that the hip and knee come into full extension after each flexion, and they will not do this if they are simply allowed to come in contact with the mattress; the body sinks into the mattress at the hip level, consequently there is slight flexion of the hip and, as a result, slight flexion of the knee. Therefore it is necessary to turn the patient into a prone position several times a day and see that the affected weight-bearing joint comes into full extension.

Gentle rhythmic massage is given daily, as is also muscle training. Heat is helpful in any form chosen, and for a substantial part of every 24 hours. No force is used at any time on these joints. If these procedures are carefully followed, it is perfectly astonishing how soon the patient will have 90 degrees of motion and full power in the joint. Too much emphasis cannot be put on careful supervision of after-treatment.

SUMMARY

Degenerative arthritis is probably the result of often repeated small trauma. It may be aggravated by low-grade infection or chemical and metabolic toxemia. Once roughening in the joints is established, the mechanical irritation of this roughening is sufficient cause for prolongation of symptoms and disability.

Degenerative arthritis is a disease of the latter part of three score years and ten, and has been said to be the result of the wear and tear of life. In my opinion this is true, but we have not given sufficient consideration to the factors which cause the wear and tear, which should be eliminated if possible before surgical treatment is instituted.

Thorough removal of all mechanical irritating products of joint degeneration will, in a large percentage of cases, render the patient symptom free. Even when the degenerative process has progressed to a point at which there is practically no healthy cartilage, the operative procedure described herein will result in remarkably good joint function. The denuded areas are covered with fibrocartilage which serves as a satisfactory substitute for hyaline cartilage in the advanced cases, and in the less advanced cases the progress of the disease is stopped, or at least long delayed, by the removal of the mechanical irritants.

Removal of the synovia has not been found necessary and has been done only in some cases of atrophic arthritis which are not reported in this paper.

The selection of patients and the after-treatment are as important as the operation itself. If the patient is not willing to help, the operation had better be left undone.

The picture of hypertrophic or degenerative arthritis as seen at the operating table in various stages of development is synonymous with the findings produced in animals by often-repeated small trauma of an unstable or constantly traumatized joint.

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PAUL BUDD MAGNUSON

Paul Budd Magnuson (1884–1968) was Professor of Orthopaedic Surgery at Northwestern University Medical School at the time the following paper was published. Although simple synovectomy goes back to Albert of Vienna (1882) it was originally intended for tuberculous synovitis and later used for so-called hypertrophic synovitis. Magnuson's concept of complete debridement of the knee joint for osteoarthrosis, including synovitis and other degenerative lesions was novel and original. Except for crude attempts at correcting the flexion deformities of rheumatoid limbs, Magnuson's procedure was one of the first, if not the first, of the operative approaches to include diseased parts of articular surfaces.

CLASSIC 67

Étude expérimentale sur l'ostéomyelite infectieuse

(An Experimental Study on Infectious Osteomyelitis)

ALEXANDRE RODET, M.D. (1814–1884)

Is infectious osteomyelitis due to a microbe, and is that microbe specific?

The works published in Germany by Rosenbach, Becker, Fedor, and Krause are not convincing on this point. These observers have studied the micrococcus which they encountered in the pus of osteomyelitis, which were characterized by cultures of an orange color which appeared in the area of solid nutrients. They have shown that this microbe, injected into the blood of an animal in which a fracture or a contusion of bone was inflicted, caused suppuration in the traumatized area (Becker, Krause); that without trauma it localizes in the muscles, the joints, and the kidneys (Krause), and causes suppuration in these organs. It is true that Krause has recovered the micrococcus, after an intravenous injection, in the marrow of several bones which were not traumatized; but he did not demonstrate in this work that the microbe would be above all a cause of osteitis; on the contrary, the results showed a great predominance of lesions of muscles, joints and kidneys over those of bone. Since such findings differ enough from those in the human disease to permit doubt of the role of the micrococcus in the pathogeny of infectious osteomyelitis, the experimental production of an identical disease or one analogous to that of man is most necessary to demonstrate the specificity of this agent.

The experiments which I made in the Laboratory of Experimental and Comparative Medicine of the Faculty of Lyon appeared to demonstrative in this sense. By the injection of cultures I produced severe lesions of osteomyelitis. The cultivated microbe was a micrococcus; its color was a yellow orange, which showed up particularly in solid cultures. It grew very well in bouillon; my experiments were done with cultures from chicken bouillon. To obtain all the effects of the microbe it is necessary to employ intravenous injections. The lesions varied according to the virulence of the material and also to the degree of resistance of the animals.

In the very acute case, where death follows 2 or 3 days after the injection, one observes lesions clearly periosteal, characterized by small areas of thickening of the periosteum, often grouped in centers of several millimeters and localized on the diaphysis of long bones ordinarily near the juxta-epiphyseal cartilage; venous congestion around the bony extremities, and often, surrounding the periosteum at the level of the juxta-epiphysis of the diaphysis. One

* Translated by Edgar M. Bick, M.D.

also finds the surface of the bone in these areas a bit more friable and porous than the normal state. Besides, small white spots, like caseated miliary abscesses, appear in the muscles (preferably those of the extremities, the abdominal wall, the intercostals), at times also in the diaphragm and myocardium; the kidneys are sites of congestion and yellow lines which follow the tubercules.

In spite of the great interest in the obvious periosteal localization, these cases are not demonstrative enough because of the multiplicity of localizations. The cases which developed a little less rapidly are much more convincing; whether because of less virulence in the microbe or greater resistance of the animals, localization is restricted and involve bone, if not exclusively, at least very predominantly, showing thereby that it is the area of predilection. Therefore one finds the lesions of osteomyelitis characteristically in the long bones of the extremities. It is at times simply rarefaction and friability of the tissue when the stripped periosteum comes off in flakes leaving a rough cortical surface. The friability is often so marked that it is easy to penetrate into the medullary canal. Finally in the most serious cases there is suppuration, loss of substance, disintegration of the tissue into a mess of caseated pus and minute sequestra, and even mobile sequestra covered by a layer of pus. In the affected area one may see orange colored small spots resembling those which the microbe forms in cultures.

The localization of these lesions is remarkable, they always sit at the extremity of the diaphysis at the juxta-epiphyseal area. They are contiguous to the cartilaginous plate which limits them and appears to appose a barrier which keeps the epiphysis sound. I have never found the epiphyses involved, nor the articular cartilages. When the articulations contain pus, it is entered through the synovial sac from the diaphysis. The usual sites of these lesions are the proximal extremity of the humerus, the distal extremity of the femur, and the proximal extremity of the tibia.

These lesions have been produced by the micrococcus cultivated to the third generation. They have occurred in all the cases without traumatic provocation.

In summary, the microbe which was found in the pus of infectious osteomyelitis, disseminated through the entire body of the rabbit by intravenous injection, and there free to choose its site of predilection, shows a marked preference for bone, especially for the most rapidly growing parts. It determines the necrotic and suppurative juxta-epiphyseal lesion, analogous to other agents of human disease which bear a specific role.

The history of this microbe presents other interesting points but because these are still under study, I wished only to call the attention of the Academy to the demonstrated fact of the experimental production of a disease comparable to infectious osteomyelitis.

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Alexandre Rodet (1814–1884) was trained in Paris and became chief surgeon at the hospital of l'Antiquaille in Lyon where he spent the better part of his career. In 1884 the present paper by Rodet on experimental infectious osteomyelitis was read to the Academy of Science in Paris by Bouley, one of its fellows. It is the first recorded experimental demonstration of the disease now known as hematogenous osteomyelitis. I know of no later experiment which has added any significant information to this concisely written report.

CLASSIC 68

Beitrage zur operativen orthopädik, oder Ehrfahrungen über die subcutane Durchschneidung verkurzter Muskeln und deren Sehnen

(Contributions to Operative Orthopaedics or Studies on the Subcutaneous Section of Shortened Muscles and their Tendons)

DR. LOUIS STROMEYER (1804–1876)

Although orthopedics in our time has experienced many advances, one may with justification assert that the influence of this art on surgical practice until now has not been significant. I believe this rests now merely on the difficulties of orthopedic therapy in private practice, for one does not undertake them even in clinical institutions, but much more in the limited interest which the majority of such surgical methods can attract, because of the slowness of results as compared to most surgical undertakings. Operative orthopedics is intended to arouse the interest of my colleagues in this important branch, to open on one side a series of easier and brilliant results, and on the other hand where appropriate, to clarify the nature of various diseases which have until now been obscure.

The fortunate results of section of the Achilles tendon for clubfeet has given this objective a new impetus in our time. Although at various periods attempts had been made to gain its acceptance, it seems that now is the right moment for its general propagation. The reason for this is rather obvious. When Thilenus published his observations, orthopedics was not yet aware of its implications, did not understand the mechanical details which were essential to his method; one imitated perhaps but was deluded. A case of clubfoot operated on by Dieffenbach using the Sartorius procedure shows a visible scar 4 inches long. I have already more healed individuals than those in which other procedures were followed without success because with the others the details of aftercare were not known. Section of the sternocleidomastoid in torticollis was barely preserved, since even though more often performed than in clubfoot it received imperfect aftercare. The mechanical details which are necessary to the success of orthopedic operations can become generally known only through meritorious publications planned by numerous orthopedic institutions, as is obvious since from the publication of my first studies on section of the tendo-Achilles (1833) about 400 such operations have been recorded in published papers. The majority were performed by men such as Dieffenbach, Leonhard, Cagenave, Bouvier and Duval, after they had previously acquired the skill to restore crippled limbs

* Translated by E. M. Bick

without operation. Sectioning of tendons, aponeuroses and muscles makes no claim to displace existing methods; on the contrary it acquires all their advantages and merely offers a valuable aid in difficult cases. There is no dispute about its value. Two of the greatest poets, Lord Byron and Walter Scott, and the greatest diplomat of our time, Prince Talleyrand, suffered with clubfoot and were not cured; on all streets of great cities one sees people with clubfeet or other crippled limbs, the healing of which no one even thought of, and which could have been helped by operative orthopedics. In less than one year Dieffenbach found an opportunity to cure 140 clubfeet, and with them others who resisted his earlier methods and still others who after a year of perseverence had run away from orthopedic institutions. Even from the qualified writings of objectors to orthopedic operations one can deduce their necessity. The report of Dr. Werner on the 10 year results from his Orthopedic Hospital at Königsberg states that he cured 14 clubfeet in his Institute; of 31 treated outside the same way, only some mild cases were cured, the remaining were abandoned to their fate. Of more than 60 unfortunates with foot deformities which I have cured, only 3 were in my institution; all the others were similarly treated as out-patients. That I only discussed the most instructive of these cases, gave my statistical friends the opportunity to start false calculations.

I would not enter the discussion over the boundaries between operative and merely mechanical orthopedics; these borders will be established by practice and always depend more or less on the individual skill of the surgeon. Orthopedics then finds itself in a sphere regarding operations, similar to the position of stonemasher to stonecutter; both methods must be cultivated together and only if both were brought to a similar grade of perfection can their relationship be established. Progress would be made if both methods could be followed and perfected by the same artist. I do not wish to draw any further comparisons between the results of mechanical and operative-mechanical orthopedics; but to represent my view simply and leave to the reader whether from this instruction he decides for or against my method.

I have recorded in this volume my older observations on section of the Achilles tendon because they have at least historical interest; they stimulated the entire objectives of the newer work: then similar cases are at my command in quantity and are now already very commonly available. Perhaps a further apology is needed because I have included almost the entire literature on Achilles tendon section up to my own work. This seemed to me a not uninteresting series of successes, and so I hope to have rendered my readers a service in exhibiting these small episodes of surgery.

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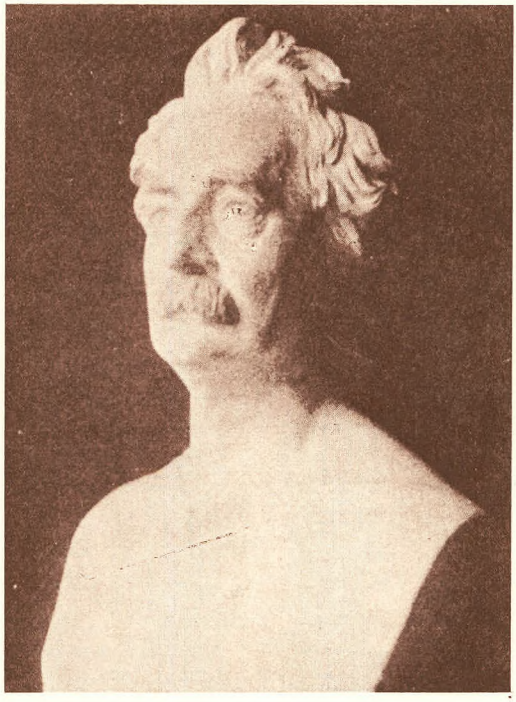

GEORG FRIEDRICH LOUIS STROMEYER

Georg Friedrich Louis Stromeyer (1804–1876) of Hanover, at times professor at various German Universities and surgeon general of the Hanoverian army, was one of the most powerful influences in developing the surgical aspects of orthopedic surgery in the mid 19th century. His outstanding contribution was the popularizing of subcutaneous tenotomy and the encouragement of its practice throughout the western surgical world. Although in the preface to his masterful and influential book, herein reprinted in English translation (I could find no previous translations) he gives credit to his predecessors who attempted the procedure sporadically, Stromeyer applied it to deformities wherever contracted tendons were approachable by the method. To appreciate the importance of subcutaneous tenotomy the horrendous proportion and devastating effects of open surgery in pre-Listerian days must be kept in mind. As becomes obvious in this preface, the technic of Stromeyer's procedure was used as a wedge for the development of musculoskeletal surgery *vis-a-vis* the brace and stretching era of the early days of our specialty. His first paper on the subject was published in 1833; Die Durchschneidung der Achillessehne als Heilmethode des Klumpfusses, durch ziver Falle erlantert. Mag. ges. Heilk: 39:195, 1833. However, the Classic of Stromeyer was his book on Operative Orthopaedics.

CLASSIC 69

Contributo alla cura cruenta della lussazione congenita coxo-femorale unilaterale

(Contribution to the Radical Treatment of Congenital Unilateral Coxo-Femoral Dislocation)

ALFONZO POGGI, M.D. (1848–1930)

I have decided to publish the present case of congenital coxofemoral dislocation because the satisfactory immediate and subsequent result obtained with the radical reduction presents a contribution of a certain interest to the cure of an articular deformity about which there still exists not a little controversy.

I come directly to the presentation of the clinical case.

Olga La Forni, aged 12, was a student in Bologna, whose mother died of a chronic intestinal disorder, the father and brother still alive and well. She was one of twins. The male twin died on the 15th day, the delivery having proceeded without obstetrical help.

Olga suffered no serious illness except typhus at the age of 9. When she first began to walk a defective gait was noticed by her parents. However nothing was done. During the following years the defective gait became more severe until it became an obvious limp. Recently she could no longer stand or walk because of pain in her left hip. Therefore she was admitted to the Clinic on August 11, 1888.

To this short history I shall add data concerning the objective examination which will disclose the marked degree of deformity, to make up for the lack of a preoperative photograph.

Examining the patient in dorsal decubitus and with both limbs parallel the eye was struck by the marked degree of atrophy of the entire left lower extremity, and by the shortening, measured from the anterior superior iliac spine to the internal malleolus of 8 cms. The measurement taken from the apex of the great trochanter to the external malleolus was about 0.5 cm less in the affected limb.

Movement both active and passive, tested slowly, was free in flexion and adduction, limited in abduction and external rotation. The left greater trochanter was so prominent as to deform the lateral and posterior contour of the articulation. Above the trochanter one noted a hard mass which followed the movement of the femur, more pronounced in adduction and internal rotation, was obviously the displaced and dislocated head of the femur palpable in the external iliac fossa. With the fingers placed in the left inguinal fold, as recommended by Pravaz, one was able to verify the absence of the head of the femur from its natural position. A lumbosacral curvature was of mild degree, and the apex of the greater trochanter was 3 cms above the Roser-Nelaton line. Traction on the left leg easily brought the sole of the foot into the same plane as that of the right foot, but one noted the corresponding lateral inclination of the pelvis and slight movement downward of the femoral head on the ilium.

Examining the patient in the erect position, both from the front and back as well

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Translated for Clinical Orthopaedics and Related Research by Dr. Joseph Ferrara, of New York City.

as from the left lateral position, some of the deformities already mentioned became more evident and other new ones became visible. I shall record the most important. In the erect position the plantar surface of the left foot did not rest on the ground except the heads of the metatarsals. The foot therefore was in equinos position. The curves of the torso were pronounced because of the corresponding deviations of the vertebral column. The lordotic position was very noticeable and the increased degree of the lumbosacral curvature was related to the posterior displacement of the femoral head. And in fact using the experiment of Margary, a plumb line placed in the apex of the axilla the line passed 5 cms anterior to the anterior margin of the greater trochanter, while on the normal side the line grazed the margin of the greater trochanter. To the lumbar lordosis was added an unsightly protuberance of the abdomen. The scoliosis with convexity to the left was well marked, and the left shoulder was therefore more elevated than the right. These deviations were the result of the left inclination of the pelvis.

All the indicated deformities which were so apparent through her clothing, the deformed way of walking that tilted the trunk laterally and posteriorly with every step, the pains which developed after standing or walking a short distance were the reasons that caused in Olga a strong wish for a cure and specifically a painless and less abnormal gait.

The nature and extent of the dislocation offered little hope for significant improvement by conservative orthopedic measures. Having tried in vain the method of closed reduction recommended by Professor Paci on January 29, 1888, I prepared to operate in the surgical amphitheater in the presence of the students instead of the late lamented Professor Loreta. I had decided in my own mind to hold myself to the most rational method, to replace the femoral head in its natural position, deepening or reconstructing the acetabulum, even adjusting the femoral head if it were altered in shape. I would only have to hold to the method of Margery if after opening the joint I would have found contraindications to the plan. The operation was performed under chloroform anesthesia and with meticulous attention to asepsis and antisepsis.

I preferred to open the articulation with the semi-circular incision of Anthony Withe rather than the currently more popular incision of Langenbeck, because it seemed to me that in this specific case the transverse division of the muscular fibers would lead more easily to the femoral head. Having cut the fibrous capsule which was rather thick, the bare head appeared within the large capsular sac covered with synovia, but without any signs of a new acetabulum with the inner capsule interposed between the articular head and the outer surface of the ilium, though not too adherent to it. A little effort in forced adduction and internal rotation of the limb caused the head to come out. The head was small and deformed, did not have the shape of a spherical segment, but that of an irregular oval with the surface in contact with the slightly altered ilium. The rest of it was covered with cartilage and at its apex was topped by a small protuberance, the remains of the insertion of the round ligament which was absent. The head was attached to a slender and short neck at a greatly obtuse angle to the greater trochanter. The capsular sac already referred to disclosed a foramen in the antero-inferior part through which I passed my index finger with some difficulty, and reached the acetabulum. I enlarged the pathway of communication with longitudinal incisions and discovered the boundaries of the acetabulum although they were of small circumference. The cavity was filled and I noted a small swelling of cartilaginous consistency which may have been a remnant of the insertion of the round ligament.

Because of these observations it seemed possible to me to reconstruct the articulation to its normal form. I deepened the acetabulum, reshaped the deformed head giving it its proper contour, and by means of well

directed traction and incisions in the capsular ligaments, I was able with only little difficulty to replace the head into the newly deepened acetabulum. I then detached the capsular edge from the iliac bone, removing the exuberant parts, and with three layers of sutures in the capsule, the muscles and the skin, with drainage tubes inserted, I closed the large incision.

With the reduction of the dislocation the disappearance of the marked deformity was noted in the supine position and therefore the disappearance of the protrusion of the greater trochanter, the lumbosacral curve and the feeling of emptiness on palpation of the inguinal region. The shortening of the limb was notable less, being only 2 cms, this the result of atrophy of the limb as was noted in the physical examination; and to the shortening of the neck and femoral head, both incompletely developed. Finally one might add that proof of a good reduction was the fact that the limb could be raised without difficulty.

The dressing was applied and the patient returned to her bed in the supine position with one pillow under the buttocks to keep the pelvis elevated and with traction (extension and counter extension on the operated limb by means of Volkmann's apparatus).

The postoperative course was uneventful. The temperature did go above 37.5 C and after 50 days, the patient began to be about with crutches, the use of which was advised for a time to spare the articulation while walking. The joint was mobilized by massage and manipulation. The wound had healed and the patient enjoyed a good result for the duration of her stay in the hospital.

The two photographs were taken the day before the patient was discharged from the Clinic, that is April 24, 1889, 3 months after operation.

The description of the immediate results and the 2 photographs* one in profile and the other a frontal view show well enough the successful result obtained.

* It was not possible to reproduce the photographs for publication.

Now nothing of importance remains except to add that the correction was maintained and that the present condition of Olga was satisfactory 13 months after the operation. In truth none of the deformities returned, the shortening has remained 2 cms; but the joint has regained its principal movements, not at all painful. Because of this the patient can sit comfortably and can walk at length without discomfort. There remains only an insignificant degree of limp which would be corrected with a proper shoe.

Bologna, March 4th, 1890

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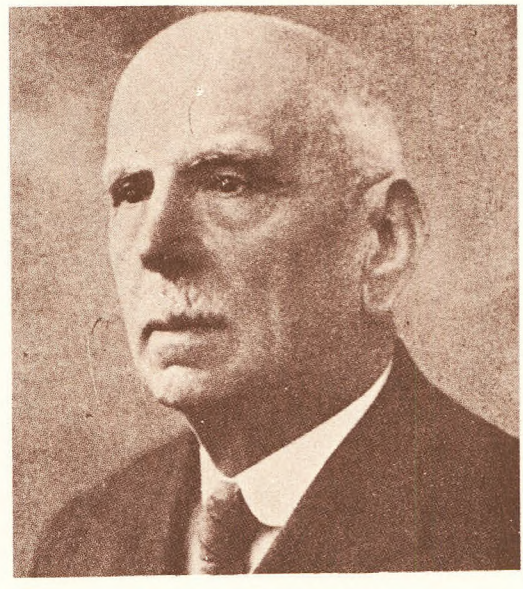

ALFONSO POGGI

Alfonzo Poggi, (1848–1930) was chief of the Surgical Clinic in Bologna at the time he presented this classic paper. It remains the first recorded case in a major journal, at least the first referred to in the mainstream of orthopaedic literature in which surgical correction of a congenitally dislocated hip included reconstruction of the acetabulum.

CLASSIC 70 Diseases of the Hip, Knee and Ankle Joint with Their Deformities Treated by a New and Efficient Method

HUGH OWEN THOMAS (1834–1891)

It is proposed in this treatise to introduce to the notice of the Profession the Theory and an Efficient Method of treating inflammation of the hip, knee, and ankle jonts. This method, judging from the results, after many years of experience and very frequent opportunities of trial in practice in over one thousand cases, is, I feel confident, a vast improvement on all the modes of treatment hitherto practiced in this department of Surgery.

CHAPTER I.

PREVIOUS HIP JOINT APPARATUS

DURING the last twenty years, various designs in wood, iron, wire gauze, leather, gutta percha, gypsum, silicate of potash, solutions of shellac, plaster of Paris, and their combinations have been used in the treatment of hip joint disease. I have used very many of these in practice during my early career, have well considered every known method and appliance in use both in Europe and America, and I trust it will not be deemed presumptuous if I point out what I consider to be the merits and demerits of these various appliances; many of them having been constructed at the suggestion of gentlemen well qualified to do so.

In France, Bonnet seems to have designed the favorite appliance; but in vol. ii. of his "Traite des Maladies des Articulations," page 327, he does not report well of it, for the reason, I believe, that it extends no higher than the pelvis. Charrière prolonged the upper portion of the instrument, causing it to embrace the trunk—an important improvement (Fig. 2, Number 1). This machine is an efficacious one, but very cumbrous; and owing to its high price (250 francs), is only attainable by wealthy patients and the larger charities. We may describe this instrument as one of "posterior fixation."

Our professional brethren in the United States have been most prolific in the invention of means for treating this disease. To Dr. H. S. Davis, of New York, is accorded priority in the invention of the "Perineal and Side Splint with Counter Extension" (Fig. 2, Number 2). It is arranged with the intention that the patient should not remain at rest, but that he might continue to perform all the movements of his joint. The designer of this instrument supposes that by its use the weight of the trunk is removed from the joint, and the surfaces relieved from pressure.

Following in the wake of Dr. Davis, we find Dr. Louis Sayre, of New York, whose appliance (Fig. 2, Number 3), is the same in principle as the last named, but designed as an improvement upon it.

Taylor's (Fig. 2, Number 4), again is a modification of Sayre's appliance, the difference consisting principally in the extension of the steel bar down to the ankle. This is also advertised as permitting the limb to be adducted or abducted, an objectionable fea-

ture superadded to the other faults of the Davis-Sayre design.

We have also Washburn's Splint (Fig. 2, Number 5), designed for poorer patients. This appliance is devoid of such complications as screws, racks, and pinions, which mar so much the usefulness of instruments employed in this department of surgery. It consists of a pelvic band, outside steel bar, and knee cap; the end of the steel bar being attached by adhesive strap to the ankle; and is, in principle, identical with that of Davis'.

Another variation met with is the instrument of Dr. J. C. Hutchinson, of Brooklyn, U. S. (Fig. 2, Number 6). This is a design similar to Taylor's, but it possesses an inside as well as an outside steel bar, the bars being attached by means of an iron joint to the sole of the shoe.

The last five appliances are variations of one type, and may be called "perineal extension instruments," illustrating alike the erroneous principles which led to the construction of the original splints of Davis and Sayre, each equally possessing their practical defects. These gentlemen have attempted to cure hip joint disease by relieving pressure, while yet permitting movements of the joints.

I hold that for mechanical reasons, this relief of pressure must be infinitesimal, if at all, and I know, from practical experience, that a cure, free from defect, is impossible with the use of these appliances. I admit that, when applied, some relief from pain may, and often does occur, (whatever be applied,) and not as a result of the application of this instrument; and I do not regard such relief to be of benefit to the patient under the circumstances.

I know that often when rupture of the joint takes place, some relief follows, and I am disposed to offer this as an explanation of those instances in which marked relief follows the application of this irrational method. I confidently believe that the non-resolution of the inflammation is due to pressure and friction of the inflamed joint surfaces, which these machines increase rather than arrest.

In the year 1863, Dr. Davis published a description of his instrument. I became acquainted with it in the same year, but on rational grounds I was opposed to, and did not venture to use it.

Since the visit of Dr. Sayre to England, and the exposition of his method to the London surgeons, I have seen several instances in which his apparatuses were skillfully applied, and from personal knowledge I am satisfied that in not one of these cases was the disease arrested or even benefited.

The best commentary upon this method is the remarkable frequency with which its principle advocate has had to perform excision of the joint.

The next class of instruments are those we find designed upon the principle of ischiatic support, and to Dr. Andrews, of Chicago, is ascribed the merit of having designed an ingenious contrivance—(Fig. 2, Number 7). This consists of the ordinary crutchhead, attached to a steel stem passing down the inner side of the thigh, and fixed to the heel of the boot, and is supposed to support the body effectually by counter-pressure against the tuberosity of the ischium and groin. This may take a fraction of the weight of the body off the hip, but makes no provision for controlling the joint movements, and consequently it is of no practical value.

Dr. Bauer, of New York, has also adopted a modification of this design, which consists of the inside stem and crutch-head, with the addition of an external stem, both stems being attached to the shoe (Fig. 2, Number 8).

Another method, which has occasionally been made use of in this country, is that practiced at the Verral Institution, and consists of an anterior reclination of the whole body upon a double inclined plane: much the same position as that used for treatment of spinal curvature in that establishment.

Another instrument, partaking of the perineal type, is that designed by Mr. Barwell,

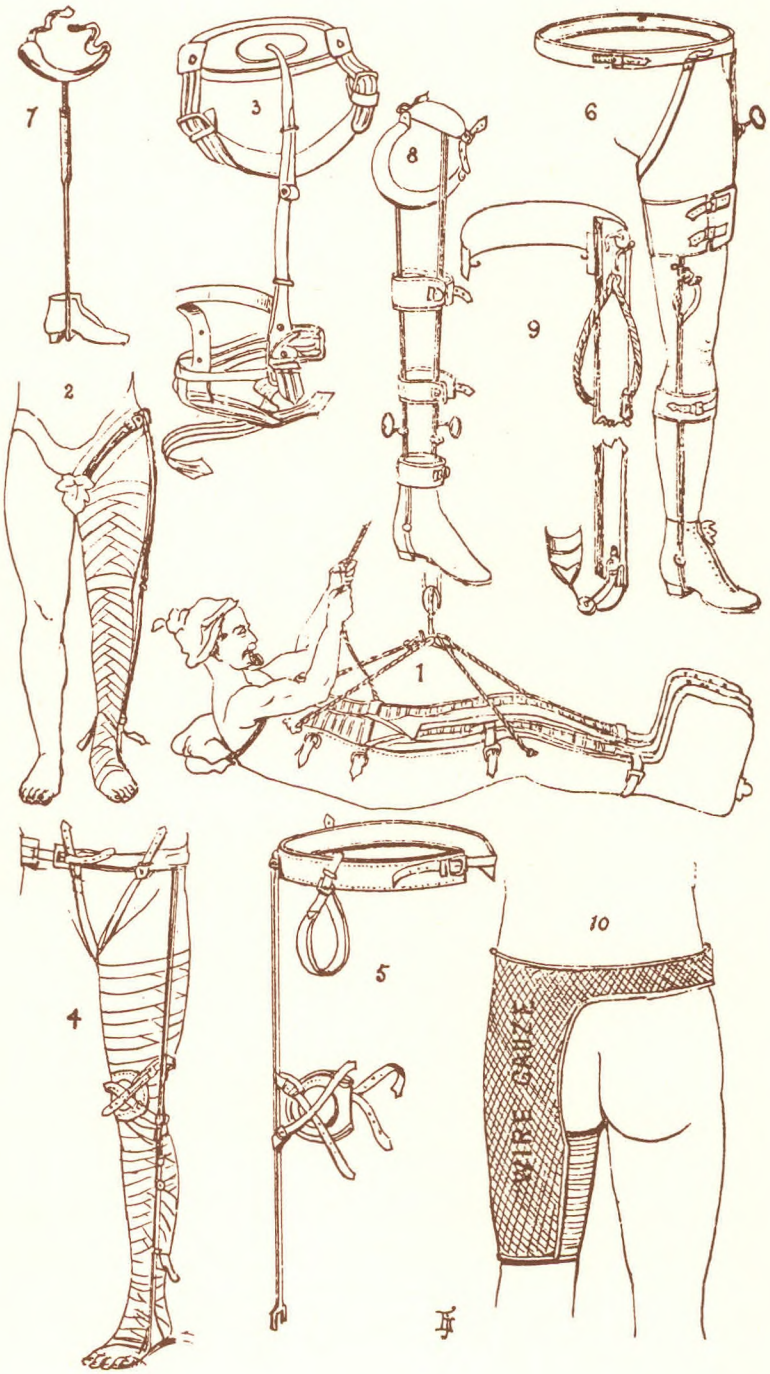

FIG. 2. Orthopedic appliances.

of London, and which consists of an outside wooden splint, perineal band, pulleys, and pelvic band, with an arrangement for elastic extension (Fig. 2, Number 9).

Appliances which are intended to effectually fix the hip joint must be attached to the thoracic portion of the trunk, as well as to the lower limb. Instruments, however ingenious,

which extend no higher than the pelvis, seldom attain the desired result. When the patient is disturbed, the length of the splint, attached to the lower extremity, acts as a lever, to resist the force of which leverage the pelvic portion and band are not sufficient. Owing to this defect, Bonnet's original design was not satisfactory to himself. But Charrière has converted Bonnet's instrument into an admirable appliance, by continuing the body portion up to the scapula, as shown in the figure. It is possible, with great care and attention, to obtain some benefit occasionally with Mr. Barwell's apparatus, and I admit, that with the exception of the old-fashioned long splint, it has been, for years, the best instrument at the surgeon's disposal. Mr. Barwell's appliance possesses an advantage over all the American designs, in that it has some little control over the movements of the joint. Painless nursing of the patient, however, is impossible with his appliance, or with any "side splint," a fault possessed alike by all the others to which I have referred.

Professor Hamilton's apparatus for hip joint disease, as described in Tineman & Co.'s Catalogue, seems constructed to control the movements of the joint, but is not long enough, and so is of very little value, and I can best convince the reader of this by referring him to Figure 2 Number 10, which is taken from the above catalogue; allied to the last two is Mr. Hilton's appliance, a drawing of which is given in his essay on "Rest and Pain."

Finally, we come to the old-fashioned long splint, which, when applied from the axilla down to the ankle, is an instrument possessing merits beyond any of those I have previously discussed; yet, it has its faults, as, being applied laterally, it can only partially control the movements of the joint, and the nursing of the patient is not performed without pain, while, where deformity is present, it cannot be applied.

I will conclude by referring to the method of treatment by weight and pulley, which amounts to no more than confinement to bed. Dr. H. G. Davis, the author of the perineal system of treatment of hip joint disease, is credited with having suggested the use in hip affections of this useless, and, worse than useless, injurious method of treatment, when applied in hip disease, and in its application, deceptive and irrational; for surely if relief of pressure be required, the only direction in which this is possible is clearly in the axis of the neck of the femur; any method of extension in the axis of the body merely transfers the pressure from the upper part of the acetabulum to its lower quarter. Continuity of extension, *per se,* is not a remedy in joint disease, as I shall subsequently show; in its application it involves unavoidably a fractional degree of fixation which is sufficient to mask the evil of this ridiculous mal-practice. The idea of practicing extension in joint disease has originated, no doubt, from observing its effect in the treatment of fractures, under the supposition that it is the best antidote for muscular spasm. I assert that a fractured thigh, if treated by extension only, would be accompanied with vastly more muscular irritability than if the same case was placed in a modern appliance with retention in which the limb was retained and fixed immovably, in the strict meaning of the term fixation. Then we should not have the slightest muscular excitement. Traction is a very inefficient sedative in joint disease, as well as in fractures, compared with the effect of the immobility modern surgical appliances place at our disposal, while I admit that continuous extension is next in value to retention as an aid in the treatment of certain fractures, though of secondary value compared with an immobility that places the limb at perfect ease.

Our Transatlantic brethren deserve praise for having studied diligently to improve the treatment of these joint affections, but by ignoring in all their designs the fact that friction is a greater evil than pressure, they have devised methods of less efficacy than those previously in use. (Friction may be defined as

a combination of motion and pressure, consequently it is to be specially avoided in joint disease. Efficient enforced rest in joint disease, as well as in fractures, is the infallible remedy for quieting the irritated muscles; not extension.)

In confirmation of the correctness of my opinion as to the evil of friction in joint inflammation, I refer to the lower jaw articulation. In this joint we rarely have inflammation, but when this does occur, it is more liable to be followed by ankylosis than in any other joint, in consequence of the fact that the patient is obliged to make some use of this joint daily.

In chronic inflammation of shoulder joint we have an illustration of the continuous extension method readily provided for us, by the weight of the limb itself, yet, when the movements of the joint are not effectually arrested, which they seldom are, we have ankylosis to that degree, that even the great mobility of the scapula cannot mask. Any practical surgeon will recollect the marked relief in some cases, given to the patient by supporting the upper extremity, the reverse of continuous extension.

The various mechanisms to which I have referred may be described as of two classes: first, those models which are intended to permit the joint to be in action, and are supposed to relieve pressure; secondly, those that are constructed for the purpose of attempting an arrest of the joint's movements. The first I shall dismiss as useless and injurious; it includes all the American models, Hamilton's design excepted: this last is a step in the right direction, but has no value in practice. The second I regard of some value, and can be subdivided into lateral and posterior fixation.

The first includes Barwell's instrument and the old Long Splint, single and double. The second includes Charrière's model of Bonnet's "grand appareil." As to the lateral fixations, I have already stated my opinion when referring to the instrument of Mr. Barwell, that the long splint is a useful means to success when skillfully and frequently adjusted, and when the patient lies still; but that its palpable defects are the readiness with which it may fail, for instance in nursing, or should the patient endeavour to rise, or not remain contentedly still, as is often the case with children, who continually attempt to flex the limb, or especially to turn in bed, thus causing the splint to rotate from its position towards the front. I have already expressed my approval of Bonnet's apparatus, and only take exception to its cost and cumbrousness. My method illustrates the superiority of posterior fixation over all other methods, and is the only one by which, efficiently, friction and concussion can be arrested, pain alleviated, and a cure secured and that without deformity, no matter to what stage the case has progressed, conditionally on a strict observance of the principles and details which I have found essential, and shall explain in the following chapters.

The design that I shall submit to the profession is free from the defects of all the previous appliances; is cheap, and within the reach of the poorest; is light, and can be applied under the clothes without much disfigurement to the sufferer's appearance, and enables the attendant to nurse and handle the patient, as though he were a toy, without pain; and can be applied for the purpose of rectifying cases of hip-joint deformity, though they may have existed 20 years.

I have not entered into the demerits of the shellac, silicate of potash, and other solutions, as they are not usually applied beyond the pelvis.

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HUGH OWEN THOMAS

Hugh Owen Thomas (1834-1891) was one of the memorable leaders of the Liverpool school of orthopaedics which has continued its eminence to this day. Thomas's contributions to the clinical care of skeletal disease were immeasurable. The present extract is from the 1876 issue of his 1875 volume on diseases of the hip, knee, and ankle joint. It includes the opening paragraph of his preface, and Chapter 1.

Until the introduction of chemotherapy and antibiotics in the 1940's there was no direct treatment for pyoarthrosis or tuberculosis of the joints. If the patient lived through the disease the orthopedic surgeon's talents were directed toward preventing severe contraction and deformity. The joint either anklyosed or ended with limited motion. The job was to keep it in reasonably good alignment. To this end the Thomas splint, with its almost infinite variety of subsequent modifications, was designed.

For those who would know more of the vastly informative contributions of Thomas it is a pleasure to note a reprint of this 1876 2nd Edition arranged by Leonard F. Peltier, published in Boston by Little Brown & Co. in 1962.

CLASSIC 71

Recollections and Remarks on a Few of Our Eminent Orthopaedic Surgeons of the Early Twentieth Century

ALFRED R. SHANDS, JR., M.D.

My entrance into orthopedic surgery was just 50 years ago at the Johns Hopkins Hospital. It started with an orthopedic internship under the triumvirate of Doctors Baer, Bennett and Johnson. The Hopkins service in 1923 had just been lengthened from two to three years; the *first* year was termed an internship, which now would be a junior residency, the *second* year an assistant residency in children's work, and the *third* year a residency. In between the first and second years there was usually a year in general surgery. I spent this time at Johns Hopkins. Before 1923 at Hopkins one could go on the orthopedic service straight from graduation, complete training in two years and start out in teaching or practice immediately.

In 1923 Doctor William S. Baer (1872–1931) was the Professor and chairman of the Department. It was said that he had been told about 1900 by Doctor William S. Halstead, Professor of Surgery, to go away, find out what orthopedic surgery was all about, come back and organize a department. This he did extremely well. Doctor George E. Bennett had joined him as an associate in 1910 and Doctor Robert W. Johnson, Jr. in 1919. Once Doctor Baer was asked what was the greatest thing he thought he had done in his professional career, and his answer was "in having something to do with the training of George Bennett." Doctor Bennett completed his orthopedic residency at The Hospital for the Ruptured and Crippled in New York under Doctors Virgil P. Gibney and Royal Whitman before becoming associated with Doctor Baer. Incidentally, Doctor Bennett was asked in about 1931 to return to New York to be the Surgeon-in-Chief of The Hospital for the Ruptured and Crippled. This was before Doctor Philip D. Wilson, Sr. came from Boston to take over. In 1923 Doctor Baer was at the height of his career. He had three major professional interests, 1) Arthroplasty, particularly of the hip joint, 2) Manipulation of the sacro-iliac joint for back pain and sciatica, and 3) Treatment of arthritis by vaccines made from gland cultures, and one non-professional interest — chow dogs. Doctor Baer was a stimulating chief and a very clear and forceful lecturer; but unfortunately he left very little in print by which he may be remembered. He was not what would be called a good technical surgeon. This title was better suited to Doctor Bennett. In surgery of the hip, the loss of blood did not bother Dr.



FIG. 1. William S. Baer (1872–1931) of Baltimore.

Baer. There is no doubt that Doctor Baer did as much for the development of arthroplasty and hip surgery as any other surgeon of his period. At this time Willis C. Campbell of Memphis, William R. McAusland of Boston, and Vittorio Putti of Italy were the three best known in our country for arthroplasty. Smith–Petersen came along in the late twenties and early thirties with his cup arthroplasty which proved to be the most popular for a long period of years. Doctor Baer used to tell his residents to pay attention to what the Chiropractors and the Osteopaths were doing. "They are taking our patients away from us," he would say. His results with the use of vaccines in arthritis were not what the young resident thought to be satisfactory. Undoubtedly, in most instances, if the patient showed improvement, psychotherapy was involved. His work with maggots for the treatment of osteomyelitis came after I left Hopkins. This work was sound, in spite of some unfavorable criticism, but never did prove very popular, and with the increasing use of the sulfa drugs in the 1930s and penicillin with its derivatives in the 1940s, the incidence of osteomyelitis rapidly decreased and the maggot treatment disappeared. Doctor Baer nearly always had a cigar in his mouth. If not smoking, he was chewing it. I often saw him go into the surgical suite, scrub while the ashes dropped from his cigar, and have a nurse take it out of his mouth and put his mask on him as he walked into the operating room. One of the major interests of Doctor and Mrs. Baer was their chow kennels. They were about the best in the country. Very often a sick chow would be more important to him than a sick patient. Many times he was known to leave his office by the back door with a waiting room full of patients, go out to his kennels to look after a sick dog and return while the patients wondered why they were kept waiting so long. In spite of this, his patients, with a few exceptions, adored him. One of the duties of the residents at the Children's Hospital School was to assist the "Chief" in eye operations on his chows. The operation was a turning in of the lower or upper lid. The correction of this congenital defect, characteristic of the chow dog, was necessary for the dog to be at its best in a show. Doctor Baer had a peculiar snort or inspiration and also a characteristic laugh. He was always full of stories and experiences. He was extremely loyal and helpful to his residents, both during and after their residencies. Unfortunately, Doctor Baer did not take care of his health. He was 'way overweight, had high blood pressure and kidney disease, would not follow a reducing diet, nor follow good medical advice, and died suddenly at the age of 59.

While I was growing up in orthopedics, the two great names in the South

were Mike Hoke and Willis Campbell, with whom I became well acquainted. Doctor Hoke (1874–1944) has been described by some as one of the "great brains" of all time in orthopedic surgery. Another of our greats living in the mid-nineteenth century who was also spoken of as one with "great brains" was Henry Gassett Davis (1807–1896), of New York, who was known for the American Method of continuous elastic traction which revolutionized the orthopedic treatment of that day. Doctor Hoke wrote very little and to learn what was in his brains one had to visit him in Atlanta. Some people, for example Leo Mayer, would go to Atlanta and literally sit at his feet to learn from "the great master." He was an excellent teacher in his quiet effective way. He was known, probably best, for his work in foot surgery, the triple arthrodesis and the flat foot operation, and his well-leg traction technique. He was not well known for his work with scoliosis, a subject in which he was deeply interested, although in 1903 he published a classic article which was spoken of in 1928 by the English orthopedic surgeon McCrae Aitken as being an "epoch" in the treatment of scoliosis. Probably his greatest contribution to orthopedic surgery and the crippled child was his part in the founding of the Scottish Rite Hospital for Crippled Children in Atlanta in 1915, which was the example to the Shriners in founding their many hospitals for crippled children. Doctor Hoke went to Warm Springs, Georgia as the Medical Director previous to Franklin D. Roosevelt's presidential nomination. During his 4-year stay, Dr. Hoke became well acquainted with the President who came to Warm Springs for therapy and rest, but also became a very bitter critic of the President's socialistic policies. On one occasion at a meeting of the American Orthopaedic Association in Washington in 1933, I was sitting at a table with Doctor Hoke, Guy W. Leadbetter of Washington and John J. Nutt, of New York. Doctor Nutt was



FIG. 2. Michael Hoke (1874–1944) of Atlanta (Artist Jack B. Wilson).

a great talker and started expounding in a rather loud voice on the subject of Roosevelt's polio condition and his braces. After talking at length on how terrible the braces looked, and how inadequate they were functioning, Doctor Hoke, who had been very quiet during all of the conversation, asked if he might say a word. He turned to Doctor Nutt and in a very soft but emphatic tone said, "Doctor Nutt, I measured President Roosevelt for his braces, I supervised the making of them, I fitted them, and I have seen him repeatedly since he has been wearing these braces. I think they are very satisfactory." There was not another word from Doctor Nutt. Doctor Hoke employed a full-time artist for quite a long period of time to



FIG. 3. Willis C. Campbell (1880–1941) of Memphis (From: J. Bone Joint Surg. 23:716, 1941).

make illustrations for his papers, particularly on the foot. Very few of these drawings were ever used, for Doctor Hoke had very few publications. In 1943 I visited him in Beaufort, South Carolina after he had retired from practice in Atlanta. He showed me many boxes of drawings and asked me what he should do with them. They were sent to Alfred I. du Pont Institute, in Wilmington. He died the next year. The drawings were later divided; some went to Oscar Miller, one of his first pupils, in Charlotte, some to Ed Irwin, his successor at Warm Springs, some to Beverly Raney at the University of North Carolina, some to Lenox Baker at Duke, and some were kept at the Institute in Wilmington. Doctor Hoke was a small, thin, wiry man with a big nose and a delightful smile, a fascinating story-teller and extremely popular with those who knew him. He had been the quarterback on the University of North Carolina football team in his college days, weighing only 125 pounds. Many years later he was named THE ALL-TIME QUARTERBACK of the University. Doctor Hoke, who was on the first Medical Advisory Board of our Institute, could not have been more helpful in our first planning. He had had wide experience with crippled children's programs and in planning for the Shriner's Hospitals. We were very fortunate to have him as well as Doctor Robert B. Osgood, who also had been on the Shriners' Advisory Board, help us in our original thinking. Mrs. Alfred I. du Pont was devoted to Doctor Hoke; the admiration was mutual.

I first visited Doctor Willis C. Campbell (1880–1941) in Memphis in 1928, a year after completing my residency at Johns Hopkins. I was a guest in his home. The Campbell Clinic was then well established with Spencer Speed second in command. Orthopedic surgery has never had one with more drive, energy and dedication than Willis Campbell. Just previous to my visit his life had been threatened because of a physical altercation with a rival orthopedic surgeon in the Baptist Hospital. I shall never forget the night I went with him to a meeting in the Peabody Hotel. It was cold and rainy. When I got into the back seat of the chauffeur driven car, I felt something hard under the lap robe. It was a pistol. Doctor Campbell got in and I said, "Doctor Campbell, why is there a pistol here?" He told me his life had been threatened and he had obtained a police permit to carry a gun, but he thought that with a visitor from out of town in the car with him, he would be less likely to be shot at. As might be expected, I was a little on the nervous side. On several occasions I played golf with Doctor Campbell. He

was not a particularly good golfer but loved the game, and there was no doubt that he loved to win. In fact, some of his contemporaries used to joke him about whether he had counted all of his strokes. He liked to play so much that at times he felt his day was lost unless he could get out on the links. His associate, Spencer Speed, was one of the best golfers the American Orthopaedic Association has ever had. Doctor Campbell is remembered for many great things he did in orthopedics, but there are two I think are the most important, namely, the parts he played in the organization of our Academy, and of our Board. He was the spark plug behind the organization of both. He was a great talker and writer as we all know, and left many excellent contributions to the literature, especially his "Operative Orthopedics" which has been so successfully continued by his successors at the Campbell Clinic. He was an internationalist and was one of the most active of the American members of SICOT. He had the ability to pick and surround himself with good brains, which undoubtedly is the reason why the Campbell Clinic has become one of the leading orthopedic centers of our country, if not of the world.

Probably the most aggressive, and I am sure some people thought the most egocentric orthopedic surgeon of this day of Baer, Hoke and Campbell, was Fred H. Albee (1876–1945), of New York. Fred was born in Maine, educated at Harvard, trained at the Massachusetts General Hospital and started practicing in Waterbury, Connecticut. He became interested in orthopedics through Doctor Charles Ogilvy, of New York, who came to Waterbury for regular orthopedic clinics. Albee left Connecticut in 1906 and started in New York as the radiologist and assistant in the Dispensary at The Hospital for the Ruptured and Crippled where he came under the guiding hand of Virgil Gibney. Albee had an inventive mind and when

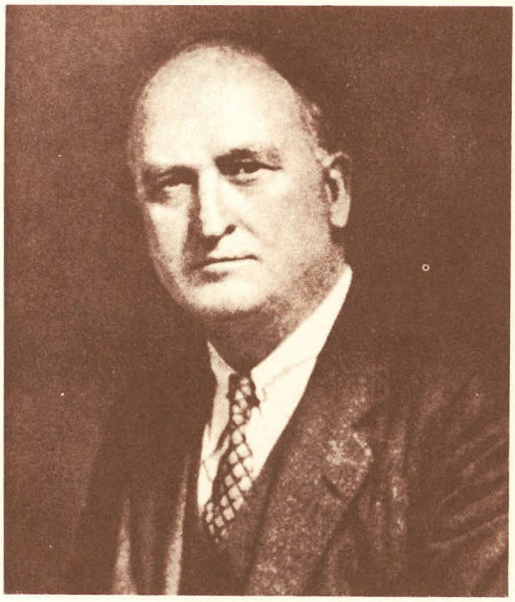

FIG. 4. Fred H. Albee (1876–1945) of New York (From: J. Bone Joint Surg. 27:345, 1945).

he found out what an electric saw could do in bone surgery, his star ascended quickly. He was considered by some to be a mechanical genius. I knew Fred Albee extremely well and on one occasion during the war years, when I was in uniform and could not be with my family, I spent a delightful Christmas with the Albees at their home in Venice, Florida. He and Mrs. Albee could not have been more perfect hosts. The first time that I realized that his health was failing was in 1944 when he came to the Orlando Army Air Force Hospital to talk at a staff meeting. He fumbled with his slides and could not remember too well. I am sure that many times in speaking at meetings he might not have remembered too well, but his audience never knew it. It was about a year after this that he died. At meetings Fred Albee was constantly jumping up to discuss papers. On one occasion at an A.O.A. meeting, I was sitting next to Doctor Hoke who was not one of Doctor Albee's admirers. Fred got up, walked down the aisle past Doctor Hoke



FIG. 5. Robert B. Osgood (1873–1956) of Boston (From: J. Bone Joint Surg. 39A:726, 1957).

to discuss a paper and Doctor Hoke turned to me and said, "There goes the little red fox again." Albee was very much interested in the Alfred I. du Pont Institute and came to visit me in Wilmington on several occasions. During construction I remember his intense desire to see everything in the new building. He climbed up ladders, and inspected the construction from top to bottom. Fred was one of our great pioneers in rehabilitation, which mantle he passed on to Henry Kessler, who became one of the foremost national leaders in rehabilitation. Fred had been responsible for the founding of the New Jersey State Rehabilitation Commission after the first World War when he was Colonel Albee in command of the Army Rehabilitation Hospital at Colonia, New Jersey. In 1929 he was President of the American Orthopedic Association and arranged for a joint meeting with the British Orthopedic Association in London. This meeting was a great success. In his day he probably was the best known American orthopedic surgeon abroad, particularly in Latin America. He was one of the founders of SICOT. There was a deep feeling of antipathy towards Fred Albee felt by many of his American orthopedic contemporaries, including Doctor Baer. In the fall of 1929 Doctor Baer went abroad for the organization meeting of SICOT for the express purpose of keeping Fred Albee from being elected President. He did the unheard of thing in that day by going from New York to France, spending two days at the meeting in Paris, and taking the next boat back home. Sir Robert Jones, of Liverpool, a great favorite with everyone, was elected the first President. Albee never became a SICOT President, which, I am sure, was a great disappointment; however, he did hold the office of Vice-President. Albee received many honors and was decorated by many countries. On one occasion he was to receive a special honor and medal from the King of Spain. He spent a great deal of time in studying Spanish as he wished to accept the honor in Spanish from the King. He took with him an old fashioned talking machine with Spanish language records to continue his Spanish studies on the way. When he crossed the Spanish border, the customs officers could not be made to understand what the machine was and took it away from him, thinking it was a bomb of some sort. When he arrived in Madrid, he was terribly disappointed when a third or fourth official in the State Department awarded him the decoration and he never did see the King of Spain. He was a tremendous eater and a dynamo of energy who never wanted to stop. Fred was another who literally killed himself by not following doctors' orders. One of the nicest things which has happened to me was in 1959 when Henry Kessler asked me to give the annual Albee Lecture at the Kessler Institute. The subject of the lecture was Fred Albee and it gave me the opportunity to evaluate some of Fred's great contributions to orthopedics. This lecture was published in a condensed form in *Clinical Orthopaedics* in 1962 (Vol. 23).

Of the elder ones in the Boston School of Orthopaedics, I was best acquainted with Doctor Robert B. Osgood (1873–1956). Although we had met at many meetings, I did not really know him until about 1933 when we were associated in the organization of the American Rheumatism Association (A.R.A.). We served together for many years on the Executive Committee and when he was President of A.R.A., I held the post of Secretary. In 1937 when I became Medical Director of the Nemours Foundation he was on the Medical Advisory Board. He was a great help to Mrs. du Pont, the Trustees and myself in his advice in the organization and plans for this Foundation and the Alfred I. du Pont Institute. It was his thinking that the Institute should be modeled on the plan of the Massachusetts Hospital School at Canton which had been started in 1907 by Doctor Bradford. Doctor Osgood was a great friend of Sir Harry Platt, of Manchester, England, who had had some of his early orthopedic training in Boston. Two years ago Sir Harry gave me a large file of his correspondence with Doctor Osgood, most of which was about the orthopedic situation in Boston after the first World War. Doctor Osgood and Sir Harry were very closely associated as orthopedic consultants under Sir Robert Jones during this war. Sir Harry told me that on many occasions after a hard day's travel to the front line hospitals and casualty stations in France, he and Doctor Osgood would meet at an Officers' Club for dinner. Doctor Osgood would never have anything to drink stronger than a sherry while he, Sir Harry, would always have his whiskey. Doctor Osgood would say, "I do not want to become an alcoholic and have softening of the brain as I grow older." And the sad thing was that his memory gradually failed him starting in about 1946 or 1947, ten years before his death. Boston has never had an orthopedic surgeon who has written more and contributed more to our specialty than Robert Osgood. He was Chief of the Orthopaedic Service at MGH after World War II, succeeding Doctor Brackett and then in 1922 he went to the Children's Hospital to succeed Doctor Lovett as Chief. When his home was broken up at his death, Ellen Osgood, his daughter, sent to the Alfred I. du Pont Institute a small bronze statue, which had been done at the end of World War II, of her father in uniform. The sculptor was Bryant Baker who was in Doctor Osgood's medical unit at one time. Bryant Baker later became one of the great sculptors of the country. This statue is now in the Museum of the Institute. Doctor Osgood was one of the early radiologists at the MGH and Children's Hospital. Unfortunately, he developed skin cancers from X-ray burns and never could scrub much for surgery. His interest in arthritis became very intense as he grew older and with Ralph

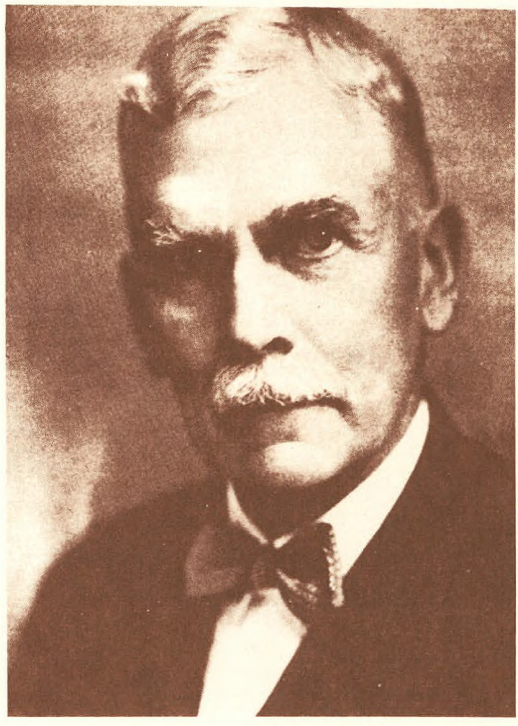

FIG. 6. Joel E. Goldthwait (1866–1961) of Boston (From: J. Bone Joint Surg. 43A:463, 1961).



FIG. 7. Elliot G. Brackett (1860–1942) of Boston (From: J. Bone Joint Surg. 25:245, 1943).

Pemberton, of Philadelphia, he published a very good book on arthritis. He had an amazing memory, particularly for poetry and people. He spoke and wrote extremely easily, clearly and with an excellent choice of words. He had the most perfect command of the English language of anyone with whom I have ever been associated.

Joel E. Goldthwait (1867–1961) was another of Boston's great orthopedists of the early and mid-Twentieth Century. Doctors Bradford, Brackett, Lovett, Goldthwait and Osgood were the great five of Boston in the early part of the century. Doctor Goldthwait was always known for his work with posture. In his early days he had much to do with the organization of the Posture League of America. As he grew older nearly all of his practice was non-operative involving orthopedic medicine rather than surgery, although in his early years he described two good operations, one for recurrent dislocation of the patella and the other for fusion of the ankle. I remember making rounds with Doctor Goldthwait in 1930 at the Corey Hill Hospital in Boston and was very much impressed with what I called his "penetrating eye." When he looked at a patient you had the feeling that the patient believed every word he said. The only other person in my professional career who could approach this "penetrating eye" of Goldthwait was Doctor Lewellys F. Barker, of Johns Hopkins, who was the Chief of the Private Medical Service when I was a medical intern. On one trip to the Academy meeting in Los Angeles in 1938 I saw a good deal of Doctor Goldthwait and his second wife, on a special train from Chicago to Los Angeles. Doctor Campbell was also on this train. Doctor Campbell was in some ways a great maker of society presidents. For some reason he had the feeling that Doctor Goldthwait should be honored by being elected the next President of the Academy and apparently had discussed his nomination with him. I happened to be the Chairman of the Nominating Committee that year, which Committee felt that Doctor Goldthwait was too old (72 years) and too far out of touch with national orthopedics to be considered. Doctor Bennett was made President-Elect and Doctor Campbell was overheard telling Doctor Goldthwait why he was not to be nominated. It must have been rather embarrassing for Doctor Campbell to explain.

Another one of Doctor Bradford's great pupils in Boston was Doctor Elliott G. Brackett (1860–1943), one of the most lovable and kindly persons we have ever had in orthopedic surgery. He undoubtedly became interested in orthopedics because as a young man he had been under the care of Doctor Bradford for a serious crippling condition. As a result of this condition he always limped. In spite of his disability, during the first World War he was Colonel Brackett, the Chief of the Orthopaedic Services of the United States Army in the Surgeon General's Office. Doctor Goldthwait was the Chief of

Orthopaedics in the A.E.F. with Osgood and Baer as his associates. Doctor Goldthwait was retired with the rank of Brigadier General, the only General from civilian ranks orthopedics has ever had. The first good reconstruction operation of the hip was described by Doctor Brackett. In 1923 the Brackett and Whitman reconstruction operations were the two most common operations done for a hip disability requiring surgery. Doctor Brackett became interested in writing and editing and in 1921 he took over the editorship of the American Journal of Orthopaedic Surgery from Doctor H. Winnett Orr, of Lincoln, Nebraska, changed the name to The Journal of Bone and Joint Surgery and made it one of the great surgical journals of the world. No one could have been nicer to a younger man than Doctor Brackett was to me. Two years before his death Doctor Brackett honored me by asking me to be on his Editorial Board. Doctor Brackett was a great upholder of journal standards and was sharply criticized by many for turning down so many manuscripts for publication in The Journal. The situation became so acute at one time that there was serious thinking on the part of a few of starting another journal. I was one of the ones approached concerning the editorship of a second journal. My only qualifications at that time were the "Handbook of Orthopaedic Surgery" and the "Progress of Orthopaedic Surgery." Doctor Brackett was very fortunate in having Miss Florence Daland with him in the Journal office. She was a very positive person, a clear thinker, an excellent grammarian, a tireless worker and had a great deal to do with the success of the Journal. No one in orthopedics has had more general respect and certainly more admiration among orthopedic surgeons, young and old, than Doctor Brackett.

There are many, many others I would like to write about but lack of space will not permit. It might be appropriate to quote a poem from the *McGuffy Reader* entitled "The Inquisitive Boy":

Son — How big was Alexander, Pa
That people called him great
Was he like old Goliath tall
His spear a hundred weight?
Was he so large that he could stand
Like some tall steeple high;
And while his feet were on the ground,
His hands could touch the sky?

Father — Oh, no, my child, about as large
As I or Uncle James.
'Twas not his stature made him great
But greatness of his name.

Son — His name so great? I know 'tis long,
But easy quite to spell
And more than half a year ago
I knew it very well.

Father — I mean, my child, his actions were
So great, he got a name
That everybody speaks with praise
That tells about his fame.

All of those whom I have written about so briefly made lasting contributions to orthopedic surgery, were famous in their day and left great NAMES behind them.

ALFRED RIVES SHANDS, JR.

Alfred Rives Shands Jr. of Wilmington Delaware, published an invaluable volume on the early orthopaedic surgeons of America in 1970 (St. Louis, C. V. Mosby). He was then Medical Director Emeritus of the Alfred I. du Pont Institute of the Nemours Foundation in Wilmington. He had been president of the American Orthopaedic Association 1953–1954, and its Historian from 1965–1970. His continuing contributions to orthopaedic biography remain an important source of its references.

CLASSIC 72 Infections of the Hand

ALLEN BUCHNER KANAVEL (1874–1938)

SEQUELAE OF INFECTIONS OF THE HAND

CHRONIC PROCESSES, OSTEOMYELITIS, ARTHRITIS, CONTRACTURES, AND ATROPHY

IN cases showing a long-continued suppuration, we ask ourselves what structures are involved which prolong the trouble, or why we have inefficient drainage. Frequently both factors are at work. By far the most frequent causes are osteomyelitis, arthritis, and necrosis of tendons.

Areas which were primarily poorly drained cavities are soon complicated by one of these factors. Suppurative arthritis seldom exists without concomitant osteomyelitis. Such cases frequently give a history of primary tenosynovitis, followed by osteomyelitis, ending in arthritis.

Involvement of the wrist-joint has been discussed in the previous chapter.

The pathology of these cases naturally varies with the tendency of the tissues to react to the particular germ which is the exciting cause, the length of time the process has existed, and the structure involved. Grossly the most important findings are the sinuses, which are an almost constant accompaniment of chronic disease. Here we note several types, and while there is a distinct difference between them, any system of classification is inadequate. We might say the osseous and connective-tissue types, or the acute, subacute, and chronic. While the pathology presents some justification for either system, yet the reactive resistance of the individual and the kind of germ enter into the subject as varying factors; consequently only generalized statements can be made.

The chronic osseous type presents three pictures, varying with the bones involved: (1) Those cases where the terminal phalanx is the seat of osseous destruction; (2) where the finger proper is involved; (3) where the metacarpals and carpal bones are involved.

INVOLVEMENT OF THE FINGER PROPER

Those cases (first group) showing chronic processes in the terminal phalanx have already been discussed in the chapter on Felons (Chapter II).

The second group of cases noted in the chronic osseous type is that which comprises suppurative processes of the proximal and middle phalanges. We all have had opportunity to observe that the proximal interphalangeal joint particularly may become involved early, either primarily or secondarily. In the case of the metacarpophalangeal-joint, however, there is more fibrous

tissue intervening between the tendon sheath and the joint and the adjoining bone; therefore, the sheath erodes through at some less resistant point, as, for instance, at the proximal interphalangeal joint, in the course of the tendon over the proximal phalanx, or at its proximal end in the palm of the hand. Frequently I have seen a sinus lead from the proximal end of the sheath of a tendon through the palmar fascia, and the metacarpophalangeal joint still remain intact. Again, the metacarpophalangeal joint is likely to escape in cases of palmar abscesses where the diaphysis of the metacarpal has become involved, or even when the process has been so severe as to extend under the annular ligament and invade the carpal articulation. It has been my experience in these cases that the distal articulation frequently escapes even in long-continued synovial disease and extensive osteomyelits.

In the ordinary case of chronic suppuration in the finger it is the proximal interphalangeal joint that is at fault, and the pathological condition noted in Figure 119 is fairly typical. The constant irritating discharge coming from the necrosing bone, passing through the connective tissue rich in lymphatics, produces an excessive deposit of granulation tissue, building up a small volcano-like structure, from which oozes forth a constant stream of pus, and through which winds a tortuous canal leading down to the necrotic bone. Where bone alone is involved, I have seen this crater clearly defined, occupying no greater extent than the length of one phalanx and raised above the surface for a distance half the diameter of the finger. This characteristic picture, however, is seldom seen, owing to the very frequent involvement of the tendon or the joint in the same process. Here, while the development of granulation tissue is still excessive, the mouth of the crater is generally much wider, owing to the excessive discharge from the tendon sheath. The granulation tissue is not so circumscribed, although very abundant. Moreover, the picture loses some of its force, owing to the associated swelling of the finger along the tendon sheath, the absence of which in the first case serves to accentuate the local tumor formation. Again, if the sinus be upon the dorsum there is less granulation formation, owing both to the smaller amount of connective tissue and probably also to the great reduction in the number of lymphatics.

It is not necessary to go into the minute pathology of osseous necrosis, since that process is well known and described in the ordinary text books. However, a few details peculiar to these two phalanges should be mentioned. We so often see three processes in conjunction, so that it is difficult to say in what sequence they developed—namely, tenosynovitis, arthritis of the proximal interphalangeal joint, and necrosis of the middle phalanx. The cross-sections here presented demonstrate the close proximity of the tendon sheath to the bone and joint respectively. From the character of the tissue it would seem reasonable to assume that first the joint is involved, and the phalanx sequentially. In the few early cases that I have been able to observe discriminatingly, the joint seemed to have the more extensive involvement of the two. However, if that be true, why does the middle phalanx suffer so much more than the proximal one, a fact which I have had the opportunity to verify frequently. Is it that the point of invasion is the epiphysis of the middle phalanx? Does the fact that that phalanx only has an epiphysis articulating with the joint have any bearing on the subject? This question must be left for further study.

Again, destruction of the epiphysis is frequently noted, while the diaphysis is only partly involved. The anatomical relation of the sheath of the tendon to the joint capsule and the epiphysis may help to explain this, but it is possible that the vascu-

lar nature of the epiphyseal tissue may have considerable bearing, since the involvement may have its origin through the blood supply rather than by direct erosion. That isolated destruction of a diaphysis of a phalanx may occur at times cannot be questioned, and a study of the cross-sections demonstrates how easily this can occur if the tendon sheath be eroded.

What we most often find upon operation in these cases is a suppurative arthritis with extensive destruction of both the epiphysis and shaft of the middle phalanx, while the proximal surface of the joint, that is, the head of the proximal phalanx, may be only slightly or not at all eroded; at least, the articular surface is still clear and shining, with possibly one or two minute foci of destruction. Frequently it has shown a larger area of necrosis upon the shaft just at that point where the ligaments of the joint are attached. Indeed, at times, either upon the volar or dorsal surface, varying with the site of the original infection, I have scooped out at this site an area the size of a small pea, the articular surface apparently being free, while the epiphysis of the middle phalanx was almost entirely destroyed.

TREATMENT: In the chronic processes involving the finger proper, the diagnosis must be made first as to the structure involved. If the tendon sheath, it must be opened throughout its extent to give perfect drainage. Frequently it will be necessary to remove the tendon in these chronic cases. The possibility of localized involvement must always be borne in mind. In these cases a plastic exudate forms and prevents extension along a sheath; here only so much of the sheath as has been involved should be exposed. If the joint be invaded, some judgment is called for, since in the very earliest stages it may recover with partial restoration of function if the infection is a mild one, the joint surfaces not destroyed, and other structures which might prolong the suppuration are uninvolved. In a great majority of the cases, however, considerable destruction of the proximal phalanx will have taken place when the case comes to operation, and the question arises whether an amputation should be advised. Certain sociological factors come into consideration. If the patient be a laboring man, with a family dependent upon him, and at examination we find an extensive destruction of the joint with a tenosynovitis, amputation offers the quickest method of giving a serviceable hand. If, however, the patient desires to preserve the finger, in a majority of the cases one can be assured that the finger may be preserved, but that it will be somewhat shortened. Exceptionally the finger may be preserved with considerable function. In certain cases it becomes imperative to make the attempt, as for instance, in infections of the thumb. This member is so valuable that some sacrifice is justifiable in the attempt to preserve it. In Case XLVII, quoted below, the articular surfaces and a considerable portion of the shaft of the proximal phalanx were removed. There was no involvement of the tendon sheath. A fairly serviceable opposing member was thus saved to the hand.

The procedure when the proximal interphalangeal joint of the fingers is involved is as follows: Owing to the frequent destruction of the proximal end of the middle phalanx, this is chosen for attack, and the entire epiphysis and generally about half of the shaft is removed. If the articular surface of the proximal phalanx is intact, it is not disturbed, otherwise this may be removed also, my desire being in the first place to remove all necrotic bone, and secondly to separate the ends of the bone so far that only a fibrous union will take place, thus allowing some motion at this joint if the tendon is intact. Otherwise no motion can be promised. These fingers are dressed in slight flexion, so that if no function results they will not be in the way and will still be of some use, at least

for cosmetic purposes. In some cases I have tried, with moderate success, a variety of extension on a straight splint. The proximal end is fastened at the wrist, and at the distal end, adhesive straps are fastened to the end of the splint and the distal portion of the finger, so that the ends of the necrotic bones are separated. The details of this mechanical contrivance may be seen by examining Figures 125 and 126. This aids in preserving the functioning joint, although it is somewhat difficult to retain in position. Not much can be promised in the way of function in a majority of cases. That in exceptional cases these figures can be saved with a moderate amount of function even in some cases of combined suppurative arthritis and tenosynovitis, is demonstrated by Case XLVIII.

Treatment of Cases Involving the Hand Proper

The treatment in those cases in which the chronic process lies in the palm may be confusing. We should determine first the location of the pus. Does it lie in the synovial sheaths or in the fascial space? Are the bones or the wrist-joint involved? While theoretically difficult to determine, it is not so confusing as in the acute cases, since there are generally sinuses which can be followed down to the hidden pockets. X-ray photographs may show necrotic bone. Complete anesthesia is essential. No operation upon infected hands should be begun without it. The ramifications should be followed up carefully and with patience. I shall not speak in detail of the factors which lead us to diagnosticate the presence of pus in the various sites, since this has already been discussed exhaustively in the previous chapters.

Various sinuses leading from the tendons to the surface will be followed down to the respective synovial sheaths. The sinuses found at the most proximal point of the finger sheaths designate the corresponding sheath, and this should be cut down upon and followed distally along the finger until every part of the tendon bathed in pus is exposed. Where the little finger tendon is involved, the extension of the sheath in the palm should be borne in mind, and the opening continued proximally over this when the grooved director inserted into the infected sheath on the little finger passes up into this without obstruction. Here the sheath should be opened throughout its extent up to the annular ligament, the incision lying to the ulnar side of the tendons. The incision should be limited to the annular ligament until the decision has been made as to whether the infection has extended under this into the proximal end of the sheath above the annular ligament. If this is diagnosticated, the ligament should be cut and the incision be continued into the forearm as far as the upper end of the sheath. Instead of this last incision the upper end of the sheath may be drained by incisions upon the ulnar and radial side of the forearm as described in the chapter on Forearm Involvement. It is not wise to open the sheath above and below the ligament and leave this latter intact. Having thoroughly opened this, the question then arises: Has the radial bursa, *i.e.*, the sheath of the flexor longus pollicis, become involved? If so, this must be opened throughout its extent down to a thumb's breadth, distal to the annular ligament. The incision should stop here for fear of injuring the motor nerve to the thenar area.

If the tendons have become necrotic, removal is indicated; on the other hand, one is often surprised at the amount of vitality present in the tendons which have lost their synovial covering, therefore after opening a sheath considerable conservatism is justifiable when it comes to a question of preserving or removing a tendon. Some of the chronic sluggish processes in the fingers have seemed to be benefited by the Klapp suction cup.

If the fascial spaces are involved, they should be drained after the methods described in Chapter XVII.

In considering the treatment of those cases in which the suppurating ostia appear upon the dorsum, particularly between the knuckles, I have already pointed out that in a majority of cases these are really sinuses leading from the palm along the lumbrical canals, and the perfect drainage of the palm along the lumbrical canals, as already mentioned, will end in rapid recovery if uncomplicated by tendon or bone involvement.

If the bones of the hand or wrist are involved, they should be removed or the necrotic part curetted out. In treating the wrist-joint the general principles as to the removal of bones, which have been enunciated in Chapter XXVII, when dealing with carpal involvement, should be borne in mind. These should not, however, interfere with the paramount rule that all dead bone should be removed.

Atrophy and Contracture

The anatomical and clinical evidence already adduced shows the tendency for the infection to extend in juxtaposition to the bloodvessels and nerves. The former leads to contracture about the veins and lymphatics, and consequently a persisting distal edema. The most serious sequelæ, however, ensue because of the extension along the nerves—metacarpal, ulnar, and median—leading secondarily to trophic changes in the part. This secondary change follows probably upon contraction of the scar tissue about the nerves, since they are not likely to be destroyed by the process. At times we see the median nerve persisting, partly isolated from the surrounding tissue, although in conjunction with the tendons it may be destroyed at the wrist-joint from pressure necrosis by the non-distensible annular ligament.

This secondary change is particularly noticeable in the atrophy of the distal phalanges, and even of the whole hand. This sequela of nutritive and tropic disturbance yields slowly or not at all to the restorative processes of nature. Massage, passive motion, and constant use of the hand carried out systematically under the careful personal supervision of the surgeon may aid nature. Adhesions between the joints, when they are not the result of the destruction of the synovial coverings, may be treated by repeated non-violent passive movements under nitrous oxide anesthesia, or by the various appliances designed to produce passive motion, particularly those which act by exhausting the air, and hence, in addition to producing mobility, favor active congestion of the parts. In case of neglected tendon-sheath infection one expects to see the characteristic claw hand. Experimental investigations as to the restoration of destroyed tendons have been carried out, but as yet nothing definite can be recommended in cases of loss of finger tendons, although something may be hoped for in the future. Experience has taught me that scientifically made incisions based upon the anatomy I have pointed out will provide complete drainage of all the pockets and in the end will give a much more serviceable hand than we have had the fortune to secure in the past. It cannot be urged too strongly that we should make careful study as to the possible position of pus in the hand, to the end that we may make early and radical incisions and thus prevent these cases of atrophy and contracture.

Resume—Chronic Infections

Necrosis of the distal phalanx ordinarily ends in sloughing of the diaphysis alone. Joint function should be preserved. Incision should be made laterally instead of upon the volar surface (see Chapter 1).

The proximal interphalangeal joint is most commonly involved. The proximal phalanx escapes while the epiphysis and part of the diaphysis of the middle phalanx are destroyed.

Conservative operations may be done with some success.

Isolated involvement of the tendon sheaths may be present. Incision of the sheath should expose all involved parts.

Chronic palmar abscesses frequently point on the dorsum, passing along the lumbrical canals. Palmar abscesses may be opened along these canals.

Chronic dorsal abscesses may point at a distance from the focus, owing to the dorsal aponeurotic sheet.

The carpal joints are frequently invaded from the radial bursa; abscesses and sinuses appear upon the dorsum, as well as upon the flexor surface. Every effort should be made to preserve the integrity of the tissue between the first and second row of carpal bones. (See Chapter XXVII.)

Serious forearm abscesses lie dorsal to the flexor profundus digitorum, and may be opened either in front, in connection with an incision in the palm, or by lateral drainage.

Trophic changes result from the tendency of the pus to extend along the nerves and blood vessels.

Complete function can be promised patients suffering with palmar abscesses uncomplicated by tendon-sheath or osseous infection.

Neglected tendon-sheath infections give rise to the claw hand. Tendon-sheath infections operated upon early give good function, except that flexion of the two distal phalanges may be lost.



ALLEN BUCHNER KANAVEL

Allen Buchner Kanavel (1874–1938) of Chicago was one of the first surgeons to become specifically interested in infections of the hand. In his time such infections were a cause of constant and widespread loss of economic time among workingmen and a frequent cause of death from septicemia. His monograph on *Infections of the Hand* became a classic of American and later worldwide surgical literature. Beyond that, it was the instigator of a continuing interest in the surgical anatomy of the hand, continued by Bunnell who in his early years repeatedly dealt with the sequelae of such infections. Parts of the chapter on sequelae in Kanavel's *Infections of the Hand* are relevant to contemporary clinical surgery and warrant reproduction here. However, it is Kanavel's detailed study of the surgical anatomy of the hand to which the foundations of modern hand surgery owes its beginning.

CLASSIC 73

Injuries of the Leg

Fractures and Joint Injuries*

SIR REGINALD WATSON-JONES,

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INJURIES OF THE LEG

The difficulties that may arise in the treatment of fractures of the shafts of the leg bones include: 1) a high incidence of open and infected fractures because the tibia lies superficially just beneath the skin; 2) a tendency to redisplacement of the fragments when swelling subsides, particularly in oblique and spiral fractures; 3) serious disability if the alignment or rotational position of the fragments is imperfect because the knee and ankle joints normally move in the same parallel axis; 4) conspicuous disfigurement if apposition of the fragments is imperfect because the tibia lies subcutaneously; 5) frequency of slow union because there is often a poor blood supply of the distal fragment; 6) a still greater frequency of slow union if continuous traction is employed especially if a heavy weight is used and the fragments are distracted; 7) sometimes nonunion if slow union is not recognized and immobilization is not suitably prolonged; 8) a tendency to recurrent edema of the foot and leg after removal of plaster, and a tendency to rigid clawing of the toes if early exercise is not practiced.

FRACTURE OF SHAFTS OF THE LEG BONES WITHOUT DISPLACEMENT

Isolated fractures of the shaft of the fibula may be sustained from direct violence; they cause no functional incapacity. The shaft of this bone serves only for the attachment of muscles and ligaments, and it bears no weight, so that immobilization of fractures is unnecessary and the patient may be allowed to walk with the protection of a crêpe bandage. Some precaution is needed to be sure that the fracture is in fact an isolated injury because the shaft of the tibia may be fractured at a very different level. Fractures of the neck and upper shaft of the fibula are sometimes associated with ruptures of the medial and cruciate ligaments of the knee joint; fractures of the lower shaft of the fibula are almost invariably part of fracture-dislocations of the ankle joint; and even fractures of the upper third of the shaft of the fibula may be associated with dislocations of the ankle joint.

* Taken from *Fractures and Joint Injuries*, by R. Watsin-Jones. Vol. II, 4th ed., Baltimore, Williams and Wilkins Company, 1955.

Greenstick and subperiosteal crack fractures of the shaft of the tibia are often sustained by children, and a similar type of fracture may be seen in adults. There is no overriding or loss of apposition of the fragments, but only angulation which is easily corrected by gentle molding. The limb should be hung over the end of a table with the knee flexed to the right angle and the leg in the line of gravity. A lightly padded plaster is then applied from the toes to the tibial tubercle. When the plaster is hard it is extended to the groin with the knee in a position slightly short of full extension. If post-reduction radiographs show that alignment is not perfect the angulation should be corrected by wedging the plaster. After 8 or 10 weeks the degree of union may be tested clinically; if it is not sound, immobilization in a full-length above-knee plaster cast should be continued for a further period.

Fractures of The Shafts of The Leg Bones With Displacement

It is sometimes difficult to reduce and immobilize fractures of the shafts of the leg bones when there is overriding and complete loss of apposition of the fragments of a horizontal fracture, or sliding of the fragments of an oblique or spiral fracture. Simple manual reduction may be unsuccessful. Moreover, if the fracture line is oblique, and swelling is severe, redisplacement often occurs despite the application of a well-fitting plaster.

Treatment by Manipulative Reduction

It is usually possible to reduce a displaced fracture of the shaft of the tibia by simple manipulation, and to maintain the reduction by applying a plaster-cast while the limb hangs vertically over the end of a table; but the use of a tibia-traction apparatus is a great help. Figure 1 shows the one that I have devised and used. While the plaster is setting the rotational position of the fractured limb can be controlled by the operator's knees holding the patient's foot, the lateral displacement of the fragments being controlled by the operator's two hands.

Insertion of Traction Pin. A traction pin is driven through the tibia one inch above the ankle joint. Transfixion of the tibia is more satisfactory than transfixion of the calcaneum, especially if the pin is to be left in the bone. Low-grade serous infection of a calcaneal pin track often causes chronic osteomyelitis, persistent sinus formation and stiffness of the subtalar joint. A pin passed through soft tissues immediately above the calcaneum is not free from the danger of septic arthritis of the ankle joint, and it may cut right through the tendo calcaneus. The safest position, even in infected fractures of the leg bones, is the tibia one inch above the ankle joint.

Reduction of the Fracture. The technique is the same whether the injury is a closed fracture, an open fracture after excision of the wound or an infected fracture after drainage of the wound. A stirrup is fitted to the pin, the thigh is supported on the sorbo-covered rest, the limb is lengthened by the coarse adjustment of the apparatus, and if further traction is needed it is secured by easy rotary movements of the fine adjustment handle. Traction is increased until the limb is taut and the operator feels the crepitus of fragments in apposition. This indicates that overriding has been corrected. The traction is such that angulation is also corrected. If the axis of the pin is correct there can be no rotational displacement and the toe and patella point in the same direction. The fragments are then locked against each other by the firm lateral pressure of the operator's two hands. This is an essential step, without which accurate reduction cannot be expected. Strong lateral pressure is needed. Radiographs in at least two planes are then taken, and if the reduction is satisfactory a plaster is applied.

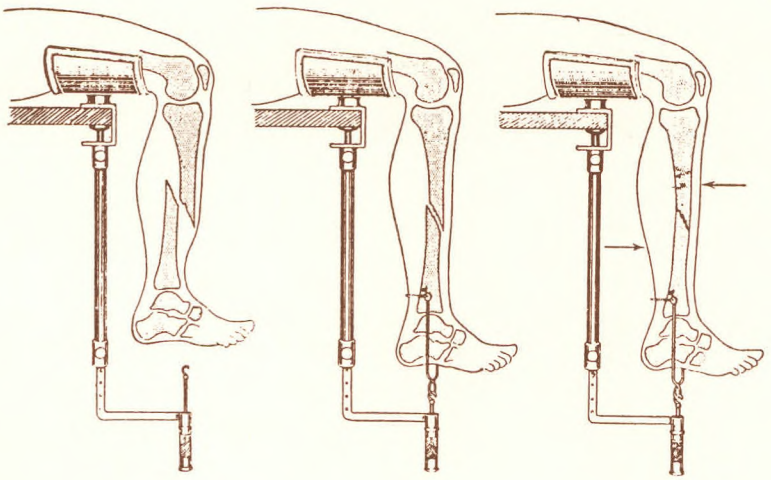

FIG. 1. Tibia-traction apparatus with a thigh-support, clamped to any table, to which is fixed an L-shaped traction bar with coarse and fine adjustment. Length and alignment is secured by the apparatus while the limb hangs in the line of gravity, and apposition is maintained by the pressure of the operator's hands. (Watson-Jones, "J. Bone Joint Surg.," 1932, 14, 591.)

Application of Plaster. A plaster slab is guided through the stirrup, and applied over a thin layer of wool from the toes to the upper calf. Special care should be taken by using wool-padding or felt to prevent undue pressure over the malleoli, the back of the heel, and the neck of the fibula. If several hours have already elapsed since the injury was sustained no other padding is needed, but if the limb has not yet begun to swell it is advisable to use a double strip of thin wool bandage over the foot and leg before the encircling turns of plaster bandage are applied. The wool helps to accommodate swelling and if, after a few hours, impairment of circulation of the toes indicates that the plaster is too tight it can easily be cut longitudinally over the front of the foot and leg and through the wool bandage without injury to the skin. The plaster is then completed, and while it is setting strong lateral pressure is again maintained with the palms of the operator's hands. As soon as the plaster is hard, traction is released and the knee is straightened to a position of 30° short of full extension. The plaster is then extended to the upper thigh, and molded round the knee in order to prevent rotational displacement.

Continuous Traction after Reduction. Fractures of the tibia should be reduced accurately and be immobilized in a simple plaster cast. In former years it was customary to maintain continuous traction from a skeletal pin in the lower shaft of the tibia, or perhaps in the calcaneum, especially when it was thought that the fracture was of an unstable type which might redisplace. But we now know that such skeletal traction always delays union, and if there is actual distraction of the fragments the rate of union is seriously delayed. Thus the technique of continuous traction has been almost entirely abandoned in the treatment of these fractures. If the fracture is of such instability that, after manipulation and immobilization in plaster, there is danger of serious redisplacement, it is better to perform an open operative reduction and fix the fragments with a plate and four screws, a bone graft and screws, or perhaps an intramedullary nail.

Replaster After Two or Three Weeks. After the swelling has subsided a new plaster is nearly always needed. This should be almost completely unpadded—perhaps with one or two layers of stockinet beneath it—extending to the groin with the knee slightly flexed.

Wedging the Plaster. If the alignment is not accurate it should be corrected after the plaster has set by wedging. The technique of

such wedging of the plaster is described on page 171. It is of special value in fractures of the tibia because the slightest trace of medial or lateral angulation causes serious incapacity, and whereas a surgeon may hesitate to remove a plaster and apply a new one with the object of correcting a few degrees of angulation, fearing that some other displacement may arise, he need not hesitate to use the wedging method with its accurate control and safety.

Preventing Rigid Clawing of the Toes. Rigid transverse flat foot with rigid clawing of the toes often complicates leg fractures and may cause persistent disability long after the fracture has united. In applying plaster to the forefoot there is a tendency to pull up the first and fifth metatarsal heads by the turns of bandage, and to hyperextend the metatarsophalangeal joints of the toes so that the transverse arch is convex towards the sole. Even before the fracture was sustained, many patients have had mobile transverse flat foot with clawing of the toes—symptomless because it was mobile and correctable. After long immobilization in the faulty position, with neglect of active exercise, mobile clawing becomes rigid clawing; the toes cannot be flexed to the gound. With every step body-weight is carried through the metatarsal heads and there is crippling pain and a sensation as of walking on small stones. Two precautions are needed to prevent this complication: 1) the plaster over the forefoot should be so molded that the metatarsal heads lie in their normal slightly arched position so that the metatarsophalangeal joints can be flexed; 2) the toes must be exercised actively and flexed fully at the metatarsophalangeal joints many times a day.

Duration of Immobilization. After 10 or 12 weeks, if radiographic examination shows continuity of bone trabeculae between the fragments, the plaster is removed to allow clinical tests of union. Union is sound when tenderness has disappeared, when no pain is elicited by straining the fracture, and when there is no longer elasticity or springing of the fragments. If union is not firm a complete plaster should be reapplied fram the toes to the upper thigh with the knee slightly flexed. The knee should not be straight because the tibia and femur can then rotate together, and a plaster to the upper thigh does not prevent rotation strain of the fracture.

Weight-bearing in Plaster. Weight-bearing should not be permitted until the fracture is firm to clinical tests. When union is clinically firm, but there is not yet sufficient radiographic evidence of consolidation for the plaster to be discarded, a walking-plaster may be applied. It extends from the toes to the upper thigh with the knee slightly flexed. A sorbo rubber pad may be fixed to the heel with strapping and a boot is fitted so that the patient dresses normally and walks several

TABLE 1. Effect of Traction and Distraction on the Rate of Union of 319 Closed Fractures of the Tibia

Soundly united in	*10 to 12 wks.*	*12 to 16 wks.*	*16 to 24 wks.*	*24 to 48 wks.*
		Per Cent		
Continuous immobilization without traction	45	30	20	5
Continuous immobilization with traction	22	21	52	63 5
Excessive pull and distraction	None	6	25	

TABLE 2. Effect of Distraction and Infection on the Rate of Union of 319 Closed Fractures of the Tibia

	United in	*Less than 16 wks.*	*16 to 24 wks.*	*24 to 48 wks.*
			Per Cent	
Closed fractures without traction		75	20	5
Closed fractures with distraction		6	25	63
Open fractures with infection		6	29	56

miles a day. The full-length plaster is not discarded until there is clinical and radiographic evidence of firm union of the fracture.

Danger of Short Plaster and Walking-Irons. A short below-knee plaster is not safe at any time. Rotational movement of the upper fragment is not controlled by a short plaster, and the strain delays consolidation or even causes resorption of the newly formed callus, thus giving rise to non-union. Short irons and caliper splints are also unsafe. If the callus is elastic an iron will not prevent secondary angulation; indeed bandaging the limb to an outside iron actually produces angulation. A fracture of the tibia is either united so firmly that an iron is unnecessary, or it is not soundly united and much greater protection is required.

Disadvantage of Continuous Traction in Fractures of the Tibia. Traction on the tibia causes delay in union of fractures of the shaft. The average delay in a reported series of 804 lower limb shaft fractures was in the region of four weeks.[6] Even when excessive pull and distraction were avoided only 22 per cent of tibial fractures treated with traction united soundly in 12 weeks or less, whereas 45 per cent of fractures treated without traction were united at that time. If traction is unduly heavy, and the fragments are allowed to distract, the delay is much more serious. Even if separation of the fragments amounts only to a quarter of an inch, and even if it is corrected within a week or two, few distracted fractures of the tibia unite in less than 4 months and most unite only after 6 or 12 months of continuous immobilization.

It is therefore clear that although light skeletal traction may sometimes be needed during the first week or two in serious open and infected fractures of the shaft of the tibia, it should never be used in simple closed fractures. If the fracture is so unstable that simple manipulation reduction with immobilization in plaster does not suffice to prevent redisplacement, it is better to use operative reduction and internal fixation.

Treatment By Operative Reduction and Internal Fixation

The surgeon who proposes to avoid the delays of continuous traction by operating on a fracture of the shaft of the tibia must remember that infection of the wound causes even more serious delay. Consider Table 2 which compares the influence of distraction and infection on the rate of union of fractures of the shaft of the tibia. It is evident that distraction and infection are equally harmful in delaying union; but whereas the penalty of distraction is limited to slow union, the penalty of infection may also include chronic osteomyelitis with persistent discharge from sinuses and established non-union. There is no justification for the treatment of fractures of the shaft of the tibia by operative reduction and internal fixation except in the hands of surgeons who can rely on first-intention healing of the wound with complete certainty. It is not enough that most wounds heal with-

out infection: every wound must heal without infection. Let it be perfectly clear that despite all recent advances there are still many infections that cannot be controlled by chemotherapy. No surgeon is at liberty to undertake operative reduction and internal fixation of fractures of the shaft of the tibia unless there is a near-certainty that the wound will not be infected. There can be few greater disasters than to convert a closed fracture into an open infected fracture with its sequestration and persistent non-union. If you will look back to pages 214-217 it will at once be evident how lamentable may be the consequence of infection, and how even a minor degree of persistent infection causes non-union. Let no surgeon even think of using operative reduction with metallic internal fixation of fractures of the shaft of the tibia until he has a certain experience of non-touch technique with avoidance of operative infection, and takes care not to operate through the site of lymphatic drainage of recently healed wounds or pressure sores.

Screw Fixation of Oblique and Spiral Fractures. In oblique and spiral fractures internal fixation is best secured by one, or perhaps two, screws transfixing the fragments. Through a 4 or 5 inch incision the fracture is reduced and the bone ends are held in a suitable bone clamp. The axis in which the screw will lie must be selected carefully so that an equal thickness of bone will be engaged in each fragment. To avoid subcutaneous projection the screw-heads are countersunk into the bone.[5] The length of drill-hole must be measured accurately. Non-ionizable metal screws of the correct length are driven home, the stability of reduction is tested, the periosteum is closed, the skin sutured and a padded plaster applied. The plaster is changed to an unpadded cast after two or three weeks. Weight-bearing in plaster may be permitted after about 6 weeks and the plaster can usually be discarded in 10 or 12 weeks.

Plating or Bone-grafting Transverse Fractures. In transverse fractures it may be possible to use a single screw, but the technique is more hazardous and selection of the correct axis for the screw is more difficult than in spiral fractures. For this reason, transverse as well as comminuted fractures should usually be treated by means of a bone or metal plate and four screws. A plate of non-ionizable metal causes no reaction, and if it is fixed on the lateral surface of the bone, deep to the anterior tibial muscles, no thickening or tenderness remains over the subcutaneous surface of the shin. A bone plate cut from the opposite or the same tibia, and fixed to the fractured bone as an onlay graft, is still better. Even in recent fractures the blood supply may be so impaired that union is slow. The decision to operate and fix the fragments having been made, it is therefore advisable to use a device which will aid repair and accelerate union. After the fracture has been reduced, and the accuracy of alignment and rotational position have been confirmed, a full-thickness cortical and medullary graft, half to three-quarters of an inch wide, is fixed to the freshened lateral surface by four stainless-steel screws. Several examples were illustrated in the first volume.

Fixation of Tibial Fractures by an Intramedullary Nail. Intramedullary nail fixation which is so successful in fractures of the shaft of the femur, fractures of the upper shaft of the ulna, and fractures of the shaft of the humerus, where insertion of a straight nail is so easy, has also been advocated in fractures of the shaft of the tibia where the insertion of a curved nail through the upper tibial tuberosity down the shaft of the bone is far from easy. We are bound to say that despite all the advertising of manufacturers of nails who in their wanton publicity have tried to create medical journals of their own, it is not yet clear that there is real merit in the attempt to secure fixation of fractures of the shaft of the tibia by intramedullary nailing.

Fractures of the Shaft of the Tibia With Slow Union and Non-Union

Even when the dangers of traction and distraction have been avoided the blood supply of the tibia is such that fractures in the lower half of the shaft of the bone may unite very slowly. If this is recognized, and immobilization is suitably prolonged, sound union by bone with perfect functional recovery can still be relied upon.[3, 4] The temptation to change the method of treatment must be resisted; requests to shorten the plaster must be refused, and complete immobilization in a full-length plaster should be continued for 3, 6, 9 or even 12 months.

If union is still delayed it may be wise to do a bone-grafting operation. It will be recognized from earlier chapters that the essentials of such an operation are: 1) to refreshen the sclerosed fracture-surfaces; 2) to implant cancellous fragments of bone which have vital osteogenetic properties; and 3) to ensure that the fragments are immobilized and protected from shearing and rotational strains. Sometimes there is such complete lack of fixation of the fragments that the internal fixation of a whole-thickness onlay or inlay graft is needed. But often there is already a slender bridge of united bone and all that is needed is to refreshen the surfaces and, without tearing them apart, to excavate a hollow at the level of fracture and pack into it fragments of cancellous bone cut from the ilium. The apposition and alignment of the fragments was satisfactory; without disturbing the position, or the bridge of union which was developing, the antero-medial aspect of the fracture site was excavated and packed tightly with iliac bone chips. The fracture united within three months.

Double Tibio-fibular Synostosis. When a large part of the shaft of the tibia has been destroyed by virulent infection and dense avascular scar tissue lies between the fragments, it may be better to relieve the disability by double tibio-fibular synostoses. The upper shaft of the fibula is grafted to the upper tibial fragment and the lower shaft of the fibula is similarly fixed to the lower tibial fragment.[1, 2] The fibula becomes a weight-bearing bone and undergoes a remarkable degree of hypertrophy.

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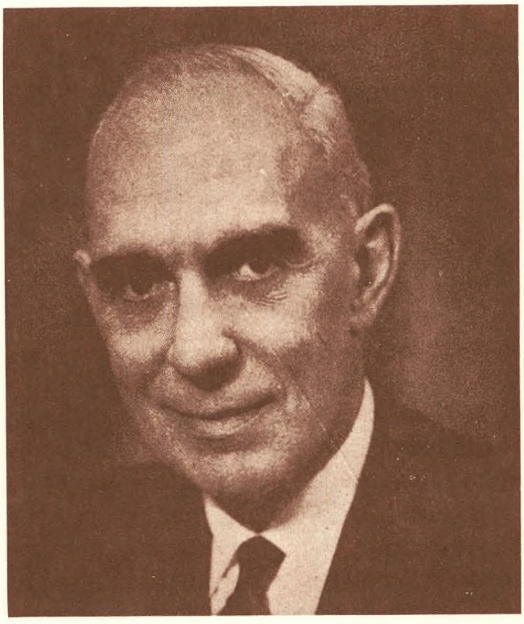

SIR REGINALD WATSON-JONES

The career of Reginald Watson-Jones (1902-1972) was associated chiefly with Liverpool where Hugh Owen Thomas and Robert Jones were among his ancestral kinsmen. During and after World War II he was among the leading teachers and activists in the area of fracture therapy. His book *FRACTURES AND JOINT INJURIES* remained a standard reference for several decades. He was a powerful individual towering high above his contemporaries. At a dinner tended to him by some of his peers in New York City, Dr. Robert Kennedy introduced him as "Sir Reginald Watson-Jones, always positive, never in doubt, and by the grace of God usually right."

CLASSIC 74

Kritisches und Experimentelles zur Genese der Arthritis deformans, insbesondere über die Bedeutungder aseptischen Knochen und Knorpelnechrose

(Clinical and Experimental Observations About the Etiology of Arthritis Deformans and Especially the Significance of the Aseptic Bone and Cartilage Necrosis)

GEORG AXHAUSEN* (1877–1960)

The clinically and anatomically exceptionally impressive picture of chronic deforming arthritis has been of great interest for a long time to various investigators. This interest has not diminished during careful clinical investigations, and radiological and pathological findings have led to a clearer delineation of joint diseases of different causes. I will, therefore, abstain from detailed enumeration of the characteristic radiological and histological findings in bone and cartilage, assuming those are well-known facts.

Like a red thread the question of the cause runs through all radiological and histological publications. Many experiments have been made to explain the histological changes and the basic pathological and anatomical laws. I, therefore, have no intention to repeat the different theories.

Almost without exception the investigators have related findings to general pathological and anatomical concepts evidently shying away from any new attempt to look for the real basis for the pathological causes. Only recently decisive forward steps have been made as illustrated by the publications of Wollenberg leading him finally to the presentation of a thoroughly detailed theory summarized in his publication about the cause of arthritis deformans.

In most cases this is a secondary phenomenon superimposed on a primary joint involvement of different etiology with arthritis deformans following trauma, tuberculosis or syphilitic joint involvement. The greater the manifestation of arthritis deformans the more the primary pathology recedes. There are also a number of cases where a primary condition cannot be proven, representing the well-known so-called "spontaneous or genuine arthritis deformans." How can we explain the occurrence of characteristic changes on so many various occasions? How is it possible that various causes are followed by the same histological picture while there are other cases where no definite cause can be found?

In my research about osteoblastic calcinosis, I stressed the close correlation between the hemorrhages and the focal necrotic

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areas. With Wollenberg putting great importance on the anticipated congestive hyperemia in the osseous system and citing statements of von Recklinghausen who considered the massive bone formation os osteoblastic calcinosis a result of true congestive hyperemia, I have to emphasize that von Recklinghausen's findings must be contraindicated as I have paid special attention to the conditions under which new bone formation and bone transformation occur in osteoblastic carcinoma and find the observations by von Recklinghausen not valid. A great number of histological slides contradict the hypothesis of a congestive hyperemia causing massive new bone formation. (Virchow, Archives, Vol. 195, page 399M.) As to more details I am referring to the original publication. . . .

The first reports of von Recklinghausen's are closely related to his emphasis on the importance of the vascular system in bone pathology, especially in reference to the genesis of osteomalacia, and osteitis deformans. The basis of von Recklinghausen's concepts is only an assumption that the osteoporotic pathological bone is caused by halisteresis equal to deprivation or loss of calcium.

I will, however, not go into details concerning the relation between such an alleged congestive hyperemia and arthritis deformans but want to point out the peculiar ideas of Wollenberg concerning the effects of bone changes by lack of, or by excessive, bone metabolism. First, the effect on the bone. It is assumed that in bone with poor circulation, due to metaplasia a regressive development occurs to tissue with less demand for blood supply, as, for example, cartilage or connective tissue. The same genesis is attributed to the cartilaginous islands within the bone described and diagnosed enchondromas as well as fibrous foci by Ziegler. The always present-proliferative cartilaginous reaction which cannot be explained by involution are analyzed by Wollenberg stating that if a certain amount of bone has insufficient nutrition, involution occurs while excessive nutrition causes cartilaginous proliferation. Similarly, cartilaginous proliferation causes hyperemia within the undernourished segment and is termed "collateral hyperemia." This hyperemia is supposed to bring a segment of the undernourished tissue back to normal circulation to arrest the already manifest regressive process and to stimulate metablastic bone for pathologic cell proliferation. . . . It is a misconception to consider the bone capable of great metablastic changes and to assume its natural transformation into cartilaginous cells. It is actually just the opposite which occurs. We well know that a transformation of connective tissue and cartilage tissue into bone can take place directly by absorption of organic interstitial tissue substance and disposition of calcification by metaplasia. I described typical changes of that kind in my publication with illustrations of osteoblastic carcinoma. Never in the whole concept of bone pathology has there been any objective evidence to prove a different mode of metaplasia. Such a metaplasia, along with other findings, leads to the assumption of absorption of calcium ions with calcium deprivation equivalent to a type of halisteresis. Lacking the formation of calcium deposits in osseous bony tissue, the body is not able to do it. If there is still any doubt that this also applies to arthritis deformans, one has to look to the illustrations in Ziegler's work and compare them with the text to note this typical phenomenon, when newly formed interstitial fibers coalesce into thick bundles forming well-textured osseous tissue. This is followed by the formation of the well-known "interglobular spaces" and large "osteoblastic cavities." It is significant to read the comment by Ziegler in which he states "where there appears such a fibrous metaplasia of the bone, the bone marrow also shows fibrous qualities certainly because ultimately the bone originates

from the fibrous formation of the marrow itself." As to the illustration of Ziegler showing the transformation of bone to cartilage, it is typical for any callus specimen showing cartilaginous tissue amidst young osteoid tissue. The possibility that this cartilage originated by metaplasia from spongiosa trabeculae is proven by the excessive cell formation found everywhere in the cartilage many times surpassing the number of cells in the lamellar bone. Thus cartilage originating from lacunar bone and increasing cells of the evolving bone would have to be necessary, an observation which we could not confirm.

At this time, in contrast, I want to direct your attention with a few words to the seemingly unimportant detailed findings which, however, deserve consideration in the experiments regarding bone pathology. There is very little bone formed for the amount of bone formation quantitatively, and it is in no proportion to the enormous amount produced by the covering free bone transplantation. It is also incorrect to postulate that the presence of bone tissue acts as a nutritional stimulus for more production of bone. I cannot see it in the slides with the periosteal bone transplantation and in those especially showing transplanted periosteum around the calcified bone enhancing bone-forming material. It is the organic connection of the living periosteum and the nutritionally-dependent decayed bone which causes the extensive new bone formation. In other words, new bone formation is directly caused by the effect of aseptic bone necrosis with surrounding ossific-forming tissue. As a biological law, the body tries to replace dead tissue (except in infection) and it is the function of the bone and periosteum with its proliferative capability to act as replacement and one cannot deny that by proliferation of bone, its bone-forming proliferation ability and potentiality. This is the "aseptic bone necrosis." The main factor is the stimulus coming from the bone-forming organs and this does not stop until all bone detritus is absorbed which may, in some cases, require many years. Those facts explain a number of other observations which were difficult or not at all explicable.

In the field of bone pathology the importance of the frequency and the significance of aseptic bone necrosis has been unjustly neglected. Not only in surgical but also in pathological textbooks the bony growth has been identified with infectious and sequestrating necrosis. In Kaufman's textbook the following statement is made: "Necrosis of the bone is local decay of one bone segment. The fragment called sequestrum is the result of local circulatory impairment and is separated by reactive inflammation plus tissue reaction becoming separated from the living, healthy tissue." This comparison is by no means justified. It has been proven that transplanted decayed bone tissue in the case of virulent circumscribed infections was able to transform a partially sequestrated area to the main surviving portion in spite of necrosis, being enhanced by covering healthy periosteum. There is no better demonstration ad oculos than to see the difference between aseptic and infectious bone necrosis as can be demonstrated in animals by objective histological observation; even in infectious necrosis the necrotic segment is not identical with the later sequestration. I was able to explain this theoretically and later clinically (chronic osteomyelitis) with histological proof that the remaining necrotic bone stays in the tissue complex and gradually is substituted by the adjacent tissue. The demarcation, of course, is by no means between the dead and the living bone but within the necrotic segment. It can be surmised that in such necrotic areas, in spite of infection, substitution and preservation of the whole necrotic area can occur without the development of demarcation and sequestration. This concept is based on the surgical experience of Oltheimer who coined the term "exfolatio insensibilis." The difference between aseptic and infec-

tious bone necrosis was shown in the well-known experiments by Buch in acute osteomyelitis but Buch himself was not aware of this. Buch, by electric cautery, destroyed the bone and marrow of the long bones to differentiate four different types and demonstrated that there was no sequestration in some while others showed various degrees of sequestration. He found the texture of the bone, even in the first degree, was markedly changed and he called it "ostitis without necrosis." Massive periosteal callus occurred while solid bone was changed into porous bone. . . .

Not even now does one have the right idea about simple or aseptic bone necrosis. In every fracture, the ends of the fracture fragments become necrotic. Here too, the necrotic bone is being substituted by periosteum causing close fusion of the fragments, showing the same changes as observed in bone transplantation. Examined recently in a case of luxatio ossi lunati plus fratura ossis navicularis, one segment of the navicular bone was found to have almost totally necrotic bone tissue and in the fracture of that bone it was regenerated. The cartilage was found to be necrotic only adjacent to the fracture site and in the first stage of bone proliferation in these areas. There is no doubt that necrosis is the most important causative factor for callus formation. This fact—the significance of aseptic necrosis for the healing of fractures—has been completely ignored even in recent publications about callus formation (Fracture healing). It is considered most likely that the occasionally noted effect of callus-stimulating medications (for example the injection of iodine solution) causes necrosis within the fracture area leading to bone replacement. . . .

If necrosis of the outer bone layers occurs, aseptic necrosis will develop. The aseptic necrosis changes to substitution of decayed bone by living tissue coming up from the deeper located haversian channels. This regenerative substitution often becomes over-expanded, hypertrophied, causing an elevation and thickening of the bone surface where the periosteum has been removed; however, the outer surface is smooth, covered by newly formed periosteal-like membranes which can be easily removed while, on the margin, we note overgrowth of adjacent periosteum.

Considering the effect of aseptic necrosis we have to localize the effect on the subchondral layers of the joint surface in arthritis deformans. Such necrosis has been described by Walcoff, 17 cases have been confirmed by Reinberg. They did not consider those findings as very important, however. According to my findings, these are very important new bone forming reactions which can enhance spongiosa sclerosis. In addition, the genesis of marginal osteophytes is due to a periosteal reaction with necrosis of the underlying bone fragments.

An even more convincing finding than focal bone necrosis is the cartilage necrosis in arthritis deformans representing early regressive changes and early manifestations. If aseptic necrosis, indeed, is the main stimulus for the ossification centers, how does aseptic necrosis act towards the still-living cartilaginous cells? I was able to analyze this phenomenon when transplanting cartilaginous-osseous fragments in my experiments with peripatellar cerclage. I will report this in detail in a later publication.

I want to stress one point again, that is the fact already mentioned that arthritis deformans appears as a secondary reaction in many different joint diseases. It is well-known that focal bone and cartilaginous necrosis can appear in joint fractures and joint infections *i.e.* tuberculosis, lues, and so-called spontaneous arthritis deformans can be talked about with vascular etiology, with tissue decay, without difficulty as due to vascular changes similar to arteriosclerosis or lues. I have however no intention to present a new theory about the etiology of arthritis deformans.



GEORG AXHAUSEN

Georg Axhausen (1877–1960) graduated from the Military Medical Academy of Berlin, remained in the German army for some years and started his academic work in Kiel 1904–1906. After several more years with the army he returned to Berlin as instructor in the surgical division of the Zahn-ärztlichen Institute. He was one of the pioneers in studies of bone graft and necrosis. Necrotic bone was frequent in prechemotherapy days so that studies in non-infections, that is aseptic bone necrosis were innovative. He was the first to use the word aseptic necrosis, or at least the first to appear in the mainstream of medical publications. Phemister's work on the same subject followed and recognized Axhausen's contribution, and Phemister's famous phrase "creeping replacement" is well described in this Classic. In the 1950's the term avascular necrosis came to replace aseptic necrosis. The original paper covered 20 pages but contained much detailed criticism of contemporary work and theories irrelevant to today's readership and have been left out of this edited reprint.

CLASSIC 75

Traite dés membranes en général et de diverses membranes en particulier

(A Treatise of the Membranes in General and on Different Membranes in Particular)

MARIE FRANCOIS XAVIER BICHAT (1771–1802)

No part of the physiology of the bones abounds more in hypotheses and less in discoveries, than the history of the synovial system.

Many discussions and few facts; a long series of assumed principles; a brief assemblage of proofs: this is nearly the analysis of all the hitherto known works on this subject. The notions already received throw but little light on those yet to be acquired.

It is, in some sort, necessary to inspect things in a new point of view: this I am about to attempt in the following treatise, whose object is to make known: (1) the mode by which the synovia is transmitted to the articular surfaces, (2) the general distribution of the synovial membrane, an essential agent in this transmission, (3) the particular dispositions of this membrane, in the several articulations.

ARTICLE I

Of the mechanism, by which the synovia is transmitted to the articulations.

Every fluid, different from the blood, cannot be separated from it, to be afterward transmitted to any organ, except by one of the three following modes: (1) by secretion, a function characterized by the existence of a gland between the blood vessels which bring the blood to it, and the excretory vessels which carry off the secreted fluids, (2) by exhalation, distinguished from the first function by the absence of this intermediate gland, and by the immediate continuity of the blood vessel and the exhaling duct,* (3) by transudation, a phenomenon purely physical, almost always cadaverous, rarely observed during life; the simple transmission of a fluid through the pores of an organ, toward which it is mechanically determined.

Let us examine which of these three modes is that chosen by nature, for depositing the synovia on the articular surfaces.

1. Is the synovia transmitted by secretion to the articular surfaces?

We are indebted to Clopton Havers for the system, which places in the glands the sources of the synovia. Casserius, Dulaurens,

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From *Treatise on the Synovial Membrane,* edited by Edgar M. Bick, M.D.

* This distinction between secretion and exhalation extends only to characters, perceptible to the eye. It is however probable, that there exists in the glands an immediate communication between the blood vessel and excreting duct; so that the difference of the two functions seems to relate merely to the more numerous folds, and the more complicated intermixture of the two vessels, for secretion; to their shorter passage and more direct course, for exhalation.

Séverin, and Fab.ab Aquapendente, had obscurely designated these organs in the articulations. Cowper also thought he had perceived them, but Havers made them the particular object of his researches, described them in the different joints, and distinguished them into two classes, one principal, the other accessory: he assigned to them characters so obvious, that according to him, they cannot be mistaken.

Reddish, spongy points or eminences *(pelotons)* formed of membranes reflected on themselves, situated sometimes without and sometimes within the joints, always so disposed as to be secured against a too strong compression, pouring through ducts in form of fringes the fluid they secrete; such are the characters traced by Havers, and which all anatomists admire after him, and whose accuracy Winslow, Haller, Monro, Albinus, and Bertin have particularly consecrated in their works.

Some anatomists however of the present century have thrown doubts over these glandular bodies. Lieutaud confounds them with the fatty cellular tissue: Desault did not at all distinguish them from it. Every thing confirmed me in the same opinion, which a great many considerations seem indubitably to establish.

These considerations I proceed to lay open in succession.

These reddish balls or points are met with only in certain articulations. There are several in which their existence rests merely on supposition. Most of the mucous capsules of the tendons certainly present not one of them, though Havers, Albinus, Junke, and M. Fourcroy admit them in all, founded no doubt on analogy, and not on inspection; yet the synovia is separated equally in these two cases, and lubricates the surfaces of the joints and tendinous sheaths. This secretion is therefore independent of glandular action.

If we examine the synovial glands more clearly marked, like that of the cotyloid cavity, we there discover no trace of that parenchyma unknown in its nature, but remarkable for its structure, which in general composes the glands, and which, distinguishing them from every other part, forms their true organic character.

No excretory duct can be demonstrated in these organs. Those admitted by Havers, in form of a fringe, are imaginary. Bertin himself has acknowledged this fact, though he attributed to these bodies a glandular structure. The transudation of fluids injected through arteries near the articulation, no more proves the existence of these ducts, than it does in the cavity of the serous membranes, where it equally takes place, and where however it is well proved, that no gland pours forth the albuminous humour which habitually lubricates this cavity.

Inflation completely resolves these adipose eminences, into cellular tissue. Maceration produces the same effect. When a boiling, for sometime continued and gradually raised, has extracted all the fat from them, there remains only a mass of cells, collapsed on one another, resembling those of the ordinary cellular tissue.

The glandular character is manifested in some pathological cases, by a particular tumefaction and induration, of which the organs, other than the glands, such as the muscles, tendons, etc., never offer an example. The liver, the kidneys, the salivary organs, all the sensible glands, are remarkable for this.

Such even is the validity of this character, that it serves to point out glands whose tenuity, in the sound state, conceals them from our view.

For example, the existence of the cryptæ of the stomach, of the urethra, and several other mucous membranes, was first founded on the analogy of the other membranes of this class, but principally on the accidental development which these cryptæ, or small glands, acquire in certain diseases.

On the contrary, the pretended synovial glands never exhibit to the observer a similar development. In the diseases of the joints, a common obstruction seems always to identify them with the neighboring cellular tissue.

They have not, like the other glands, diseases separate from those of this tissue, doubtless because they have not a proper vitality; because, being only productions of the contiguous cellular tissue, they partake of its nature, its properties, and ought of consequence to participate in all the conditions of the cellular tissue, while this in its turn must immediately receive the influence of their diseases.

These considerations form, I think, an amount of data sufficient to solve the problem proposed above, in establishing the following general proposition: *The synovia is not transmitted by secretin, to the articular surfaces.*

Let us pass to the second mode of transmission pointed out by authors.

2. Is the synovia transmitted by transudation to the articular surfaces?

It was an opinion anciently received, that the marrow of the long bones oozed out through the pores of their extremities and through those of the cartilages which terminate them in order to lubricate the articular surfaces. Havers revived his idea, forgotten at the time he wrote, united this source of the synovia to that he had placed in the glands, and thus formed of this fluid a mixture, compounded of two fluids differently transmitted to the articulation. Most of those who followed him, adopted his opinion on this subject. Those even, like Desault, who rejected the existence of the articular glands, and by that also the secretion of the synovia, cannot admit its transudation, by reason of the following observations: (1) a long bone, divested of its soft parts, and exposed to the air, permits a greasy exudation to escape through the pores of its cartilages, which continues till all the medullary substance is completely exhausted. The mechanical compression of the cartilaginous extremity of a long bone, instantly produces the same phenomenon. These facts, evident in the dead bone, are they also real in the living? Various considerations which I am about to expose, lead me to believe the contrary.

The vital energy, whose effect is to impress on all the organs it animates, a degree of tone sufficient to resist the access of the fluids, leaves, in its absence, the fibers of the same organs in a state of laxity, which everywhere renders them permeable.

Thus transudation is no longer considered but as a phenomenon purely cadaveric, which being here transformed into a vital phenomenon would present a manifest exception to the laws of nature, particularly characterized by simplicity and uniformity.

The oily exudation takes place in the above experiment, not only through the pores of the cartilages, but also through all the surface of the bone; so that in reasoning from what is here observed in the dead body, it is evident, that during life, the entire bone should be, as it were, immersed in an atmosphere of synovia; a consequence, which, disproved by the most simple inspection, demonstrates the fallacy of the principle from which it results.

The articulations of the cartilages of the larynx are lubricated, like those of the bones, by the synovial fluid; yet here any transudation of marrow is impossible, since it does not exist in the substance of the cartilages.

The marrow is almost always untouched in the diseases which, affecting the articulations, alter the humor that lubricates them. Reciprocally the synovia suffers no change in diseases of the inside of the bones, whose special influence is exerted on the medullary organ. An experiment confirmed me in this fact, which the various diseases of the bones also demonstrate. I opened on the sides, two

long bones of one of the hind legs of a dog, so as to introduce into it a red hot probe, which, having been several times repeated, completely destroyed the two medullary systems.

Necrosis soon followed this experiment previously made by Troja, but which presented to me a result, which escaped his notice; that was, the soundness of the articulation which united the two gangrened bones. This phenomenon, confirmed by several experiments, dissipates every doubt as to the non-transudation of the marrow to form synovia. Should not this fluid in fact have ceased to moisten the joint after the destruction of the medullary organ, if this transudation did really take place during life?

Desault, in order to explain the manner in which the synovia is separated from the blood, added to this pretended transudation of the marrow an oozing, furnished by all the parts contained in the joint, such as the capsular and interarticular ligaments, the internal fat, the cartilages, etc. One comparison will be sufficient to estimate this hypothesis.

What would be said of a system in which, in order to explain the production of the serous fluid of the abdomen, one should place its source in the liver, the spleen, the intestines, and in general in all the organs of this cavity?

It would doubtless be answered, that a fluid, the same in its nature, could not be supplied by parts so different in structure, and that it is much easier to find its single source in a single membrane which invests all the gastric viscera. The application is exact and the analogy complete, as to the articular cavity.

From what has been above stated, I think we may conclude, without fear of error, that, *The synovia is not transmitted by transudation to the articular surfaces.*

I pass to the last mode suggested for the separation of the synovia.

3. Is the synovia transmitted by exhalation to the articular surfaces?

The solution of the two preceding problems seems naturally to bring us to the inquiry here proposed. In fact, there are two data, on the certainty of which, I think, we may rely: (1) secretion, exhalation, and transudation are the only means by which a fluid, differing from the blood, can be transmitted to an organ; (2) secretion and transudation are foreign to the transmission of the synovia. Now, from these two certain data, may we not infer this consequence also certain: exhalation is the mode by which the synovia is conveyed to the articulations? But let us add to these negative proofs considerations, which establish this proposition positively.

The most striking relations or affinities are observed between the synovia and the fluid which lubricates the walls of the serous membranes. (1) The relation of composition. These two fluids are essentially albuminous; albumen predominates in both, although a little different in the two. Havers had already pointed out this analogy; he knew that these two fluids are coagulable, by alcohol, the acids, and caloric, without knowing the principle to which this property is owing. (2) The relation of functions. Both are destined to lubricate surfaces of much motion, to lessen the consequent frictions, and to prevent fatal adhesions. Both are in the same state, on their respective surfaces. A dew is diffused over these surfaces, which is soon taken up. (3) The relation of diseases. Inflammation dries up the source of both, and produces adhesions more common in the serous membranes, more rare in the joints, where they produce anchylosis. Both are subject to morbid additions, which a common word designates, that of dropsy. (4) The relation of absorption. The lymphatic system is the route through which both enter the circulation, after having remained a sufficient time on their respective surfaces.

Do not these various affinities which, with some small differences of composition, so visibly connect the synovia with the humor of the serous membranes, lead us to this very plain conclusion, to wit, that these two fluids, being analogous in all these respects, should they not also be similar in the manner of their separation from the mass of blood? Now, it is a point of physiology at this time generally acknowledged, that the fluid of the serous membranes is supplied by exhalation; we are accordingly clearly conducted from one induction to another, even to this, which answers the question above propounded: *The synovia is transmitted by exhalation, to the articular surfaces.*

This precise, strict induction drawn from palpable and constant facts, will become, I think, a demonstrated truth, if, to the analogies previously established, we add that of the membranous organ, the essential seat of the exhalation of the synovia. This membrane will engage our attention in the following article.

ARTICLE II

Of the synovial membrane considered in general

We have seen in the treatise on the membranes in general, all the great cavities lined with a serous membrane, which forms, by its folds, a sort of sack without opening, which embraces both the organs and the parietes of the cavity.

There exists in all the moveable articulations, a membrane exactly analogous, whose uses are the same, whose nature is not different, and which I call *synovial,* because its parietes incessantly exhale and absorb the synovia.

1. Exterior organization of the synovial membrane.

We should accordingly consider every synovial membrane as an unopened sack spread over the organs of the joint, over the diarthrodial cartilages; on the internal face of the lateral and capsular ligaments, over the whole of the interarticular ligaments when they exist, over the jutting bundles of fat in certain articular cavities, etc. From this membrane these various organs borrow the smooth, polished, shining aspect which characterizes them in these cavities, and which they have not anywhere else. Thus in exactly dissecting the gastric organs, the peritoneum might be raised, its sack remaining untouched; in the same way we might conceive the possibility of detaching and insulating this membrane, without the intimate adhesions which it contracts in some places. All the parts it embraces are without the articular cavity, though projecting into this cavity; as the lungs are found on the outside of the sack formed by the pleura, the liver without the peritoneal pouch, etc. etc.

(1) However firm may be the adhesions of the synovial membrane, they can be destroyed without solution of continuity, by a slow, careful dissection, begun where the membrane is reflected from the cartilage over the capsule; long continued maceration likewise permits it to be removed in fragments. (2) After certain inflammations, this membrane becomes thick and opaque, and is thus distinguished from all the contiguous organs, from those even to which it most closely adheres. (3) The mucous bags, bursae mucosae, of the tendons, are quite as adherent, as the syonvial membrane, to the cartilages of their sheath and to this sheath itself; yet every one acknowledges their insulated existence. (4) There are articulations in the fibrous capsule in which the fibers, being separated, leave intervals between them, through which the synovia would escape, if the synovial membrane did not line them.

When air is thrown into the joint, we see it rise through these spaces, and present a texture altogether different from that of the capsule.

Bertin made this observation, but he supposed these pellicles were insulated, and did not perceive that they were dependent on the continuity of the membrane, extending

over the whole articulation. (5) We observed in the article on the serous membranes, that the smooth and polished aspect which the surface of the organs of the cavities presents, is always given them by these membranes, and that they never receive it from their own proper structure: now we shall see, that the synovial membrane has the same structure as the serous; it appears therefore, that where the articular organs present this character, they receive it from the synovial membrane, though it cannot be so well distinguished on these organs, as where it is free. Besides, the articulations, evidently deprived of this membrane, do not present this smooth and polished aspect.

Such are the surfaces of the symphysis pubis, of the sacro-iliac symphysis which are, though contiguous, unequal, rugous, etc. We have also proved that this organic form never originates from compression.

If we add to these various considerations, the analogy of the synovia with the serous fluid, an analogy which confirms that existing between the two sorts of organs whence these fluids flow, we shall be easily convinced, I think, that notwithstanding the adhesion of the synovial membrane in divers points, it should be considered in a manner exactly analogous to that of the serous membranes, that is, as real sack without any opening, everywhere continuous, and spread over all the organs of the articulation. Further, have we not seen the fibro-serous membranes present similar adhesions, though the separate existence of the two layers, of which they are composed, is generally admitted?

Agreeably to our idea of the synovial membrane, it is easy to imagine how certain organs traverse the articulation, without the synovia's escaping through the aperture which receives them, or through that which transmits them exteriorly. The synovial membrane, being then bent round these organs, forms for them a sheath, which separates them from the fluid, and insulates them from the joint. Thus the tendon of the biceps is more inclosed in the articulation of the arm with the omoplate, than the umbilical vein, urachus, etc., in the peritoneal cavity. With the least attention, we succeed in separating it from the portion of membranes which forms its sheath.

The preceding considerations lead us also to find a perfect identity between the mucous capsules of the tendons and the synovial bags, or bursæ. In the preceding example, these two sorts of membranes are evidently continuous; for the capsule of the bicipital groove is of the same nature with that of the tendons, which have one of them insulated, like the flexors for example.

2. Interior organization of the synovial membrane

We have just seen, that by its exterior conformation, the synovial essentially pertains to the class of the serous membranes; it ought also to be ranked there by its internal organization. This organization is all cellular, as dissection, inflation, and above all, masceration prove.

The cyst or sack forming ganglions, is clearly nothing but a production of the cellular organ; now we know this sack exhales and contains a fluid similar to the synovia. Wherever the synovial membrane is free, it is connected exteriorly with this organ, and is confounded with it, in a manner so immediate, that in successively removing its different layers, we seen them gradually condensed, and at last closely united between them to form it. Just as in the serous membranes, no fiber is there seen distinct. It becomes transparent, when it is exactly separated on both sides, which is easily done in the knee, in a very great extent.

I will not recur to the various proofs which have confirmed the cellular structure of the serous membranes; all these proofs are likewise applicable to the synovial which

seems to be a mere net-work of absorbents and exhalants. According to this, it is easy to conceive what are the fatty, reddish bundles, disseminated about the articulations. They perform, in regard to this membrane, the functions of the abundant cellular tissue, which envelopes the peritoneum, pleura, *etc.* Here the blood vessels are divided without end before they arrive at the membrane, where their ramifications, successively decreasing, terminate at last in the exhalants.

3. Vital powers of the synovial membrane

Organic sensibility is the sole property of the synovial membranes in the ordinary state, as many trials on living animals have convinced me, wherein these surfaces were denuded and irritated by divers agents. But the increase of life, produced by inflammation, in exalting this sensibility, transforms it into that of relation; as is observed, (1) in wounds where these membranes are exposed to the contact of air; (2) in the prolonged irritation which they suffer from foreign substances, accidentally developed in the articulation; (3) in the different diseases of the articular surfaces, etc.

This mode of sensibility of the synovial membranes serves to confirm what I have already decided above; to wit, that most of the articulations, the ginglymoid especially, are destitute of fibrous capsules. Indeed, I have shown that the capsules, as well as the lateral ligaments, have a mode of relative sensibility, which is developed in the sound state, by the pulling they experience. Hence if a ginglymoid articulation, in an animal, is laid open, and all the contiguous organs removed, excepting the synovial membranes and lateral ligaments, and the joint is then twisted, the animal gives signs of the sharpest pain. But if we then divide the ligaments, leaving the synovial only, the twisting is no longer felt, and we may now distend and even tear the joint with impunity. There was therefore no fibrous capsule, joined to the synovial.

This experiment, easily repeated in the anterior or posterior limbs, may there serve to ascertain the articulations, where there is a synovial membrane only, and those having the addition of a fibrous capsule.

The latter, being of the same texture as the lateral ligaments, produce the same pains when pulled, as are experienced in experiments made on the joints invested with these capsules.

The evacuation of the articular dropsies of the knee, after which the synovial membrane collapses, and the habitual absorption of these membranes, prove their tonic powers, which otherwise have nothing particular in their development.

4. Functions of the synovial membrane

The synovial membrane seems absolutely foreign to the solidity of the articulation; the fibrous capsules and lateral ligaments alone accomplish this purpose. The smooth surface which the articular extremities borrow from this membrane, favors their movements; it may even in this respect assist the muscular action; thus the portions of synovial membrane in the knee, behind the crural muscle, in the elbow, under the triceps, in the phalanges, under the flexors, *etc.*, perform, in respect to these muscles, the functions of the bursæ mucosæ; they are to their tendons what the cellular sack, separating it from the crural arch *etc.*, is to that of the proas and iliac muscles.

The principal use of the membrane in question relates to the synovia; it exhales from many orifices the fluid, which it retains for some time, and is then returned into the circulation by absorption. Its walls are accordingly the seat of the exhalation, as the kidney for example is that of the secretion of urine.

The reservoir of the exhaled fluid is the closed sack which it forms, as the bladder is that of the urine.

The excretory vessels of this same fluid are the absorbents, which eject it into the mass of blood, as the urethra throws out the urine from the bladder. In these different respects, there is more analogy between secretion and exhalation than at first appears.

The phenomena of the retention of the synovia in this membranous receptacle, relate to itself, or to the articular surfaces. The first consist in a peculiar, but unknown alteration, which it undergoes between the exhalant and absorbent systems. The second contribute to facilitate the articular motions.

The unctuous and slippery coating, which the surfaces receive from the synovia, is singularly suited to this purpose.

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MARIE FRANCOIS XAVIER BICHAT

Marie Francois Xavier Bichat (1771–1802) of Paris, a practicing surgeon, contributed far more in his career than has generally been recognized outside of France and its medical facilities. With his important book. Traité des Membranes en Général et de Diverses Membranes en Particulier, published in Paris by Richard, Caille and Ravier in 1800, he established the science of histology and tissue pathology in Western Europe. Not until half a century later was this supplemented by books on cellular pathology by Goodsir and Virchow. The Chapter on the synovial membranes is a classic in the fundamentals of orthopedic surgery. It is a long chapter describing the anatomy of the synovial membrane in each joint; the relevant sections are reproduced here in abridged form.

Paracelsus had used the term synovia applied to the fluid, and later Clopton Havers described what he termed synovial glands, *i.e.*, the fatty villi which he interpreted to be glands producing the fluid. Bichat rejected Havers' idea of glands, and recognized their function as fat pads separate from a specific synovial membrane. He believed synovia also covered the articulations and this belief was still somewhat in vogue as late as the 1930's. In this chapter, translated by J. B. Coffin, and published in Boston in 1813, Bichat employed the term exhale with an archaic meaning: "forcing through a membranous surface." This interpretation is still found in Webster's unabridged dictionary, and referred to as old medical terminology.

CLASSIC 76

Un cas d'absence des vertébres cervicales avec cage thoracique remontant jusque la base du crâne (cage thoracique cervicale) (A Case of Absence of Cervical Vertebrae with the Thoracic cage rising to the base of the cranium [thoracocervical cage])

MAURICE KLIPPEL (1858–1942) AND ANDRÉ FEIL (1884–?)

Anatomists have been interested in the study of variations for a very long time; but while formerly no special importance was attached to them other than caprices of nature, since Etienne Geoffroy Saint-Hilare's, a rational explanation has been sought for such occurrences. They are presented as variations of the human type which is not yet fixed, varying between what formerly existed and what we are to become, but evolving constantly toward a being more simple and more perfect.

If the old writers were content to report the anomaly, each case published today adds the introduction of new ideas, sometimes a new theory which endeavors to support an explanation, but more often obscures facts really more simple. And this permits us to understand that the genesis of most of these variations are as yet little understood.

Therefore, each case merits publication in order to call it to attention, because the multiplicity of such observations could perhaps lead to lifting the veil which still covers this subject.

This ignorance, the difficulty in explaining these variations which is perhaps their main attraction. Their origin, their arrangement, the differences and resemblances which we perceive in living beings, all this creates innumerable reflexions which involve the complex problem of the relationship between man and animals.

There are few subjects more intense than that which concerns our ancestral origin; no science more than medicine can know and answer.

Anomalies may involve all the tissues, all the organs of man. But we find them especially in those parts less perfected, those which have not as yet completed their evolution. They are particularly frequent in organs which are in the process of atrophy or disappearance; those which are no longer functional, which no longer follow the rules of stability of their kind.

Accordingly the variations of the caecum and the appendix are numerous. Muscles tend to dissociate or reunite according to the need and purpose they are to perform: in the superior extremities muscles divide for more delicate functions. In the inferior extremities, to the contrary one observes this tendency to continue.

The arteries, the heart show at times anomalies which are customary in inferior animals.

In short the skeleton which seems immutable, which gives to humans their form and to which are attached the organs and tissues, does not itself escape variations.

We now observe a remarkable example of an anomaly of the vertebral column and ribs; these are the variations of structures which especially concern this study. Certain of these have been known since the 18th century. Since then reports have multiplied, and theses have been accepted on the subject.

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* Translated and edited by Edgar M. Bick,

The syndrome which we report is an extremely rare example, perhaps unique, of a variant of the thoracic vertebrae, with congenital absence of the neck and the cervical vertebrae, ribs rising to the base of the skull to the degree that permits us to refer to a cervical thorax.

The history of this syndrome has led us to some research in medical literature. We have profited by recalling the different theories available to explain these variations and we will finish with conclusions advanced by this very curious case.

We herewith present our case in details.

OBSERVATION

L. Joseph, age 46, a tailor by profession, came to the Hospital Tenon on December 13, 1911, for pleurisy with pulmonary congestions and nephritis. On the first physical examination his appearance was striking. He appeared to have no neck; the head seemed to rest on the trunk. It might be said that the vertebral column in its superior part had settled as in certain cases of suboccipital Pott's disease. But in this case we could find nothing which could explain the appearance, no vertebral pain, no Pott's disease, no history of trauma. Besides the patient gave the following history. The family history was irrelevant. His mother died at 46 years of age of a strangulated hernia the night before she was to be operated. His father was found unconscious in his bed. He was 67 years old and had gone to bed well after a large dinner. It might have been a cerebral hemorrhage. Both parents were well built, their necks normal in length.

We found nothing more in further questioning. Our patient had lost a sister, aged 39 years, 8 days following an operation for strangulated hernia in the hospital at Amiens. A brother was still living, 32 years old, in good health. He had finished his military service. We wish to stress the absence of all hereditary skeletal anomalies in this family. We questioned him especially on this point, and could not find the least pathologic skeletal abnormality among his relatives.

Personal History. We will pass rapidly over the personal history of the patient which presents no connection with the anomaly that interests us. He suffered convulsions when 6 months old. At 15 he was admitted to Tenon with moderate signs of appendicitis, vomiting and pain in the abdomen. He stayed a month at the salle Bichat, then transferred to Dr. Marchands' surgical service, but no surgery was performed and he recovered without complications. The following year he had a recurrence of appendicitis for 15 days but recovered. Six years later he returned to Tenon, this time to salle Andral. Severe left pleurisy was found. Three aspirations were performed drawing 2.5 liters of fluid. He left the hospital 6 months later and convalesced at Vincennes.

Three years later he returned to Tenon again for the treatment of pleurisy; and this time aspiration was not done and he was discharged in 15 days. Since then nothing special. The patient coughed a lot, he complained of an old chronic bronchitis, but this did not prevent him from continuing his work as a tailor.

Then the patient was admitted to our service. His appearance was quite unusual; there was absence of a neck, the head resting on his trunk astonished us. Nothing in his history or heredity had the least connection with this anomaly. The patient did not know whether the condition had been present at birth, he only knew that at about 7 years of age he had gone to a doctor who suggested an operation. At that time he presented apparently, besides the absence of a neck, a marked deviation of his head to the left, enough so that his ear touched the shoulder. This inclination lasted to the age of 12, slowly disappearing.

Examination. (Pl. XXIX). The patient was short, the head a bit large for the rest of the body; but the relationship of the length of the trunk and the limbs was not perceptibly irregular. The view of the patient, the absence of the neck is well seen in Figures 1A and B. In Figure 1A, front view, the patient lifts his head as far as he can, and this already indicates one of its peculiarities: the difficulty of movement of the head on the trunk. In the second photograph, viewed from the back, one sees the hair resting far down occupying a triangular surface reaching to the third dorsal spinous process.

Unfortunately the patient had been shaved a few days before and it was difficult to note the arrangement of his hair. We will now examine the skeleton of the patient, his vertebral column, and his thorax.

Vertebral Column. The general direction of the vertebral column is modified: it forms a curve posteriorly convex partly due to the patient's trade, as a tailor. There is also a

dorsolumbar scoliosis, concave laterally to the left.

The five lumbar vertebrae are easily seen, recognized by their large and wide spinous processes and the absence of ribs. Then taking the 11th and 12th ribs as a mark, 12 dorsal vertebrae are counted. The first spinous process, the nearest to the cranium, is a bit larger, but especially larger than those below. It appears as if two spinous processes were soldered to each other. This process is separated from the occiput by a depression which increases with the head in hyperflexion and diminishes with the head placed in extension.

These 12 vertebrae which form the vertebral segment from the lumbar region to the cranium are all associated with ribs. We will therefore consider them as dorsal vertebrae and may accept a total absence of cervical vertebrae. We believe there is no atlas, no axis, and that pivot which forms the adontoid process of the axis is partly replaced by the interval which separates the occiput and the first spinous process.

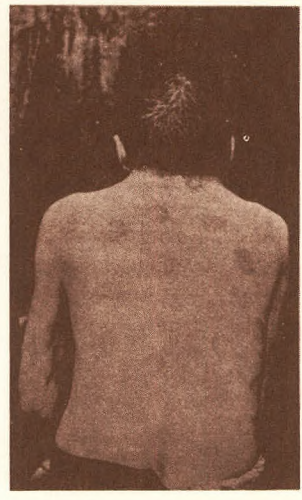
This explains the limitation of movement of the head forward and backward, giving the impression of an articulation formed of two elements with the ample movement of a flexible vertebral column. Such movement is somewhat restrained.

Anterior Posterior. If we take the chin as a guide we see that the distance from the tip of the chin to the sternal fork is 12 cm in forced extension and 7 cm in forced flexion. There is therefore little difference, 5 cm between maximum extension and flexion. In a normal individual it is almost three times greater.

Lateral Direction. Movement is even further reduced; its slight amplitude is not measurable. The movement of the head is limited. Arms and legs are slightly atrophied but retain their normal movements. . .

Roentgenography. The X-ray image is entirely characteristic. It confirms the complete absence of the cervical column. All the cervico-dorsal vertebrae carry ribs. The insertions of the first two ribs are so high that it is difficult to clearly see them attached to the vertebral column, they are partly hidden by the inferior maxilla in front, and by the base of the occiput behind. The presence of the lungs is shown by a clear zone which occupies the two thoracic cages to the top. The lungs reach above the clavicle and appear to reach a horizontal line, passing the mouth when the head is in normal position with the face in front. Behind, the lungs reach to the base of the cranium. . .





FIGS. 1A and B. Patient whose thoracic cage reaches the base of the skull; cervical vertebrae seem to be missing.

Therefore, in summary, the radioscopic examination like the clinical examination reveals a thoracic cage reaching to the base of the skull, occupied entirely by the two lungs whose superior lobes appear to mold themselves at the summit of the cage.

This was also confirmed at autopsy.

We will not discuss other organs not relevant to our subject, and which seemed to be normal. . .

Our patient then was nephritic, with pulmonary congestion complicated by pleurisy, albumen in the urine and a large heart with rapid beats (bruit de galop). He died January 19, 1912.

The Skeleton. We will first examine the thorax and the vertebral column as a whole . . . then expose the special points of interest between the column and the ribs.

Thorax. The two thoracic cavities have their properly normal dimensions. . . . Introducing the hand into the very top of the thoracic cavity one feels the first vertebra and the inferior margins of the occipital bone.

Ribs. The ribs forming the thoracic cage numbered 12 on each side. The intercostal

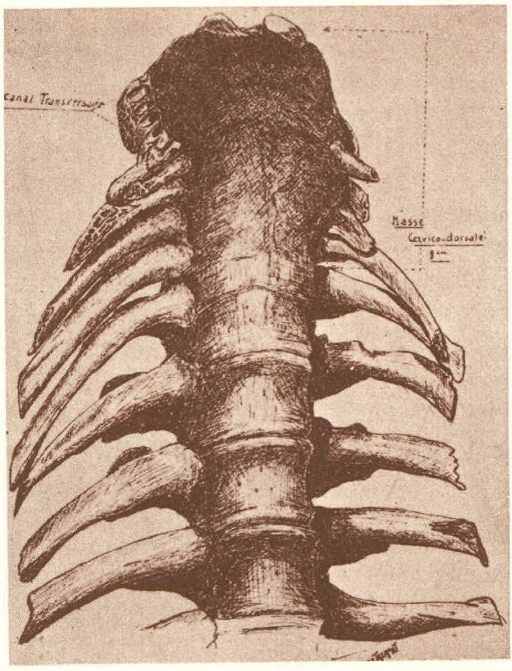


FIG. 2. Drawing shows anomaly of cervical vertebrae.

space which separates the two last ribs is much larger on the left than its opposite. The direction of the ribs is very oblique, almost vertical; this is especially noted for the first rib which limits a nearly vertical orifice, whereas in the normal individual the opening through which the neck communicates with the thorax is almost horizontal. The explanation is simple; this first rib attached to the highest vertebra so that it brings the posterior thorax to the base of the skull. But it must follow a very oblique direction to join the manubrium of the sternum, and therefore provides a cervical region which does not exist posteriorly. . .

Base of the Skull. The posteroinferior part of the occiput presents a very prominent protrusion 1.5 cm long and gives the impression of a vertebral spinous process. This arrangement favors the vertebral theory of the skull, and the opinion of authors who consider the occipital bone a vertebra and the external occipital protuberance an atavism of a spinous process. . .

The Vertebrae. The vertebral column extending from the occiput to the sacrum is formed of 12 differentiated vertebrae and an osseous mass of fused vertebrae. This mass situated superiorly includes four pairs of ribs. Below this, one sees 8 vertebrae, each one associated with a pair of ribs, and for this reason, we will consider them as dorsal vertebrae. Finally 4 vertebrae not attached to ribs are lumbar vertebrae.

Cervico-dorsal Mass. We call it such not wishing to judge the type of vertebrae by which it is constituted. This portion is certainly formed of several vertebrae fused together during the course of development. Four ribs are easily seen on each side. The start of these ribs are closely approximated, almost fused at their origin. This osseous mass is 8 cm long, with variable width greater toward the superior aspect, where it attains a maximum of 5 cm, and only 3 cm as its most narrow level. . .

The superior part of the vertebral column has no atlas or axis, no odontoid which might serve as a pivot in the movement of the head on the trunk. In our patient those movements, although limited, were partly present, easily explained by the presence of a small superior articulation, and especially by the large triangular superior aperture. . .

Seen laterally this upper mass presents, besides the four pairs of ribs already noted, a canal which we consider a homologue of the vertebral canal. This transverse canal, destined no doubt to contain the vertebral artery, is situated above the origin of the first rib, and is united to the root canal by several openings through which the nerve roots probably run.

Now if we wish to classify the vertebrae which constitute this mass and if we accept the classical contributions of morphology, we must consider them as dorsal vertebrae since only these possess ribs. . . . Actually it is only the inferior part of this osseous mass which is the relic of the 4 dorsal vertebrae; it is only in this part where the 4 pairs of ribs and transverse processes are found. Above, one sees another much reduced bony area, through the lateral side of which runs a transverse canal for the vertebral artery. . . . This canal, as we have noted, communicates by several openings with the medullary cavity; it is probable that each opening responds to a nerve root and represents the remains of a cervical vertebra. We have counted on 6 such orifices. It seems then that there were only 6 cervical nerve roots. But since we have noted no neurological defects we must assume that the number of nerve roots were normal and that two roots found another passage. The posterior portion seemed to resemble a fused cervical column. . . .

So this vertebral column is quite abnormally constructed. It merits our attention for sev-

eral reasons: The number of vertebrae forming the axial skeleton from the occiput to the sacrum is greatly reduced. There are only 12 well differentiated vertebrae instead of the normal 24. We find from the base up 4 typical lumbar vertebrae (we have already noted that the 5th is united to the sacrum).

Eight dorsal vertebrae are each provided with a pair of ribs. Finally an osseous mass completely fused in which it is impossible to differentiate vertebral bodies. This mass is 8 cm long, it is furnished with 4 of the pairs of ribs more or less united at their areas of origin, which makes us think that they constitute the first four dorsal vertebrae which perhaps in the course of development were united to the cervical vertebrae. This vertebral column ends with a wide orifice which communicates directly with the occipital opening. In front of this orifice there is a rough form of articulating surface which permits the limited movements which were noted during the patient's lifetime. . . .

All this is found in a 46-year-old man who did not seem to resent his defect to any great extent. There is no doubt we have before us a congenital malformation. The vertebral column is sound, though prodigiously abnormal. It presents no trace of a pathologic lesion, Pott's or otherwise.

Before discussing the genesis of this remarkable deformity we will cast an eye on the variations of the cervical vertebrae and the theories which might explain them. We can then construct a more precise study of the case we are reporting.

We have searched the medical literature for a similar monstrosity but have found nothing that approached it. . . .

Non-compensated anomalies with the number of vertebrae modified are very rare, but as in this case there is a certain compensation by an enlargement or diminution of the size of the vertebrae and by an exaggerated, straightening or bending of the vertebral curves. So overall, although with a lesser number of vertebrae, the column can maintain an almost normal length. . . .

The very rarity of anomalies of cervical vertebrae is further confirmed by research followed in the animal series. Of all the segments of the spine the cervical is that in which the number of vertebrae is the most fixed among animals belonging to the mammalian class. Except for certain edentates and certain sirenides, it numbers 7 vertebrae, as does the giraffe or the camel with their long necks, or the whale, the elephant or hog with their short necks. Of 40 vertebral columns of anthropoids counted by Paterson there were no variations in the cervical vertebrae which were always 7 in number, naming numerous variations of vertebrae of other sectors, dorsal, lumbar, etc. . . .

The pathogenicity of these vertebral variations is complex and uncertain; many hypothesis have been developed and the number of theories is proof of the obscurity which surround them. . . .

So the case which we have reported is difficult to explain by any of these theories. . . . We are not in the presence of a variation regressive or progressive, but of a monstrosity. . . . The etiology is uncertain, it is perhaps traumatic, it is also possibly the result of an infectious osteitis which upset the entire upper part of the vertebral skeleton. . . .

We will not discuss the pathologic factors which might have been involved, there are many; tuberculosis, alcoholism, Bright's disease, cardiac disease, idiopathic. There is no doubt that some of these defects might have existed in his ancestors, but their frequency even in healthy and well formed individuals should be as rare as those cases showing deformity. . . .

We see an object probably pathologic without morphologic significance, a deformity or anomaly formed without doubt in the first stages of development. . . .

Our patient then is not only a curious example of an exceptional formation, but also serves as a deformity requiring clinical classification.

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MAURICE KLIPPEL

Maurice Klippel (1858–1942) was attending neurologist at Hôpital Tenon in Paris, and André Feil (1884–?) was his "interne" (today, probably resident) at the time this famous report was published. A rewriting of it appeared later that year in the Bulletin of the Anatomic Society of Paris (87:185, 1912).

In the latter third of the 19th and turn of the 20th century comparative morphology was one of the most active disciplines in the scientific world of Europe and the French were the leading exponents. Names such as Cuvier, Buffon, Geoffroy St. Hilare and Lamarck dominated the field. (Ref. Chapter 7, Source Book of Orthopaedics.) In this context, Klippel and Feil's report transcended the importance of a merely unique case. In the study of human congenital deformities, even as late as the 1930's every attempt was made to relate them to some atavistic or ontologic precedent. In the present case the authors stress the fact that it bore no such relationship and suggest other possible causes for congenital deformity. Human genetics had not yet become a mature science.

Another contribution made by this reprinting is the fact that the photographs in the original publication are rapidly fading. Hopefully, these untouched photographs may preserve them for all time.

CLASSIC 77 Ober den Besten Shoen

(Dissertation on the Best Form of Shoe)

PIETER CAMPER (1722–1789)

PREFACE TO "CAMPER ON THE BEST FORM OF SHOE"

This little treatise originated in a jest. I wished to prove to my pupils, who maintained that all subjects had been treated in writing until they were exhausted, that the most trifling matter, were it but a *shoe*, might become interesting if discussed by one able to speak with entire knowledge of both causes and results.

They did not believe that I should dare to make public such a work on such a subject. I accepted the challenge, and here it is.

But, joking apart, my reasonings upon the distressing consequences of the miserable manner in which we are at present shod are founded upon a long series of observations and reiterated experience. I can only hope that the victims of fashion may profit by my views, and that many fathers and mothers will be induced to avoid the infliction of much torture upon their children. If I can succeed in persuading them of this, I shall have accomplished by object.

I shall not say—

Ridendo castigat mores,
Jesting, your manners I were fain to mend;

but—

Ridendo calceos corrigit,
Jesting, to improve your foot-gear I intend.

INTRODUCTION

"Non multum abfuit, quin sutrinum quoque inventum a sapientibus diceret Posidonius."—SENECA.

It is surprising that while mankind in all ages have bestowed the greatest attention upon the feet of horses, mules, oxen, and other animals of burthen or draught, they have entirely neglected those of their own species, abandoning them to the ignorance of workmen, who, in general, can only make a shoe upon routine principles, and according to the absurdities of fashion, or the depraved taste of the day. Thus, from our earliest infancy, shoes, as at present worn, serve but to deform the toes and cover the feet with corns, which not only render walking painful, but in some cases, absolutely impossible. All this is caused by the ignorance of our shoemakers.

We bestow reasonable compassion upon the fate of the Chinese women, who dislocate their feet in obedience to the dictates

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Taken from Camper, Pieter, Ober den Besten Shoen. Amsterdam 1781; Dissertation sur les meilleurs forme des souliers. Paris. 1781; English transl. in J. Dowie. The Foot and Its Covering. London, R. Hardwiche, 1861.

of a barbarous custom, and yet we ourselves have submitted complacently for ages to tortures no less cruel. I say for ages: C. Celsus, who lived before the Christian era, Paulus Aegincta, and Aetius, have described, with great precision, the diseases of the feet caused by ill-made shoes and sandals. It is evident that all the world did not imitate Socrates, who went barefoot.

The shoes and boots of our time are no better than those of the ancients. I know by experience the difficulty of obtaining easy ones. I have never met with such in London, and rarely in Paris; but at Amsterdam and Groningen I found several makers, grown grey in their business, who entered into my views when they saw the sad evidences of unwilling experience on my own feet; above all, however, and as having served me best, both in regard to ease in walking and excellence of the article, I have to commend a young master cordwainer of the Hague.

Experience and reflection soon led me to the conclusion that a shoe adapted to one town may not be so well suited to another. A shoe, for example, fitted for the Hague, is not so for Amsterdam, and is positively objectionable at Leeuwarden, at Groningen, and wherever the streets are paved with rolled pebbles, as nature presents them to us, and without being dressed and squared, as they are at Hamburg, Berlin, &c. Elsewhere the pavements are still worse, and there a certain habit is necessary to escape disagreeable inconveniences in walking.

I am confident, moreover, that even the best and most celebrated shoemakers have a defective method of taking the measure of the foot. My knowledge of anatomy shows me that the foot lengthens in walking, and becomes shorter when in repose. In consequence, the measure taken of the sole of the foot when in repose, according to ordinary routine, must produce a shoe too short for the same foot when it is in motion; and thus both the great toe and the heel must be pinched, and the joints of all the toes made to rise, and form eminences, the sole being of too unyielding a material to adapt itself to the necessities of the case. Experience has convinced me, also, that the heels of the boots and shoes ought to be placed more forward upon the sole, so as to support the centre of gravity of the body. I remember that in my boyhood shoes were made with the toes slightly turned up. Our travelled youth introduced the Parisian fashion of wearing them very flat and shallow, and with excessive high heels. A general revolution in the fashion of our shoes ensued. I purchased shoes of this description for myself, without noticing the change, but was painfully made aware of it at the expense of my toes, which were bruised by contact with every stone that came in my way. The reason of this discomfort was an enigma to me until, the subject of shoes and shoemaking having occupied my mind, I discovered the cause of my martyrdom.

The principles of my researches are founded upon the anatomical theory of Borelli. They have convinced me of the importance of the subject, and induce me to believe that I may of some service to my fellow-creatures, by enabling them to profit by my physical inquiries into the defects of a part of our attire with which we cannot dispense.

Men and women do not walk in the same manner, on account of the difference in the width of their hips; and children, again, move differently, in consequence of the shortness of their legs. Aged persons, whose heads (and frequently their bodies also) are bowed forward, are obliged to bend the knees to preserve their equilibrium—the center of gravity then falling necessarily more forward upon the instep.

Towards the end of pregnancy, moreover, the upper part of the female frame is thrown backwards, in order to maintain the centre of gravity; so that at this important period women bear greatly on the heel.

Ladies, old and young, in the upper walks of life, wear high and slender heels to their foot-gear; and to make the foot look smaller

and neater, these heels are carried as far forward under the instep as possible. Misled by ridiculous vanity, our burgesses have also adopted this absurd fashion. Our peasantry are wiser, they providing themselves with shoes that give firmness to their gait and render walking easy.

Tall persons walk in a peculiar manner, and require, in consequence, shoes adapted to their step. Education has also considerable influence upon the shape of the foot: a gentleman always turns out his toes, while a peasant as invariably turns them in. The celebrated M. André has fully discussed this subject, in his "*Orthopédie*," pp. 254, 255. It is incontestable that the proper position of the feet is to have them turned out, and that this attitude contributes to the stability of the body when erect; because with the two feet we then form a sort of triangle, which gives all the security of the tripod. It is with justice, therefore, that in the dancing school the position of the toes turned in is designated the false position. *Vide* "*Dictionnaire Encyclopédique*," *vol. viii, Pl. I., figs. 9, 10, 11, 12, and 13.*

The above observations lead us to the conclusion that shoes which are not adapted to the foot of each individual are defective; and that a shoemaker who would excel in his art, and who desires to furnish his customers with a perfect article, ought to have an exact knowledge of every diversity of form, more especially if he wishes to prevent corns upon the joints and between the toes, inflammation of the roots of the nails (onychia), especially of the great toes, and painful callosities. He will prevent all these annoyances by giving a proper form to his shoes: the toes will not then be bent, the nails will not be compressed, the joint of the great toe and the foot itself will no longer be subject to tumours and swellings, and the skin of the foot generally will be preserved from abrasion. I say further, if the shoemaker be intelligent, if he throughly understand his business, or have a clear conception of progression; if he can distinguish the natural from a faulty form of the foot, he will be enabled to correct any defect in his work, and preserve his customers from much torture, as well as save them from falls, bruises, and sprains. The evil results produced by ill-formed shoes, as now enumerated, must convince us of the importance of a radical reform in the manner in which they are at present made, and of the propriety of obtaining them of the best possible fashion.

My readers may, nevertheless, be surprised at finding a professor of medicine condescending to treat so humble a subject; but I flatter myself that their astonishment will cease if they peruse these pages; when they will be made aware of the immense amount of knowledge necessary to deal worthily with so important a subject. I would have them remember that the great Xenophon has not disdained to transmit to posterity judicious instructions as to the best manner of preserving the feet of the horse. A Duke of Newcastle, and other distinguished persons, have prided themselves upon their knowledge of the hoof of this animal, and have bestowed much study upon the iron shoe necessary. Our feet are certainly of as much value as those of that noble animal; and a proper charity begins at home. It is, then, to mankind that I devote my attention and care. I labour for the benefit of my fellow-creatures; and this motive, united with the example of the two great names I have cited above, gives dignity to my work, and justifies my exertions. I propose, in the first place, to consider scientifically, the foot, and our mode of progression; then to treat of shoes and boots, as worn by men, women, and children, and to enlarge upon their most proper form. The diseases and discomfort occasioned by ill-made shoes, with the means of prevention and cure, will occupy the concluding portion of this little treatise.

NOTE.—This little memoir may be considered as a supplement to my "Dissertation upon the Physical Education of Children," published in Vol. vii of the "Memoirs of the Academy of Haarlem."



PIETER CAMPER

Pieter Camper (1722–1789), Professor of Medicine in Amsterdam, published one of the most remarkable books in orthopedic literature. It was translated immediately and repeatedly into several European languages and was considered worthy of reprint as late as 1861. He was one of the outstanding medical scientists of Europe in the 18th century and his apology for discussing so lowly a subject as shoes is amply discussed in his introduction. He incidentally was also one of the superior anatomical artists of his period and, like da Vinci, illustrated his own publications. I have always considered the following small preface a gem of medical writing and the most incisive statement of the problem of childhood shoe-induced deformities.

CLASSIC 78

Sarcoma of the Long Bones

Based Upon a Study of One Hundred and Sixty-Five Cases

SAMUEL WEISSEL GROSS, A.M., M.D. (1837–1889)

ARTICLE I

In the last edition of his work on "Surgical Pathology," Professor Billroth states that "the subdivisions, made according to the histological peculiarities of the various sarcomata, are of no great value during life"; but being convinced, from personal observation, that clinical differences exist among the divisions of sarcoma as marked as are met with among the varieties of carcinoma, I have ventured to differ from so distinguished an investigator, and have studied these growths, as all morbid processes should be studied, with the view of determining the relations subsisting between their minute structure and their clinical characters. To attain this end I have carefully analyzed 165 cases, many of which are original, and the number might have been very materially increased had I included examples of mixed sarcomas. I have limited my investigations, however, to those cases alone in which the histological features of each form of sarcoma were typical, and I have used none except a few of osteoid sarcoma, about the true nature of which there could be no doubt, that were not confirmed by microscopical examination.

The primary neoplasms of the long bones, exclusive of the clavicle, the metatarsal and metacarpal bones, and the phalanges, which I shall not consider, are, in the order of the frequency of their occurrence, sarcomas, osteomas, chondromas, osteoid chondromas, fibromas, and myxomas. Vascular and cystic growths, as I shall have occasion to show hereafter, are, for the most part, nothing more than metamorphosed sarcomas, while it is extremely doubtful whether primary carcinoma ever occurs in the osseous system. Since sarcomas affect the long bones more frequently than all the other tumors combined, and as they constitute an important group of morbid growths which are not thoroughly understood, and are described under a great number of different and confusing names, I shall devote this and a succeeding paper to a description of their histology, general pathology, symptomatology, diagnosis, prognosis, and treatment, covering, as far as possible, the entire field, although in doing so, I will touch upon some points which may be considered elementary, but

* From Gross, S. W.: Sarcoma of the long bones; based upon a study of one hundred and sixty-five cases. Am. Med. Sc. N.S. 78:17-57, 338-377, 1879. (First section, edited by William Enneking.)

which I trust may prove to be instructive to those not entirely familiar with the subject.

The term sarcoma, which is of very ancient date, and was employed by Abernethy to designate tumors "having a firm and fleshy feel," was revived by Virchow, and is now employed by him and other pathologists and most surgeons to indicate a new formation of the connective tissue series, which is composed almost entirely of unripe, transitional, or embryonic cells, which serve to distinguish it, on the one hand, from the perfected tumors of that system, and, on the other, from the carcinomas. From the excessive preponderance, development, and mode of arrangement of its cellular constituents, which endow it with its peculiar characters, and from their indisposition to pass into higher tissues, they constitute a structure which is unlike any natural structure, and may, therefore, be regarded as an atypical production. The cells are contained in an intercellular substance, which is hyaline, granular, fibrillated, or alveolar, which, along with the various degenerations to which these tumors are liable, give rise to certain subdivisions. The principal varieties of sarcoma of the bones, which are determined by the prevailing form and size of their cellular elements, are the round-celled, the spindle-celled, and the giant-celled, the cells themselves merely representing different stages of development. In accordance with the dimensions of the cells, they are, moreover, separated into the small-celled, and large-celled, a distinction which is most useful, not only because the size of the cells influences the consistence of the tumors, but from the fact that it has a special bearing upon the prognosis.

Certain subdivisions of sarcoma are constituted by the nature of their matrix or intercellular substance, by their transformations, and by their vascularity. Thus, when fibrous tissue replaces in great part the ordinary intercellular substance, the growth is called a fibrous sarcoma. When the basis substance has undergone mucoid transformation, it is a myxomatous sarcoma; when it presents the appearance of the reticulum of the lymph glands, it is known as lymphadenoid sarcoma; when it forms an alveolar structure, it is an alveolar sarcoma; when the cells have undergone fatty degeneration and granules of fat and free oil are disseminated in the intercellular substance, it is a lipomatous sarcoma; the presence of certain other constituents, as the mineral salts, bone, or cartilage, produces respectively calcifying, ossifying, and chondroid sarcomas; when they have undergone cystic degeneration, they are known as cystic sarcomas; excessive vascularity gives rise to telangiectatic sarcoma; and effusions of blood, to hemorrhagic sarcoma. All these subdivisions, pure or variously intermixed, are met with in the sarcomas of the long bones, the only one that is missing being pigmented or melanotic sarcoma, of which I have been unable to find a single recorded example.

Sarcoma of the bones is generally denominated osteosarcoma, but the latter term, which is employed by clinicians, should be dropped, since, from a histological standpoint, it signifies a sarcoma, whether it be seated in or on a bone, or in the soft parts, containing osseous tissue of new formations, and is synonymous with osteoid or ossifying sarcoma. As an evidence of the confusion that has arisen from retaining that name, I may mention that Wilks and other English writers call the periosteal osteoid sarcomas osteosarcomas, while many German pathologists employ the term to designate myeloid tumors, which are always central.

According to their point of departure they may be separated into the peripheral, periosteal, or periosseous, and the central, endosteal, intraosseous, or myelogenic, a division which is not only convenient as designating their seat, but which is also justified by the fact, that, in general, they present marked differences in their histological construction, and are of different prognostic

import. Thus, the majority of the peripheral growths, which proceed from the layer of embryonic cells, or osteoblasts, which separates the periosteum from the bone, and is variously known as the osteogenic substance of Ollier, the ossification blastema of Köl-liker, the proliferating layer of the periosteum of Virchow, and the cambium layer of the bone of Max Schultze, are osteoid spindle-celled growths, while the central tumors, which develop from the medulla, and from the osteoblastic layer which lines the interior of the medullary canal, are, as a rule, giant-celled sarcomas.

In their macroscopic or gross appearances these two divisions of sarcoma present some points of difference which may be utilized for diagnostic and prognostic purposes, in the absence of microscopical examination. The central tumors, particularly those of the giant-celled variety, are inclosed in a capsule or case, which may be entirely bony, but which is usually partly bony and partly membranous. The periosteal formations, on the other hand, are limited by the outer fibrous layer of that membrane, or, in the event of its participation in the proliferation, by a capsule of connective tissue. In either event, osseous tissue is never found in the investing membrane, so that the presence or absence of bone in the capsule is of great value in the determination of the original seat of the new growth.

Although the sarcomas are very liable to certain transformations which tend to obscure their diagnosis from their naked-eye appearances, yet, in their pure forms, their structure is so dissimilar, that we may judge pretty accurately of their nature by their tints and consistence. Thus a tumor which presents a dark red or maroon color can be nothing else than a giant-celled sarcoma. Specimens which are characterized by a firm, glistening, grayish-white tissue come under the subdivision of large spindle-celled sarcoma. When there is an admixture of bony spicules and soft tissue, there need be no doubt as to its osteoid nature; should the soft portion be dense and firm, it may be termed an osteoid fibrous sarcoma; if it be soft and medullary, it will probably turn out to be an osteoid round-celled tumor; while, if it be semifluid and gelatinous, it forms a myxomatous osteoid sarcoma. Tumors which have the consistence and appearance of the brain of a newly-born child may be ranked among the medullary or encephaloid sarcomas of the small round-celled type, although the soft, small spindle-celled tumors present precisely similar features. When the tissue looks like a recent coagulum, or contains one or more cysts filled with blood, we will be right in assuming that we are dealing with a highly vascular medullary growth. These conclusions are based upon the combined clinical and microscopical characters of sarcomas, and may be held to be as true for this group of neoplasms as it is true that the gross characters of scirrhous carcinoma, for example, correspond to a known type of structure.

In their configuration, sarcomas of the long bones vary in accordance with their situation. Central tumors, whether they occupy the epiphyses or diaphyses, are generally spherical. Periosteal tumors are long, oval, or fusiform, when they occupy the shafts; while they are pyriform, with their base towards the articulation, when they surround the articular ends of the long bones; or conoidal, when they develop from a limited portion of the joint-end. Their surface is usually smooth and even, although it may be tuberous, bossed, or lowly-lobed, which is particularly liable to be the case when their investing capsules are implicated in the new formation, and when they have softened, and are about to become the seat of ulceration. Their volume varies very greatly. They may be no larger than a walnut, or they may attain huge dimensions, as, for example, three feet in circumference. In the latter event, it may be assumed that the

growth is the seat of interstitial hemorrhage or cystic transformation.

So long as they are circumscribed by their investing capsules, sarcomas merely stretch and push aside the surrounding tissues; but when their capsules take part in the cell proliferation, or are perforated, they evince a locally infectious nature, and become diffused, either through the conversion of the cells of the tissues into like elements, or through the continuous multiplication of the tumor elements. In the peripheral sarcomas, the bone generally passes through the growth unchanged. In some instances the cortex of the compact substance is the seat of condensing sclerosis; in others, it is eroded, pitted, or, as it were, worm-eaten. In others, infection of the compact tissue ensues without changes in its outer surface, through which nodules are formed in it, and give rise to what may be termed interstitial sarcoma, although I have never known a tumor to originate primarily in this situation. Again, the disease may extend along the Haversian system to infect the medulla. Finally, the tumor may occupy all these localities, so that we may even find a sarcoma which has originated in the periosteum constituted as follows: masses in the medulla, interstitial deposits in the compact tissue, a large tumor around the shaft, and, finally, one growing from the fibrous layer of the periosteum, the last two of which are merely separated and cut up into lobules by the remains of that membrane. In the central sarcomas, the original bone is usually destroyed to such an extent that not a vestige of it remains.

Next to the carcinomata of the soft parts, the sarcomata of the bones are the most malignant of all neoplasms, as is evinced by the local infection of the adjacent tissues, the occasional implication of the associated lymphatic glands, and the occurrence of secondary deposits in the viscera and tissues belonging to the same series. From their tendency to infiltrate the surrounding structures, they show a great disposition to recur locally after extirpation, so that in the performance of an operation for their removal, the rule should be to amputate as far as possible from the seat of the disease. Unlike the carcinomata, the lymphatic glands are rarely the seat of primary contamination. Thus, of 133 cases in which this point is noted, these organs were enlarged in only 23. In 13 of these the lymphatic tumor was merely due to irritation, as was shown by the fact, that in some cases it disappeared after the removal of the primary neoplasm, while, in others, minute examination failed to detect carcinomatous elements. In 5 fatal cases, the condition of the glands was not noted; while, in only 5, were they converted into a tissue similar to the parent growth. These facts are of extreme interest, as they denote, in the first place, that enlargement of the lymphatic glands should not be regarded as a bar to operative interference, and, secondly, that systemic infection generally takes place through the blood and not through the lymph channels.

The general dissemination of sarcoma, or the occurrence of secondary growths in the viscera and in other tissues, is one of the most marked attributes of this class of morbid growths. Thus I find that 46.06 per cent of all cases are characterized by this clinical feature, the metastatic tumors being found most commonly in the lungs, lymphatic glands, and other parts of the osseous system. In this connection, it should be remembered that the secondary deposits are histologically identical with the fine writers describing a case, for example, as one of sarcoma of the femur with secondary cancerous deposits in the lungs, whereas, in truth, the latter do not deviate in their structure from the original tumor. A sarcoma always reproduces its like, a carcinoma its like, a chondroma its like, so that the anatomical peculiarities of a metastatic deposit enables us to decide as to the nature of the original tumor in the event of the latter having been removed by some other surgeon. A naked

TABLE 1.

Variety	*Adjacent Tissues*[1] *Per cent*	*Local Recurrence Per cent*	*Extension to Glands*[2] *Per cent*	*Generalization Per cent*
Periosteal spindle-celled	44	60	0	100
round-celled	50	50	7.69	66.66
osteoid	40	41	6.25	65.62
Central round-celled	66	25	8.33	33.33
spindle-celled	18	20	0	23.07
giant-celled	12	8	0	22.72

[1] Infection of surrounding tissues as shown on dissection of the limb after its removal.

[2] Instances of enlargement of the glands from irritation are excluded.

eye point of distinction between the secondary carcinomatous and sarcomatous growths, as of the liver, is the presence of umbilication in the former, and its absence in the latter.

While it is true that the sarcomas of the bones are to be regarded as malignant affections, yet the signs of malignity — that is to say, infection of the neighboring tissues and local recurrence, extension to the lymphatic glands, and multiplication in distant parts — are not witnessed in the same degree in the different varieties of sarcoma, as is shown by the above table (Table 1).

From an examination of the cases of destructive sarcomas, they may be classed, in the order of their malignity, as follows: Periosteal spindle-celled, periosteal round-celled, periosteal osteoid, central round-celled, central spindle-celled, and central giant-celled; the periosteal forms being more malignant by 43.5 per cent, as will be pointed out hereafter. Hence the comparative benignity of the central tumors may, to a certain extent, be ascribed to the slight disposition which they evince to extend beyond their bony or osteo-membranous capsules. With regard to the sarcomas composed of spindle cells — and they are synonymous with the recurrent tumors of Paget — it will be observed that they are endowed with the power of general dissemination to an extraordinary degree, so that the term recurrent, as designating the characteristic peculiarity in their history, is in nowise applicable to them.

Sarcomas of the long bones evince a great predilection for their articular extremities, and the majority develop in the spongy substance of the epiphyses. Whether of central or peripheral origin, they are liable, even in the hands of the most skillful observers, to be confounded with other affections, such as aneurism, white swelling, strumous abscess, periosteal abscess, osteomyelitis, and gummata. Of these, aneurism of the bones and strumous articular osteitis have given rise to the greatest number of mistakes. They may be discriminated from abscesses by the exploring needle, and from syphilitic formations by the history of the case. Osteomyelitis, in addition to the tumefaction, gives rise to puffiness of the superincumbent soft structures, and is attended with irritative fever, and, now and then, with deep-seated throbbing pain.

From aneurism of the long bones, if there is really such an affection, and its occurrence is denied by Virchow,[1] Landi,[2] and Broca,[3]

[1] Pathologie des Tumeurs, vol. iv. p. 68.

[2] Amer. Journ. Med. Sciences, January, 1878, p. 278.

[3] Traité des Tumeurs, vol. ii. p. 212.

TABLE 2.

Nature of Tumor	*Males*	*Females*
Central giant-celled	33	30
round-celled	7	5
spindle-celled	11	5
Periosteal round-celled	10	3
spindle-celled	4	5
osteoid	22	14
	87	62

the distinction is by no means always easy, particularly when, in addition to the pulsation, there is a bruit, as happened in four instances to which I shall call attention hereafter. In the majority of pulsating sarcomas there is no murmur, or, if it be present, it is not very distinct. Then, too, in sarcoma, pulsation is not found from the very commencement, nor is it expansile, and in some cases it is not remarked until the tumor begins to grow rapidly. Aneurisms, as is well known, are extremely rare before the thirtieth year, while two-thirds of the pulsating sarcomas occur before that age. Finally, when a pulsating growth is situated away from the line of a large vessel, as, for example, in the upper epiphysis of the fibula,[4] it is far more likely to be a sarcoma than an aneurism.

White swelling is very liable to occasion mistakes in the diagnosis, and this is particularly true of those cases in which the adjacent joint has undergone destructive changes from nutritive disturbances, or has been invaded by the growing tumor, when the symptoms are so similar that a differential diagnosis, without exploratory incision, is scarcely possible.

White swelling, as of the knee, for example, usually occurs in scrofulous subjects before the fifteenth year. There is pain from the very outset, which gradually increases in severity, and finally becomes so intense as to deprive the patient of sleep and seriously undermine his general health. The skin is tense and glossy; the superficial veins are abnormally large; the temperature is elevated; the joint is stiff, if not immovable, and efforts at motion produce great suffering; the articulation, moreover, is distorted and flexed; and puncture gives vent to pus or turbid synovial fluid containing flakes of lymph. While swellings do not pulsate, nor does manipulation elicit parchment-like crepitation.

In sarcomas, the absence of suppuration, or the slight tendency to the formation of pus, is a sign of great value. Other important distinguishing features of sarcoma are the preservation of the movements of the joint, although in some cases the mobility is limited, freedom from suffering on motion, and absence of vicious position. In many cases, indeed, the patients are able to walk about without suffering or experiencing particular fatigue. In sarcoma, too, spontaneous fracture is not uncommon. Resistance to ordinary treatment, moreover, distinguishes sarcoma from white swelling. In the latter affection, rest and extension, along with gentle and equable compression of the joint, are of great benefit in relieving the pain and in restoring the impaired general health; but in sarcoma, the tumor continues to grow despite the employment of these measures, and the local suffering is greatly increased by compression. These features, which have been carefully studied by Gilette[1] and Poinsot,[2] when considered in connection with the symptoms previously referred to, will generally suffice to differentiate the epiphyseal sarcomas from strumous articular osteitis.

Sarcomas of the long bones are most frequent in those of the lower extremity; the

[4] Langenbeck. Langenbeck's Archiv, vol. xxi., supplement, p. 333.

[1] Bull. et Mém. de La Soc. de Chir. de Paris, vol. ii. 1876; p. 115.

[2] Ibid. vol. iii. 1877; p. 208.

femur, tibia, and fibula being affected in 76 per cent, of all cases. Thus —

Out of 165 cases which I have analyzed, the femur was the seat of the disease in 67 instances; the tibia, 46; the humerus, 25; the fibula, 13; the ulna, 7; the radius, 6; the ulna and radius were the seat of the disease in 1 instance.

Separating these in accordance with their histological construction, 70 were examples of giant-celled sarcoma; 45 periosteal osteoid sarcoma; 16, central spindle-celled sarcoma; 13, periosteal round-celled sarcoma; 12, central round-celled sarcoma; 9, periosteal spindle-celled sarcoma.

Hence it follows that the giant-celled tumors are the most common, forming, as they do, 42 per cent of the entire number. It will also be seen that the central tumors are more frequent by 18 per cent than those which arise in the periosteum.

Males are more liable to their occurrence by 17 per cent than females, as is shown in the above table (Table 2) of 149 cases in which the sex is given.

The age at which they first manifest themselves averages 27 years. In the following table (Table 3) of 147 cases in which the age is denoted, I have separated their occurrence at the different epochs of life, from which it will be seen that 68 per cent develop before the 30th year, and 32 per cent after that period: —

Sarcomas of the long bones appear to be influenced in their histological construction by the age at which they appear. With the exception of the central spindle-celled, which are most common after the thirtieth year — the average being the thirty-sixth year — they all develop before that age, the mean being 22 for the periosteal osteoid, 23 for the periosteal round-celled, 24 for the periosteal spindle-celled, 28 for the central round-celled, and a fraction above 28 for the giant-celled.

Traumatism was the assignable cause in nearly one-half of the 144 cases in which

TABLE 3.

Between 10 and 20 years of age	45 cases
Between 20 and 30 years of age	55 cases
Between 30 and 40 years of age	26 cases
Between 40 and 50 years of age	11 cases
Between 50 and 60 years of age	7 cases
Between 60 and 70 years of age	3 cases

the etiology is recorded. They could be traced to blows, falls, kicks, sprains, fractures, and other injuries in 31 out of 60 cases of giant-celled sarcoma; 2 of 12 of central round-celled sarcoma; 4 of 16 of central spindle-celled sarcoma; 7 of 13 of periosteal round-celled sarcoma; 16 of 34 of periosteal osteoid sarcoma; 3 of 9 of periosteal spindle-celled sarcoma.

Having thus directed attention to what I consider to be some of the more important points in the general pathology and diagnosis of these new formations, I will now take up the study of the individual sarcomas, in which these data will receive more extended consideration.

In the treatment of this class of tumors, general measures being worthless, no time should be lost in resorting to amputation or excision. Although surgical interference has been followed by a mortality of 31.25 per cent there can be no reasonable doubt that it has frequently succeeded in preventing local and systemic infection, as well as prolonging life. The more rapid the growth of the tumor, the more reason there is for early operation. Indeed, in view of the difficulty in determining the true nature of the neoplasm in its incipient stages, delays are extremely dangerous, since, instead of having to deal with a pure myeloid sarcoma, the disease may eventually prove to be an osteoid sarcoma, or a small-celled medullary sarcoma, in which events, valuable time will have been lost, and the patients have been exposed to the dangers of local infection and general dissemination.

In selecting an operation the golden rule should be observed to go as far as possible from the seat of disease, without needlessly jeopardizing life. The reasons for this line of conduct will be perfectly clear, if it be remembered that the overlying soft parts, the contiguous bones, and even the joints, may be involved by extension of the disease. Hence it is that when operations have been practiced next to the trunk, or in close proximity to the tumors, the prognosis is bad, as, in the event of recurrence, nothing more can be done. In the cases of Henry[1] and Hutchinson,[2] for example, in which, respectively, disarticulation at the shoulder, and excision of one-third of the humerus had been practiced for myeloid tumors of that bone, there was recurrence in the stump, and in the lungs. So, too, in a case in which Langenbeck[3] resected 8 inches of the humerus for a tumor, as large as the double fist, which had perforated its capsule and extended processes between the muscular fibers of the flap. On death from exhaustion, 10 weeks subsequently, the muscles of the supra and infraspinous fossae of the scapula were found to be the seat of sarcomatous tubers. In all of these cases, diseased tissue had escaped the action of the knife, and precisely the same thing may happen if a limb be removed in its continuity too close to the morbid growth.

From these considerations I would establish the following general rules for guidance in selecting the point at which amputation should be performed:

For tumors of the lower epiphyses of the tibia and fibula, just below the knee; when the upper epiphyses of these bones are affected, through the lower third of the thigh; at the junction of the upper and middle thirds of the thigh for disease of the condyles; at the hip-joint for that of the upper extremity of the femur; below the elbow for tumors of the lower epiphyses of the radius and ulna; through the lower third of the arm when the upper epiphysis of the ulna is affected; at the junction of the upper and middle thirds of the arm for disease of the condyles of the humerus; and at the shoulder joint when the head of the humerus is involved.

In the event of the neoplasm being small, for example, not larger than an orange, it will not be necessary to go so high up. For a tumor of that size occupying the lower end of the tibia or fibula, the leg may, with great propriety, be amputated through its middle. On the other hand, a voluminous tumor may require the incisions to be made farther off. Thus, a growth, as large as the head, commencing in the lower extremity of the radius, had best be removed by disarticulation at the elbow.

Instead of amputation, excision of an entire joint, or of the affected epiphysis, along with the shaft, of the more slender long bones may be resorted to, particularly if the tumor presents a uniformly smooth surface, and is of a firm, dense consistence, or is inclosed in an osseous shell. Under these circumstances the surrounding tissues will, most probably, be found to be free from involvement, whereas, if the morbid growth is bosselated, and soft and elastic, or apparently fluctuating, the neighboring structures will be likely to be implicated, and amputation should be selected. In cases of doubt, excision may be commenced, and removal of the limb be substituted for it, if the capsule of the tumor is discovered to be perforated, and the soft parts infiltrated by the morbid product. If the periosteum of the adjacent bone is firmly adherent to the capsule of the neoplasm, of if the bone is eroded, the latter should also be excised, since, in these conditions, it is liable to be the seat of sarcomatous deposits.

From an operative standpoint, little can be said in favor of excision, except when the lower end of the ulna is involved in a small tumor, and the interarticular cartilage can be preserved, through which the wristjoint re-

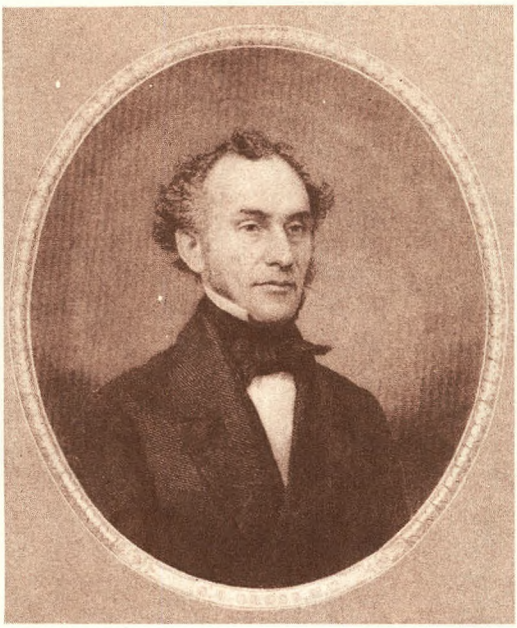
[1] Trans. Path. Soc., Lond., vol. ix. p. 367.

[2] Ibid., vol. viii. p. 351.

[3] Langenbeck's Archiv, vol. i. p. 142, case v., and Gurlt's Jahresbricht für 1860-61, p. 532.

mains unopened. In a case of this description, Mr. Lucas succeeded in giving his patient a useful limb, while in the remaining recoveries the limbs were simply incumbrances. Besides, the mortality after excisions is greater by 3 per cent than after amputation, notwithstanding the fact that the former was practiced on the bones of the upper extremity, except in two instances, while the thigh was the seat of the majority of the amputations.

Whatever operation be selected, if it be conducted near the seat of the disease, the surgeon should be prepared to encounter considerable hemorrhage. Thus in cases I and VI of the excisions, not less than forty ligatures were required, while in the case of Professor Gross (see p. 41) of disarticulation at the shoulder, the loss of blood was so great, despite compression of the subclavian artery, that death ensued in two hours.



SAMUEL W. GROSS

Samuel Weissel Gross (1837–1889) of Philadelphia was lecturer in surgical pathology at the Jefferson Medical College during the latter half of the 19th century. Although around the mid-century (1945) Boyer had named these tumors sarcoma and they had been studied by Nelaton and others, Garrison considered this extensive study by Gross the "first comprehensive work on bone sarcoma." In referring to the author of this paper, one must be wary of confusing him with his father, Samuel D. The elder Gross started in Lexington, Kentucky, but spent most of his important years as Samuel W.'s predecessor at the Jefferson, and was one of the leading surgeons and surgical pathologists of his era.

CLASSIC 79 Wiring of the Vertebrae as a Means of Immobilization in Fracture and Pott's Disease

B. E. HADRA, M.D. (1842–1903)

Present surgical interference in fractures of the spine consists in the removal of loose bones and in resection of parts of the arch, in order to free the spinal canal. The latter is done when grave symptoms indicate pressure upon the cord, or morbid changes of it or of the dura mater. Thus, mostly older cases will be submitted to resection. It is my purpose to propose to you a means of adaptation and retention of the broken ends before such damage is done, or before vicious consolidation has taken place.

The present apparatus of immobilization by position, extension, splints, braces, dressings, etc., is evidently sufficient only in the lightest and most tractable cases, which, unfortunately, constitute only a very small percentage. Aside from the enormous inconvenience, all these helps are ineffective when the broken ends are thoroughly separated. I remember two cases of dorsal fracture where I had the patients encased in plaster of Paris from the axilla down to the thigh. I know they were not benefited, but were made most unhappy by the treatment. It is simply impossible to keep the loosened vertebrae from gliding upon each other as long as no fixation can be had all around. Obviously, though, the contents of the thoracic and abdominal cavities cannot be immobilized. Still, absolute apposition is here more a necessity than in other fractures, because, aside from giving the broken bones a chance to properly consolidate, it must be the main aim to protect the cord and the spinal nerves against pressure, twisting, and also against changes due to irritation and to extension of morbid processes from the surrounding tissues. What do we do in other fractures if the usual means do not suffice to keep the parts well adapted? We do the most natural thing in the world; we fix them to each other by direct means — clamps, nails, wires, sutures, and so on.

Now, there is no good reason why vertebral fractures should not enjoy similar advantages. There is no danger in cutting down on the vertebral column, as all operators testify, as long, of course, as the cord and the nerves remain undisturbed; and even they stand a good deal more interference than is generally conceded. It is, then, a question of feasibility and efficacy. Theoretically there should be no doubt about it. Still, practical evidence alone will satisfy nowadays. The literature — at least that at my command — offers only one case where direct fixation of broken vertebrae was planned and executed, and I think this case deserves the fullest attention. It is that of

Dr. W. T. Wilkins, a short history of which is given by Prof. Keen in the "Reference Hand-book of Medical Science." It reads thus:

"I find reported a case of a child born with a hunch on its back, the mother having been severely injured the day before its birth. On operation, on the day after birth, the last dorsal and the first lumbar vertebra were found separated a half-inch, and a hernia protruded through the fissure. The spinal cord was pushed to one side. The hernia was reduced, the two vertebrae held together by a figure of 8 carbolized silk ligature, passing through the intervertebral notches of the two vertebrae, above and below, and the child was practically well in a few days."

It was my lot to test the problem in a case which was operated on last December, and I regret that I, at that time, did not know anything of Dr. Wilkins' case. I fastened together the spinous processes of the sixth and seventh cervical vertebrae by silver-wire loops, in a case of fracture which had been acquired nearly a year before. The patient is still at the John Scaly Hospital, and I must confess is not perfectly well yet, though the efficacy of the operation has been fully demonstrated. To give a short history of the case, it may be stated that a man of thirty years of age, working as waiter in a restaurant, fell to the floor, striking with great force on his buttocks. Immediately after, he felt intense pain in his neck, and was unable to move it. On examination, the sixth cervical vertebra was found pushed forward and turned around its vertical axis to the right, whilst the spinous process of the seventh vertebra appeared unusually prominent. Patient could not open his mouth more than an inch, from what cause I could never understand. Exsection was made by the head, and as the parts seemingly returned to their normal position, the neck was put in a firm cravatte. Patient, from reasons of no medical interest, left the St. Mary's Hospital a few days after his admission, and returned to his former occupation, wearing constantly his apparatus, getting along well enough with an occasional hypodermic injection of morphine. But once, when he imprudently bent his neck in a rapid and forcible way, the cravatte having been left away, he fainted, and when recovered could not stand upright. His head and neck were turned to the right and kept perfectly stiff; right hand became numb, right arm weak; girdle pains around his upper abdomen; bladder not fully under control; slight priapism. In such condition he came to the John Scaly Hospital on November 1st, 1890, ten months after the first accident. His face flushed up on the slightest provocation; his mouth could not be opened over an inch; the left upper portion of the trapezius muscle was hard and protruding, forming a tumor; his right hand colder than the left; extreme hypesthesia on the right side; head was rolled around to the right, and the vertebrae in same position as on the first observation; muscles, though, reacted alike on both sides of the body to either current. Patient was put under chloroform, not being able to stand any manipulation without an anesthetic. Head and upper portion of neck very movable, and crepitation distinctly heard. Reduction was easy, and the stiff cravatte was applied again. In spite of frequent adjustment and modification of the retaining apparatus, patient grew steadily worse. Pains in back, arms and around abdomen became unbearable, and walking impossible. He was in such a pitiful condition, that he insisted upon any operation which would give the faintest hope of relief. I finally consented to cut down on the place of injury, which I did on the 22 of December. My plan was to remove loose bones, if present; to sever the posterior ligaments, if they should be thickened and contracted; and finally, to wire the spinous processes, in order to steady the vertebral column.

From the improvement setting in every time the bones were well adjusted, I inferred

that there was no serious change within the vertebral canal, nor in the cord itself. I therefore did not consider the opening of the canal called for. Not finding loose bones, I severed the ligamentum nuchae and the interspinous ligaments transversely in several places, so as to expose the spinous processes fully, and also in order to remove the interference of the perhaps thickened and contracted ligaments which could have acted as an impediment to the replacement and retention of the dislocated parts, exactly as in other fractures or dislocations. I am satisfied that this part of the operation was not only unnecessary, but that it caused all the following inflammatory symptoms, as a good deal of lacerating was unavoidable. The main aim of the operation, the wiring of the sixth and seventh spinous process was done with silver wire, carrying it four to five times around in a figure of 8. The wound which extended from the occiput down to the first dorsal vertebrae was then closed, a small drainage tube inserted right over the place of wiring and the stiff cravatte reapplied. Patient did not improve for several days, but then gradually got better. After some weeks I thought that the wire had become loose, because he began to exhibit some of his former symptoms. He was put under chloroform again, the wire removed, and a new one fixed on. On this occasion it was easily seen that the lower end of the fractured spine slipped away from the upper for about one and a half inches to the right. From now on improvement went on more rapidly. Patient was able three weeks ago, that is twelve weeks after the operation, to move his head in a normal way in every direction, without pain. He could open his mouth fully, walk as well as anybody else; no headache; no trouble with bladder or bowels. The right arm remained somewhat weaker, but was otherwise normal in all its functions and of normal sensation. The favorable condition though made me, I fear, too careless. I allowed him to be without the bandage occasionally, and removed the wire, as it kept a fistulous ulcer from closing. He became worse again, and has now considerable pain in his right arm and shoulder. The spinous process of the sixth cervical vertebra is very tender on pressure, and requires further attention, as the probable cause of the new trouble. Otherwise patient is well, and can make use of his neck without any difficulty.

This is my case, which shows that the operation is feasible and effective. But I would be a poor surgeon if I had felt satisfied with my method and the course of my case. Further experiments on the cadaver, and further reflection has led me to believe that the proposed wiring is one of the most promising, and at the same time simplest surgical procedures, provided that it be so modified as I will describe it hereafter. Of course, it is intended only for the readjustment and retention of the broken bones, therefore, in some cases, it may fill all the indications; in others, it will simply be an addition to other operations.

But before proceeding I show you here a vertebral column, on which two adjoining spinous processes have been wired together in the three portions of the spine. Of course, more than two may be joined if necessary. You see how firmly the vertebrae hold together, and how resistant they become. In fact, common forces, as experienced in human life, are hardly able to undo the fixation of the two lumbar vertebrae. Of course, this method is possible only when the spinous processes are not fractured themselves. If so, one would have to resort to the wiring of the transverse processes, as shown also on the model.

The operation consists then of the following simple acts. A good long skin incision, the center of which should be over the seat of fracture; next the muscles on either side of the spinous processes should be lifted up and drawn aside with blunt instruments, but not more than to allow one to feel the con-

tours of the bones. Then a stout curved needle, armed with wire, is carried through the interspace between the spinous process of the broken vertebra, and that of the next upper one, as deep as possible; brought out, entered again into the next inferior interspace; brought out on the other side; entered there again into the next lower interspace; carried around the spinous process of the vertebra, below the fracture, and again carried through the middle interspace, and meeting the wire where it entered, well twisted together to a knot. In short, a figure of eight loops is carried around the spinous processes of the broken vertebra and that of the next lower one, which may be repeated as often as seems advisable. In the lumbar portion of the spine simple loops will suffice, as the processes are almost horizontal. Then the wound is closed with or without drainage. Under circumstances three or even more vertebrae may be fixed together.

All this can be done in a few minutes. The operation is nearly bloodless; involves no great laceration of tissues, and can be made thoroughly aseptic. The wires are well secured in their position by the ligaments, which remain undisturbed.

More difficult is the wiring of the transverse processes. Here the muscles have to be lifted and drawn aside much more extensively. In order to avoid impeding nerves in the loops, I think it would be best to do it as shown on the model; that is, first to surround one process, and then carry the thread to the next one, and again tie it here by a loop, so as to have only one wire in the interspace.

I cannot resist the temptation to connect my device also with the treatment of Potts' disease. Here, too, the indication in cases where the abscess or carious bones do not call for other surgical attempts, is mainly to steady the vertebral column in order to protect the cord, to prevent the diseased bones from rubbing on each other, and, finally, to make the outcome, in regard to disfigurement, as favorable as possible. Judging from my concededly limited experience, and from theoretical deductions, the proposed procedure will do better than braces, corsets, plaster jackets and the like. It seems to be called for as soon as displacement of the bones is noticed; but even if a full kyphosis should be established, it will be proper to put the patient under an anesthetic, and to wire together the spinous processes, provided that the column can be straightened to a satisfactory extent. It occurred to me that the fixation of the spinous processes acts like a lever on the bodies of the vertebrae in front, as you can see on my model. This is a great advantage in cases where intervertebral disks are destroyed, or where cavities have formed by necrotic destruction of the vertebral bodies. Evidently such gaps would be held open, whereby better drainage would be procured, the contact of the diseased surfaces prevented, and the filling up by new tissues allowed in the most advantageous configuration. Obviously also the wiring could be added to other operations, such as establishing drainage for the abscess, or to the removal of necrotic bone, or to the trephining of the arch, etc.

Summing up, I do not claim that my proposition is an operation fitting every case of spinal fracture or of sponditiitis; it is simply a method of holding the broken or disease parts together better than any other method, and with considerably less annoyance to the patient. In many cases it may do so by itself, in others it will be a desirable addition to other operations. In others again, it will be as fruitless as all other methods at our disposal. The operation is simple and free of danger, and if only a small portion of the advantages set forth could be attained, it would constitute a very desirable addition to the present means to combat such formidable and intractable ailments.



BERTHOLD ERNEST HADRA

Berthold Ernest Hadra (1842–1903) was born in Silesia. He came to the United States in 1869 settling first in Houston, Texas and moving to Austin in 1872 where he remained engaged in a thriving practice. In 1891 he operated on a fracture dislocation of a cervical spine in a child showing progressive cord deterioration, using wires wrapped around the spinous processes to stabilize the vertebral sector. The concept of vertebral stabilization was highly original and the first recorded in surgical literature. He later applied the procedure to vertebrae involved in Potts' disease. He reported these cases in the *Medical Times and Register* and later that year presented his material to the American Orthopaedic Association. This presentation appeared in their *Transactions* (4:206, 1891) and thereby came to the attention of European orthopedic surgeons who, like Fritz Lange of Munich, modified but continued its use until the advent of Russell Hibbs' spine fusion operation in 1911.

For readers with special interest, Egger's excellent in-depth biography of Hadra may be found in *Clinical Orthopaedics and Related Research,* Vol. 21, 1966.

CLASSIC 80 Ischaemic Contracture

Experimental Study

PAUL N. JEPSON, M.D. (1893–1949)

Ischemic contracture is a specific deformity following an injury to the extremities, and usually occurs in children between 3 and 12 years of age, whose blood vessels are less mature and more easily disturbed than those of older persons. In the majority of cases the injury is in the upper extremity, at or near the elbow joint. As it usually comes on following a fall or a blow in cases of fracture, and at times when there has been no fracture, there is an extensive injury to the soft parts in the fold of the joint with a resulting hematoma. Usually fixation by one or another method or tight bandaging has been applied, causing severe pressure on the structures in the region involved, and in a short time swelling and blueness of the extremity with paresthesia followed by more or less pain. Within a varying period after these symptoms, and even after the removal of the fixation or bandage, there is swelling in the muscles, especially the flexors. These muscles gradually shorten, and there follows a severe contraction of the wrist as well as of the fingers, and in the more advanced state, the claw-hand deformity results. In some cases there is limitation of supination and pronation. The joints are usually not affected. The fingers can be extended if the wrist is hyperflexed. The muscles are hard and rope-like, and often there is a slough on the flexor surface of the arm. Even the skin may have a hard leathery feeling. There may be disturbances in sensation in areas supplied by one or more nerves, most frequently only in this part of the hand supplied by the ulnar nerve, but sometimes in the area supplied by the median or radial nerves.

Following these usual initial symptoms the fingers become pale, cyanosed, and cold. Within a few hours the patient complains that the fingers are numb. He is usually more concerned than the surgeon. Electric irritability of the muscle is lost after about 5 hours of ischemia, in some cases in as short a time as three and one-half hours. The muscles become flaccid and powerless. Muscular rigidity is then noted and the painful contracture begins. This disappears in about 65 to 70 hours, leaving the muscles again flaccid and very tender to pressure. After a few more days the swelling disappears and muscular tissue begins to be replaced by fibrous tissue. Muscles then become hard and resistant, and muscular atrophy appears.

The tension on the extensor musculature of the fingers as a result of the hypertension in the metacarpophalangeal joints is practically unavoidable even though extensor muscles are usually not involved in myositic changes.

A gross pathologic study of the condition shows that the muscular tissue is pale yellow, hard and board-like, and that the tendons are usually matted together. As a rule there is a change in the joints other than a tendency toward subluxation. The nerves appear to be flattened. Microscopically there is a loss of muscle striations, atrophy of the muscle fibres, a loss of the nuclei of the muscle fibres, and an increase in connective tissue.

REVIEW OF THE LITERATURE

In 1869, and later in 1875, Volkmann described a deformity of the hand and wrist resulting from an interference of some nature with the blood supply of the muscles of the forearm. This condition was usually preceded by the application of splints or bandages for fracture of the humerus in the region of the elbow joint. In his classical article published in 1881, Volkmann said that he believed the affection was due to ischemia caused by the muscular tissue being deprived of arterial blood, in consequence of which the muscle perished from want of oxygen. He called attention to the fact that the contracture comes on sometime after the initial paralysis; that it becomes more marked as more repair tissue is laid down; and that from the onset of the condition there is considerable rigidity which is increased as more scar tissue is formed. He reported but one case in 1875 and that was in a child of 16. Mention of this case was made in his book published in 1869. Previous to this Hildegrand, in 1850, quoted a case of Hamilton's without giving the reference, but so far Hamilton's account has not been found.

So far as I have been able to determine the mechanism of an ischemic contracture as seen in man has never before been reproduced in an animal for the purpose of determining, if possible, a means of preventing this deformity. For this reason it was thought worth while to report the experiments begun in 1924 at the Institute of Experimental Medicine of The Mayo Foundation.

METHOD OF EXPERIMENTATION

Dogs weighing approximately 12 kg were used in all the experiments. Ether was used for the anesthetic and all operative procedures were carried out with sterile technic. The non-operative procedures were carried out with due regard to the comfort of the animal and morphine was freely used.

In the first series of experiments an attempt was made to produce a more or less typical contracture deformity by means of splints, casts, and bandages, but it was soon seen that it was impossible to produce a deformity lasting for any length of time by these methods.

In the second series of experiments an Esmarch rubber bandage was applied above the knee of the right pelvic limb and left on for from one and one-half to 24 hours. In the animals that wore the rubber bandage for from one and one-half to three and one-half hours, the deformity manifested by a main-en-griffe, disappeared within 3 or 4 hours after removal of the tourniquet. In those with the bandage applied for a longer period the deformity remained for 3 or more days, but at the end of this time there was normal function in the extremity.

In the next series the dogs were operated on in pairs. In one animal a simple ligation of the femoral vein was performed through a longitudinal incision over the vein on the right thigh. The vein was isolated and ligated with linen as it lay in Hunter's canal. In the second animal in this series an incision was made on the medial side of the right thigh running parallel to, and about 6 cm below, Poupart's ligament, in such a manner as to encircle a little more than one-third of the thigh, and it was carried down through the fascia to the muscle. Within a few minutes the extremity operated on was cold and bluish. So far as could be noted there was little difference in the animal having the simple ligation and the one having the incision around the thigh. First, there was spasticity of the extremity with rather flaccid paralysis of the digits, but of such a nature as to make the animal tend to curve its toes under. The deformity simulated the main-en-griffe deformity in the human being, and was maintained for from 6 to 9 days. The dogs with simple ligation of the vein maintained the

deformity slightly longer than those with the partially encircling incision.

In the next series these two operations were combined. Almost the same results were obtained as in the two previous series, except that the deformity lasted a few hours longer.

From the results of these experiments it was concluded that ischemic paralysis did not depend wholly on the procedures that had been employed. Accordingly, after the wounds had healed, an Esmarch bandage was applied fairly tightly above the knee at the site of the initial operation, fastened in place with adhesive, and left on for from 6 to 24 hours.

One of the animals was left with a deformity typical of ischemic contracture and similar to that in man. The forefoot and distal phalanges were flexed while the proximal phalanges were extended. This simulation of the typical contracture was not persistent in all of the dogs. However, the animal which wore the bandage the longest maintained the deformity for more than 18 months with no signs of improvement. The leg gradually wasted away and became hard and board-like as in the human being. When the animal attempted to put the foot to the ground, only the tips of the toes would touch and there was considerable resistance in the muscles. With exercise the deformity increased and the dog limped about as he did immediately after the application of the bandage. Another animal on which the bandage was kept for several hours still had the deformity at the end of two months, but after that he gradually improved.

A method of producing a lesion which appeared similar to that in man having been developed, the next procedure was to determine, if possible, a method of preventing such deformity. A dog in which the incision and ligation had been performed was selected for this experiment. An Esmarch bandage was applied above the knee and left on for 8 hours. At the end of this time there was considerable edema and other signs of a sluggish circulation, and the toes were contracted. Six hours later the wound was opened and the blood and serum were evacuated. Two rubber tubes for drainage were placed deep in the intermuscular space and sutured. The following day the swelling had gone down markedly, and 4 days later the dog was walking normally. This was in marked contrast to the condition of the control animals in which drainage had not been instituted. The experiment was repeated often enough to bring out the fact that intrinsic pressure is a factor which must be dealt with in this condition. . . .

DISCUSSION

It appears that direct injury to the nerves may frequently occur, but it has not been proved that such injury is the primary cause of the typical main-en-griffe deformity. There must be some other causative factor. It is true that the involvement of the intrinsic muscles of the hand can be explained only by direct injury to the ulnar nerve, but as a rule injury to some other tissue precedes injury to the nerves. In the forearm the ulnar nerve is the one most commonly affected. The explanation of delayed ulnar palsy is that peripheral neuritis develops some time after the injury.

The almost universal involvement of the flexors but not of the extensors may be explained on anatomic grounds. On the anterior surface of the forearm the soft tissues, composed of the flexor muscles, arteries, and nerves, overlie the radius and ulna, forming a good-sized pad. Besides this, the body of the anterior flexor muscles comes in direct contact with the source of the injury, whether it be splints, cast, bandages, or direct force. The ulna is situated between the splint and the extensor muscles and protects these muscles from the injury of a splint.

No other structures are more susceptible to injury than the nerves. With their close proximity to the blood vessels, a constriction lasting for a long time and sufficient to close the large vessels of the brachial region must of necessity exert marked pressure on the median and ulnar nerves, and induce neuritis with subsequent degeneration of the nerve. The extensor muscles do not suffer because the musculospiral nerve which ultimately distributes branches to this group of muscles is deeply placed in the upper arm between the triceps muscle and the humerus. In the region of the elbow joint the nerve is

protected by its position between the long extensors of the forearm. It is, therefore, not subjected to as much trauma as the other nerves because of their superficial position in the upper arm.

Embraced as it is by the pronator radii teres muscle, the median nerve is subjected to practically the same injurious forces as the muscle. Therefore, if pressure over this muscle and its associated group is sufficiently great to cause profound ischemia, the nerve must share the fate of the muscle which encloses it and suffer degenerative changes to some extent. Flaccid paralysis at the first, followed shortly by the contracting deformity, would suggest primary injury to the nerves but in all probability there is also injury to the muscle, which helps to form the contracture and resulting deformity.

On the other hand, the acceptance of a primary myositis and a neurogenic origin for this type of contracture would explain cases of Volkmann's ischemic contracture in which no fracture occurred or in which no profound changes took place in the muscles. The site of the lesion may often be indicated by the scar on the forearm.

If a fracture or injury occurs in the region of the elbow joint, the tissues are bruised and effusion of blood and serum follows. The tension in the subfascial zone in the forearm can be so great as to cause cyanosis of the whole forearm and hand. A blood clot forms in the tissues, and inflammation follows with a deposit of the inflammatory products in the tissues. This deposit in itself will cause pressure and have the same effect as a tight splint or bandage.

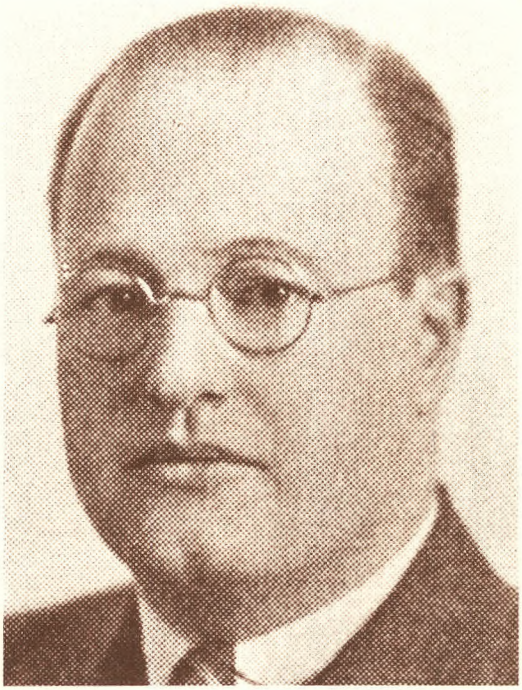
Muscles completely deprived of their oxygen supply finally disintegrate, but in a typical case of Volkmann's contracture the deprivation of oxygen is not complete. There is ischemia, the blood supply is cut down far below normal, reducing the nutrition to the muscles, and as a result the resistance of the extremity is lowered. In the specimens studied during this experiment, the calibre of the blood vessels was so markedly reduced as to prohibit the flow of the solution used in an attempt to make a roentgenogram of the circulatory tract of the extremity.

It can be understood from the discussion that no one factor is responsible for the production of the typical deformity seen in a case of the Volkmann–Leser ischemic contracture. It would seem from these experiments that the deformity in the human is usually produces somewhat as follows: First, there is an injury of some extrinsic nature in the region of the elbow joint, or to the humerus or bones of the forearm, consisting of a fracture or an injury to the soft parts only, or both; or fracture of a clavicle, and so forth. Splints, casts, or bandages may or may not be applied. When splints are used pressure sores often develop, usually coming over the flexor muscles which predispose to the formation of scar tissue. But pressure sores are not required to bring about the deformity. The tissues are bruised by the trauma and extravasation of blood, and serum follows. The tension may be so great as to cause cyanosis of the entire forearm. This intrinsic pressure causes local myositis and then a pressure on the nerves (usually the median and ulnar) and the blood vessels. There develops a flaccid paralysis followed by swelling in the muscles. Almost immediately contracting of the flexor muscles begins, resulting in the main-en-griffe deformity originally described by Volkmann. As the condition goes on, due to the diminished blood supply, the flexor muscles begin to atrophy and the tendons become matted together. When the wrist is hyperflexed the fingers can be straightened out. If the intrinsic pressure is relieved within a short time after the formation of the hematoma, the patient will usually recover.

SUMMARY

The lesion of ischemic paralysis as seen in man was reproduced in animals by bandag-

ing one extremity and by preventing the return of the venous blood. In an attempt to prevent the development of the deformity, it was found that if drainage was instituted within a few hours after carrying out the procedures leading to the development of the lesion, contracture did not ensue, or was very slight. The results of these experiments would seem to indicate that the contracture deformity is due to a combination of factors, the most important of which are impairment of the venous flow, extravasation of blood and serum, and swelling of the tissues with consequent pressure on the blood vessels and nerves in the involved area. If this is true, early drainage would be of value.



PAUL N. JEPSON

Paul N. Jepson (1893–1949) wrote this paper while he was a Fellow in Orthopaedic Surgery at the Mayo Foundation in 1921, as his thesis toward his Masters degree. Volkmann's paper (see CORR No. 50, 1967) was, of course, the Classic on compartmental syndromes and was followed by a vast literature mostly concerned with the pathophysiology of the process. Jepson's paper reprinted here was the first successful attempt to reproduce ischemic contracture in animals and to demonstrate that these contractures may be prevented by prompt surgical decompression. At the time of his untimely death at 56 years of age, he was on the Orthopaedic service of the University of Pennsylvania Medical School.

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