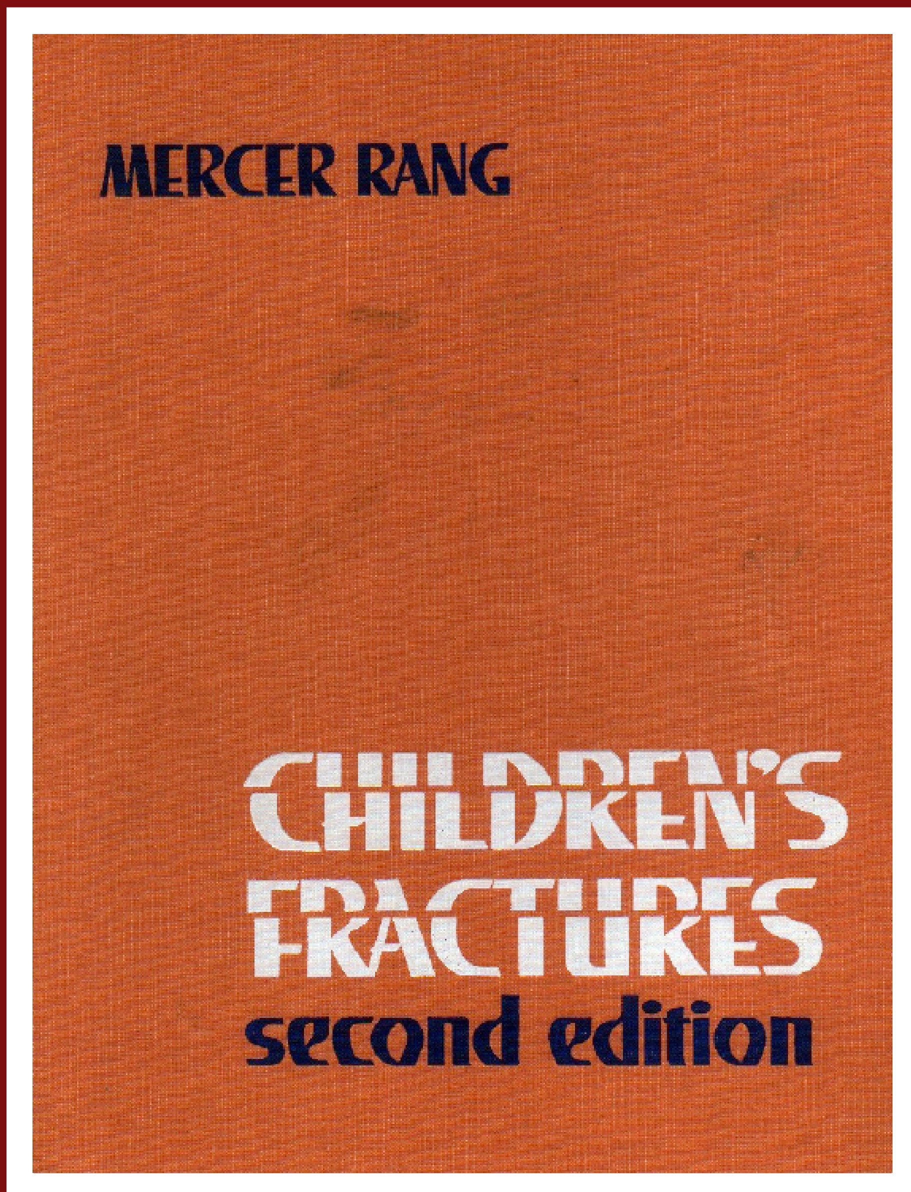
Children's Fractures

[2nd Edition]



Mercer Rang

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Children's Fractures

second edition

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1/ Children Are Not Just Small Adults

Fractures in children differ from those in adults. Because the anatomy, biomechanics, and physiology of a child's skeleton are very different from those of an adult, in children you will see differences in the patterns of fracture, the problems of diagnosis, and the methods of treatment.

ANATOMIC DIFFERENCES

The most important part of a child's skeleton is composed of radiolucent growth cartilage. Injury can only be inferred from widening of the growth plate or from displacement of adjacent bones on plain or stress radiographs (Fig. 1-1). The periosteum is thicker and stronger and produces callus more quickly and in greater amount than in adults.

BIOMECHANIC DIFFERENCES

Biomechanics of Bone

Many years ago it was thought that fractures were not so common in children as in older people because "the proportionate excess of the animal over the earthy constituents" made bending of bone possible. However, the osteoid of a child's bone is not significantly less calcified, but the density of a young bone is certainly less. Young bone is more porous (Fig. 1-2); the cortex is pitted and can be cut easily because the Haversian canals occupy such a great part of the bone. In effect, a child's bone is more like Gruyère cheese than cheddar and can tolerate a greater degree of deformation than an adult's bone can (Fig. 1-3).

Fig. 1-1. Separation of the fibular epiphysis was only a clinical diagnosis until a stress radiograph was obtained.

Fig. 1-2. Microradiographs of the distal radial diaphysis of an adult and of a child 8 years old. The Haversian canals are larger in the child. Children's bones are more porous than adults'.

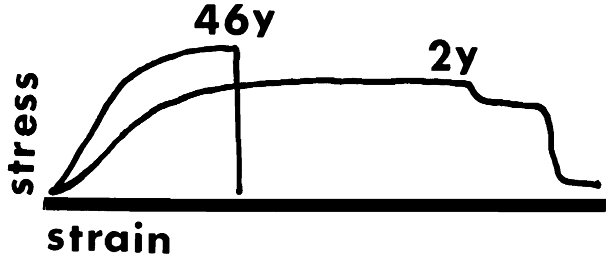


Fig. 1-3. Load deformation curves of bone for a 2-year-old and a 46-year-old. The child has a long plastic phase, and then the curve decays irregularly owing to a rough fracture surface (After Currey JD, Butler G: Mechanical properties of bone tissue in children. J Bone Joint Surg 57A:810, 1975).

Fig. 1-4. Fracture types in children.

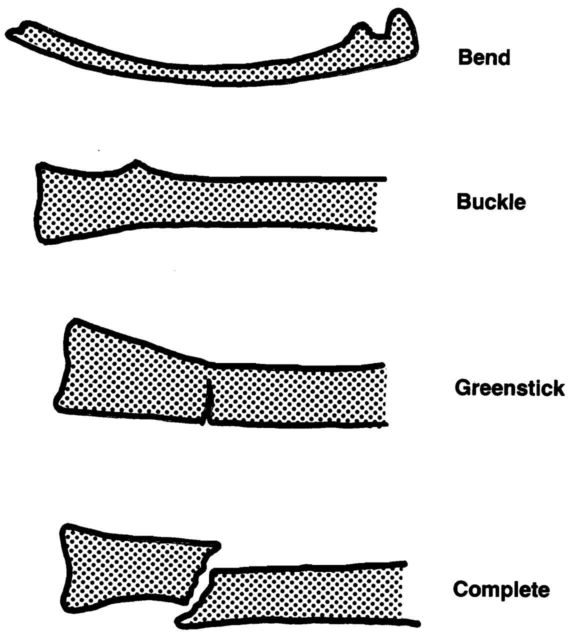


Fig. 1-5. Buckle fracture (child, 10 years). The compressed bone has erupted on the surface in the same way that mountain ranges were pushed up on earth.

Pores prevent the extension of a fracture line in the same way that a hole drilled through the end of a crack in a window will prevent the crack from extending. Compact adult bone fails in tension only, whereas the more porous nature of a child's bone allows failure in compression as well.

Classification of Children's Fractures

The porous character of a child's bone accounts for the various fracture types (Fig. 1-4):

Buckle Fracture. Compression failure of bone produces a buckle fracture, also called a *torus fracture* because of its resemblance to the raised band around the base of an architectural column (Fig. 1-5). These fractures occur near the metaphysis, where porosity is greatest, particularly in younger children. Teenaged children who do not bear weight for any reason and hence still have porous bones may sustain buckle fractures.

Traumatic Bowing of Bone. Bending of bones, most commonly recognized in the ulna and fibula, can occur without any evidence of acute angular deformity (Fig. 1-6). If you try to break a child's forearm, either post mortem or during osteoclasis, you will find that the bones may be bent 45 degrees or more before the telltale sound of a greenstick fracture is heard. If you stop before the bone fractures you will find that it will slowly, but incompletely, straighten itself out during the course of a few minutes.

This has been called *plastic deformation of bone.* In dogs the bone deforms because microscopic, shear fractures—at about 30 degrees to the long axis—develop on the concave aspect of the bone. Because there is no true fracture there is no hemorrhage, no periosteal new bone formation, and no remodeling.

Fig. 1-6. Bending of the fibula (child, aged 12). The position remained unchanged, and no new bone formed around the fibula. Remodeling did not occur, even after 4 years.

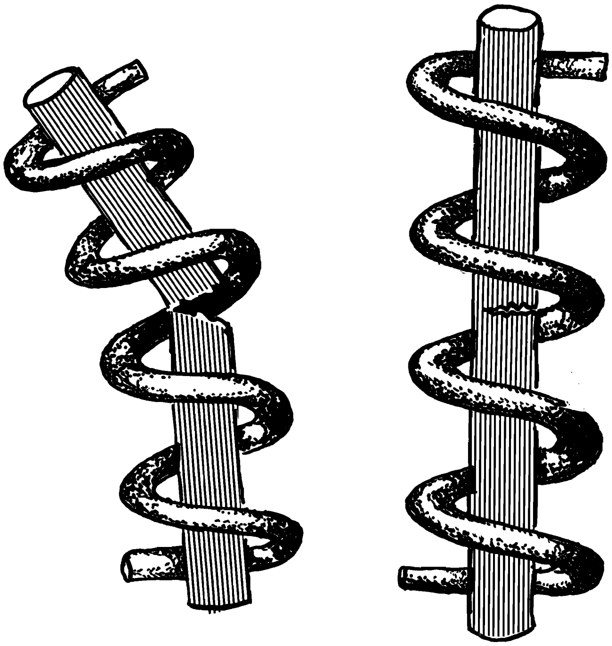


Fig. 1-7. Elastic recoil hides the maximal displacement of a fracture.

Greenstick Fracture. When a bone is angulated beyond the limits of bending, a greenstick fracture occurs. This is a failure of the tension side of the bone; the compression side bends. A greenstick fracture occurs when the energy is sufficient to start a fracture but is insufficient to drive it through. The remaining bone undergoes plastic deformation. At the moment of fracture there is considerable displacement—as in most fractures—and then elastic recoil of the soft tissues improves the position (Fig. 1-7). The fracture can hinge open again subsequently, owing to muscle pull (Fig. 1-8). Complete closure of the fracture, which is prevented by jamming of spicules, can only be achieved by completing the fracture and momentarily overcorrecting the angulation.

Anyone wishing to study biomechanics further is advised to read J. E. Gordon's *New Science of Strong Materials or Why You Don't Fall Through the Floor.*[3]

Complete Fractures. The treatment of fractures is helped by an understanding of the difference between fast and slow fractures, and between spiral and oblique fractures.

Fig. 1-8. Greenstick fracture of the radius. One cortex has bent; the other is gaping. The initial angulation was acceptable, but it increased and should have been corrected.

The surface of a slow fracture is rough, like a stubbly lawn, while a fast fracture is smooth. Young bone and a rough fracture surface make it easier to keep the ends hitched.

Complete fractures are rarely comminuted in children. This may be because a child's bone is more flexible than that of an adult. Some of the force of impact is dissipated in bending the bone, whereas in adults the kinetic energy of impact is entirely used to disrupt the intermolecular bonds in the bone.

The direction of force decides the direction of the fracture line (Fig. 1-9). A *spiral* fracture, produced by a twist, has an intact periosteum hinge along the straight, axial part of the fracture. If you can find where this is, you can determine whether the fracture can be reduced by clockwise or counterclockwise rotation. The periosteal hinge will hold the fracture stable. These fractures are not held by the three-point pressure principle applicable to transverse fractures. They are best held by a crank-handle cast, which controls rotation (Fig. 1-10). Longitudinal loading will impact the fracture.

A *transverse* fracture results from angulation. The periosteum is torn on one side as a fragment of bone buttonholes through. A transverse fracture can only be reduced by increasing the deformity to 90 degrees, so that the end can be unbuttoned; by pulling hard in this 90-degree angulation position; and then, still pulling, by straightening the bone. A three-point pressure cast was designed to hold this fracture (Fig. 1-11). Longitudinal loading will impact the fracture.

An *oblique* fracture is due to axial overload; a shear fracture propagates at 30 degrees to the axis of the bone. The periosteum may be widely torn. These fractures are very unstable. They are best reduced by distraction—a straight pull. They are held either in traction or by a cast applying potentially dangerous circumferential pressure. Longitudinal loading obviously displaces the fracture (Fig. 1-12).

A *butterfly* fracture is due to a combination of axial overload and angulation (Fig. 1-13). When the fracture is produced by a blow, the butterfly fragment lies on the side of the bone that was struck. The periosteum is most damaged on the opposite side. The fractures are unstable. When the butterfly fragment is small, three-point pressure may hold the fracture, but usually distraction is required.

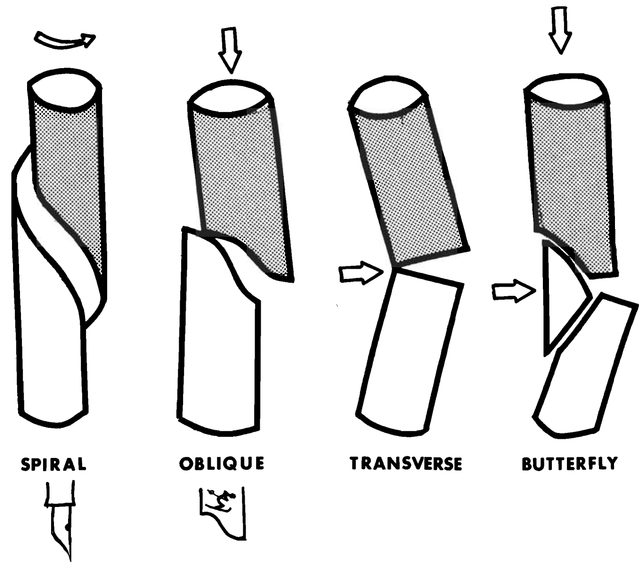


Fig. 1-9. The shape of the fracture tells you how it was produced. Spiral fractures are shaped like a pen nib. Oblique fractures are like a ski jump.

Fig. 1-10. Spiral fracture. There is an axial periosteal hinge providing longitudinal stability. A crank-handle cast prevents displacement.

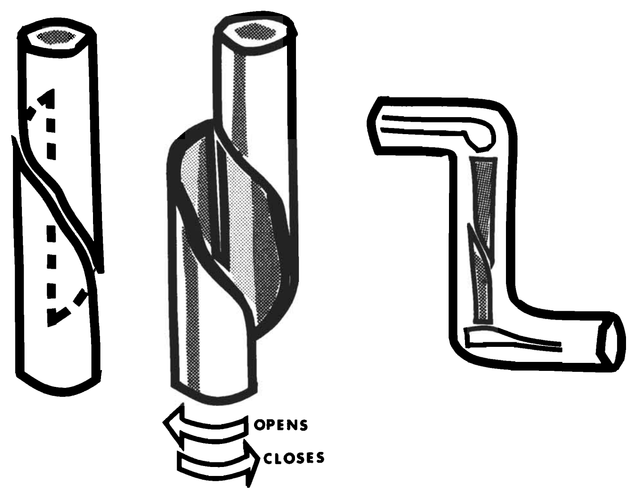
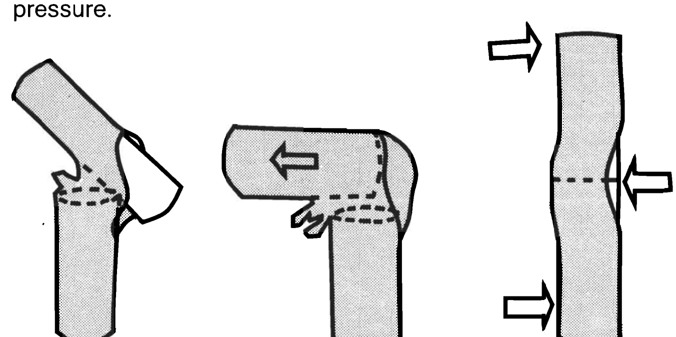


Fig. 1-11. A transverse fracture. Reduction requires retracing the path of the injury. It is held by three-point pressure.



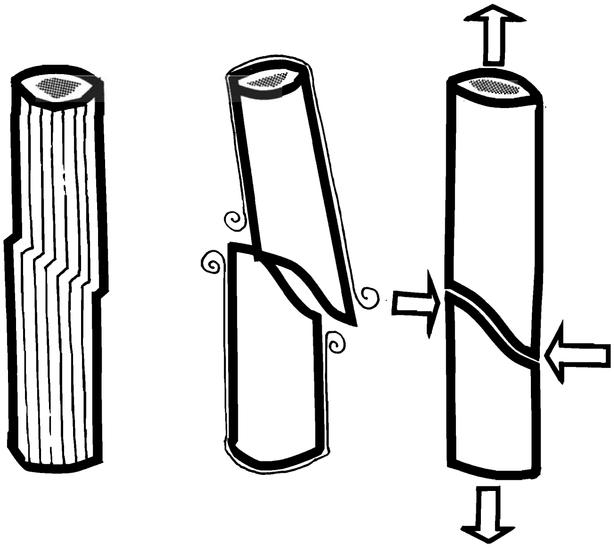


Fig. 1-12. An oblique fracture. An overloaded column fails in this fashion.

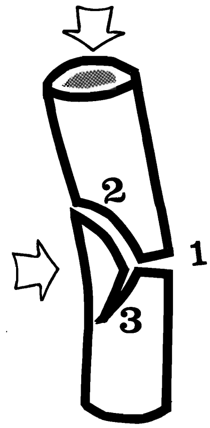


Fig. 1-13. Butterfly fracture. The numbers indicate the order in which the fractures occur.

The Biomechanics of Growth Cartilage

Ruysch was one of the earliest experimentalists to find (in 1713) that considerable force is required to separate the epiphysis from the metaphysis because they are firmly connected *externally* by the periosteum and *internally* by the mamillary processes existing between the two. In 1820 James Wilson showed that a longitudinal force of 550 pounds was required to detach the epiphysis from the metaphysis, but that if the periosteum was divided first the force required was only 119 pounds. A few years later, in 1845, Salmon again demonstrated the importance of periosteum. Although he could separate the epiphysis of a newborn's distal femur by hyperextending the knee, he could not produce displacement until he cut the periosteum.

In 1898 John Poland wrote *Traumatic Separation of the Epiphysis,* a book of 900 pages that summarized what was known about the epiphysis to that time. Since then, very little new information has been added, and anybody interested in children's fractures must read Poland's book. He was probably the first to show experimentally that it was easy to produce epiphyseal separation but difficult to produce dislocations in children. He wrote, "This is easily understood when the comparatively weak conjugal neighborhood in the young subject is realized. The violence producing the two forms of injury—epiphyseal separation in children and dislocations in adults—is frequently of the same character."[6] (This quotation is more readily understood if you appreciate that the growth plate was once called conjugal cartilage, because it joins two bones intimately together.) Poland concluded that ligaments are stronger than growth cartilage.

At least one attachment of a ligament is to an epiphysis. Hence, when a valgus force is applied to the knee of a child, for example, the distal femoral growth plate gives way, whereas in an adult the medial ligament will rupture or detach.

Growth cartilage has the consistency of hard rubber. When the plate is thick, the epiphysis can be rocked slightly on the metaphysis because of the elasticity of the plate. This property not only protects the bone from injury but also appears to protect the joint surface from the type of crushing injury that is common in adults.

In 1950 Harris revived interest in biomechanical testing of the growth plate.[4] Applying a lateral force to an epiphysis, he found that the hormonal environment greatly influences the strength of the bond between the epiphysis and metaphysis.

Bright and Elmore, in a brief but elegant paper[2] studied the force required to separate the upper tibial epiphysis in a rat (Fig. 1-14). The age of the animal and the direction in which the force is applied are both important factors. The plate is most resistant to traction and least resistant to torsion. Furthermore, the epiphysis can be displaced 0.5 mm before separation begins. In a subsequent paper they showed that small cracks developed in the plate when 50% of the force required to separate the plate was applied.[1]

The Biomechanics of Periosteum

Today it is well recognized that the continuity of the periosteum determines whether or not a fracture is displaced. The periosteum is much thicker, stronger, and less readily torn in a child than in an adult. When displacement occurs, the strong hinge of periosteum can help or hinder reduction.

PHYSIOLOGICAL DIFFERENCES

Growth Remodeling

Growth provides the basis for a greater degree of remodeling than is possible in an adult (Fig. 1-15). As a bone increases in length and girth, the deformity produced by a fracture is corrected by asymmetric growth of the physis and the periosteum (Fig. 1-16). Karaharju and associates studied fractures in puppies tibiae that had been plated with angulation.[5] The physis grew asymmetrically to straighten up the articular surface. Most of the correction occurred early.

The bump of a malunion is corrected by periosteal resorption; the concavity is filled out by periosteal new bone. This is an example of Wolff's law, which may be mediated by piezo-electric potentials. The compression side of a loaded bone develops a negative potential, which is a stimulus to bone formation. This and other theories are reviewed by Treharne.[7]

Remodeling, which restores the function of a bone to normal, must be distinguished from rounding off, which improves the radiograph but does little for the patient (Figs. 1-17, 1-18).

Overgrowth

A fracture through the shaft of a long bone stimulates longitudinal growth, probably because of the increased nutrition to growth cartilage produced by the hyperemia associated with fracture healing. In practice, an undisplaced fracture of the shaft of the femur will, in the course of a year or two, cause the femur to be about 1 cm longer than its opposite member.

Progressive Deformity

Permanent damage to the growth plate will produce shortening and often progressive angular deformity. Such complications have been recognized for many years, and in 1888, Lentaigne even diagnosed this condition in an Egyptian mummy.

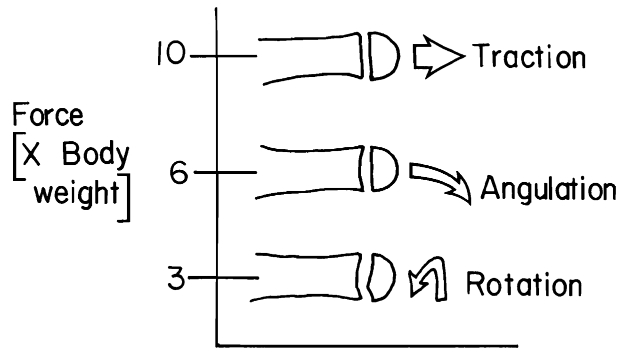


Fig. 1-14. Load required to separate the proximal tibial epiphysis of a rat using forces applied at different angles to the growth plate. (Based on Bright RW, Elmore SM. Physical properties of epiphyseal plate cartilage. Surg Forum 19:463, 1968.)

Fig. 1-15. Remodeling in a 15-month-old child. Three years later angulation has diminished from 65° to 30°. The lateral cortex has been eroded. Layers of periosteal new bone are seen medially.

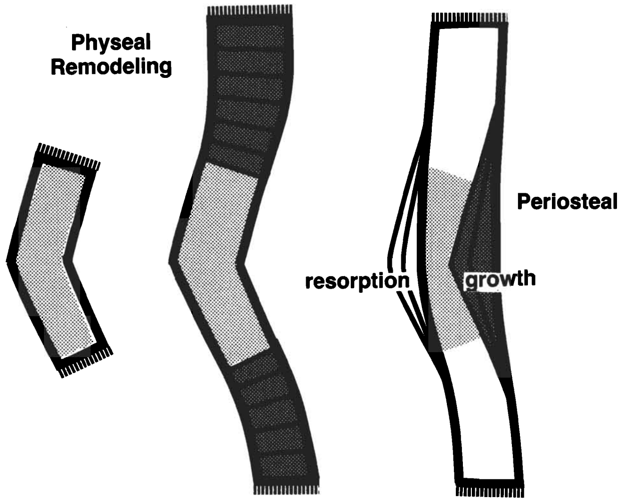


Fig. 1-16. The basis of remodeling.

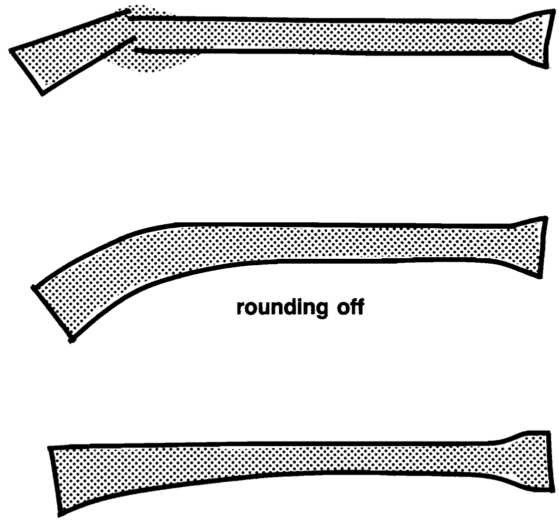
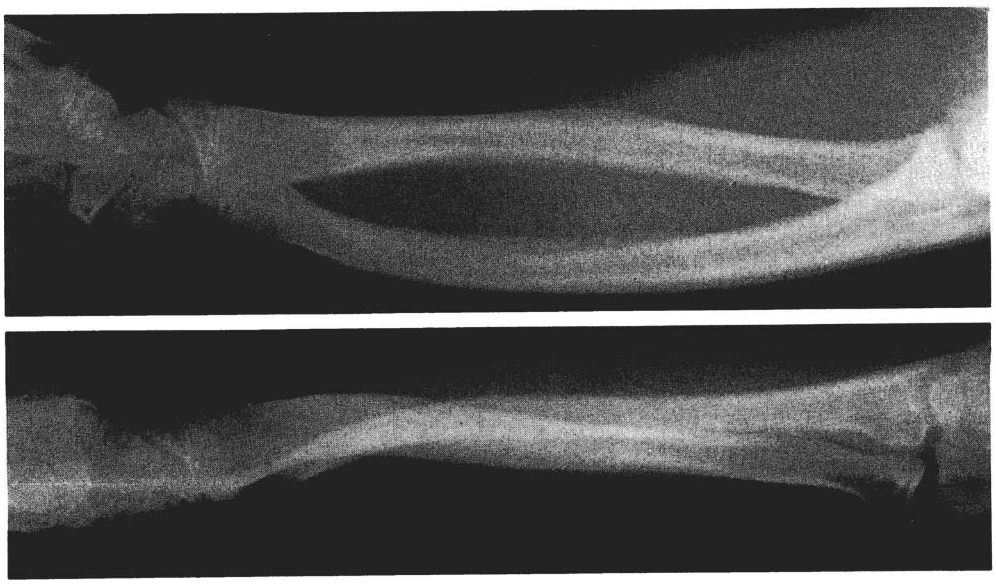


Fig. 1-17. Remodeling has two meanings. Rounding off does not help the patient; radiologists call this remodeling to lure the physician into inappropriate optimism. Realignment or "straightening itself out" is the real meaning of remodeling.

Fig. 1-18. Rounding off the corners in a 16-year-old boy. Two years earlier the radial fracture healed with 30° of dorsal angulation and 90° of malrotation. He now has no range of forearm rotation. Remodeling is not a substitute for reduction.



Nonunion

Nonunion is an adversary almost unknown to the children's orthapaedic surgeon. Displaced intra-articular fractures and the rare shaft fracture with gross interposition may not unite, but otherwise union is easily achieved. The reason for facile union is not known for certain, but the periosteum is actively, not dormantly, osteogenic.

Speed of Healing

Children heal quickly; reduction should be secured early. The orthopaedic surgeon does not have as long to deliberate over a fracture in a child as he does in an adult.

Refracture occurs under two circumstances: (1) early, when the cast is removed too soon, and (2) late, when the fracture has healed with deformity so that the fracture is a stress concentrator.

Rabbit bones pass through four biomechanical stages as they heal:

Stage I: The sticky stage. They refracture through the original fracture site with low stiffness.

Stage II: Early union. They refracture through the original site with high stiffness.

Stage III: Refracture occurs partly through the original fracture site and partly through intact bone.

Stage IV: Refracture is entirely through intact bone.[8]

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2/ Injuries of the Epiphysis, the Growth Plate, and the Perichondrial Ring

Many fractures in children heal well, whether they are looked after by a professor in a university hospital or by Robinson Crusoe on a desert island. In these days of spiralling health costs we should ask ourselves whether we are more effective in the treatment of injury than an unflappable granny. But in the injuries to be considered here the doctor does have more to offer than parental peace of mind; intervention can make a world of difference.

EPIPHYSEAL FRACTURES

Fractures of the epiphysis usually involve the growth plate but occasionally occur in isolation. They may be classified as follows: (1) avulsion at the site of ligamentous attachment, (2) displaced osteochondral fragment, and (3) comminuted compression fracture (Fig. 2-1).

Avulsion at the Site of Ligamentous Attachment

The common sites of this injury are the tibial spine, the ulnar styloid, and the bases of the phalanges. The bony fragment retains an adequate blood supply and does not undergo avascular necrosis. If the fragment is displaced, union is rare because synovial fluid inhibits callus formation. The displaced fragment may block movement or may leave the joint unstable because of functional ligamentous lengthening. These problems justify accurate reduction: closed by choice, but occasionally open by necessity.

Osteochondral Fragments

Osteochondral fragments are most commonly scalped off the distal femur, the patella, and the radial head. A displaced fragment produces the problems of a loose body and a wound in the articular cartilage. If the fragment is large and from an important part of the joint, it should be replaced and pinned back. If small, it should be removed.

Comminuted Fractures

Comminuted fractures are very unusual because the growth plate acts as a shock absorber. The only fracture of the tibial plateau I have treated personally was in a boy who had just come out of a cast. Disuse osteoporosis had made the epiphysis softer than the growth plate.

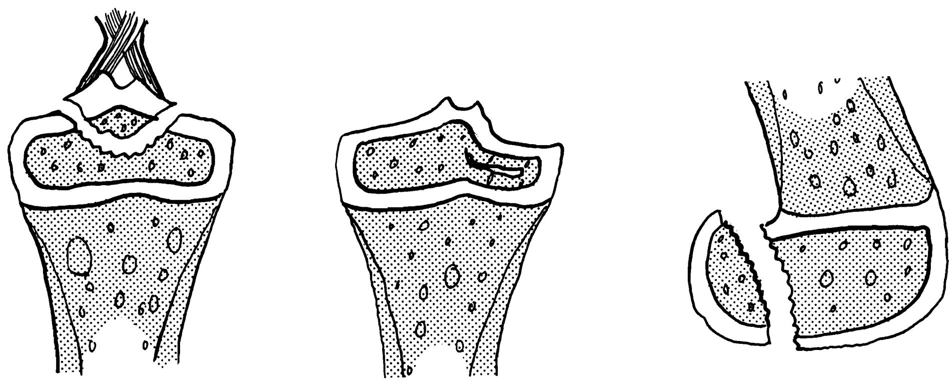


Fig. 2-1. Epiphyseal fractures not involving the growth plate.

GROWTH-PLATE INJURIES

The epiphysis is seldom fractured without involving the growth plate. Injuries to the growth plate form perhaps one-third of skeletal trauma in children. The possible consequences of such injuries are progressive angular deformity, progressive limb-length discrepancy, and joint incongruity. Although damage to the growth plate has the potential for causing many disastrous problems, in fact the area repairs well, and problems after injury are rare. When growth is disturbed, the reason is one of the following:

- Avascular necrosis of the plate
- Crushing or infection of the plate
- Formation of a callus bridge between the bony epiphysis and the metaphysis
- Nonunion
- Hyperemia producing local overgrowth

The problems and the means of their prevention can only be understood by an appreciation of the anatomy and the healing reactions in the growth-plate area.

Anatomy

The growth plate is a cartilaginous disc situated between the epiphysis and the metaphysis (Fig. 2-2). The germinal cells are attached to the epiphysis and gain a blood supply from the epiphyseal vessels, or E-vessels (Fig. 2-3). Repeated multiplication of these cells provides the cell population for the rest of the plate. The daughter cells multiply further, secreting a cartilage matrix, and increase in size, thereby producing growth. The matrix calcifies. Metaphyseal vessels enter the cell columns, remove a little matrix, and lay down bone upon the cartilage matrix to form a metaphysis. The plane of separation is most frequently the junction between calcified and uncalcified cartilage Fig. 2-4. A transverse section through the growth plate in this region demonstrates the small amount of structural matrix present, which probably accounts for the relative weakness of the area. The important germinal part of the plate—indeed the greater thickness of the plate—remains mostly with the epiphysis. This plane of separation is bloodless, so that an epiphyseal separation does not produce much swelling.

However, when the plane of separation is looked at carefully, it has been noticed that it may pass between the epiphysis and the germinal layer. Bright and associates have noted this in rats; Johnston and Jones have found this at biopsy of fractures requiring open reduction.[3,7] Obviously, if much of the germinal layer is disturbed, there is the chance of growth arrest.

The blood supply of the epiphysis is important. Dale and Harris showed that there are two fundamental types of epiphysis (Fig. 2-5).

Epiphyses Totally Clad with Cartilage (such as the head of the femur and the head of the radius). Total interruption of the blood supply to the germinal cells may follow separation. Avascular necrosis of the plate and epiphysis, and arrest of longitudinal growth naturally follow.

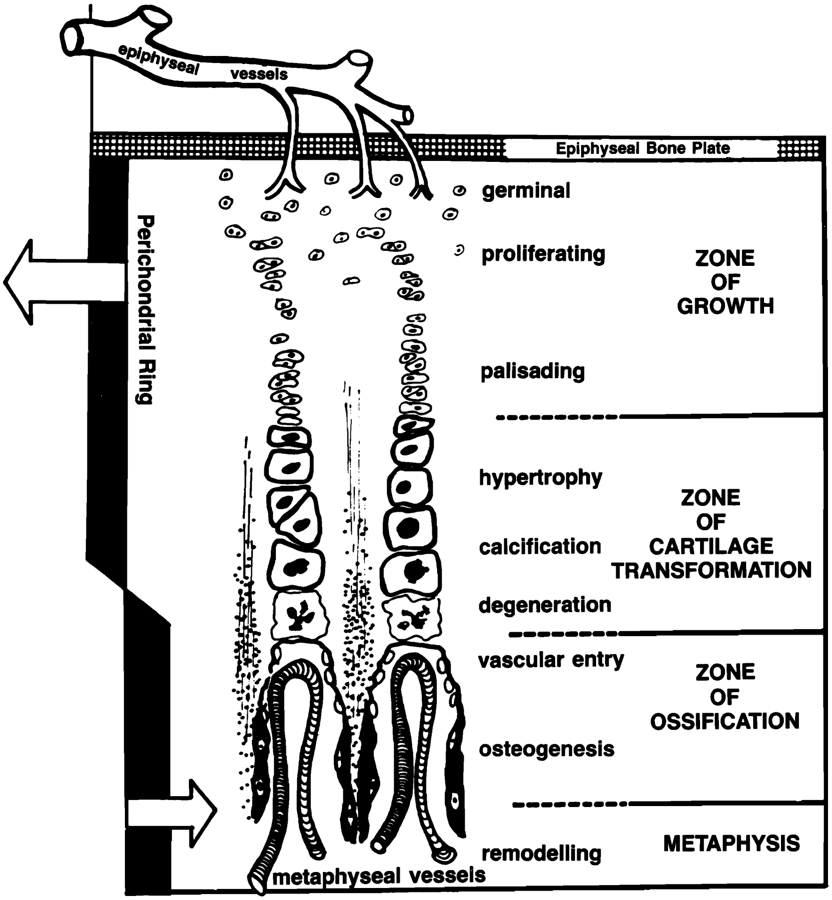


Fig. 2-2. A schematic representation of the growth plate. Separation of the growth plate invariably occurs through the zone of cartilage transformation. (Siffert RS, Gilbert MD. Anatomy and physiology of the growth plate. In Rang M (ed). The Growth Plate and Its Disorders. Baltimore, Williams & Wilkins, 1969.)

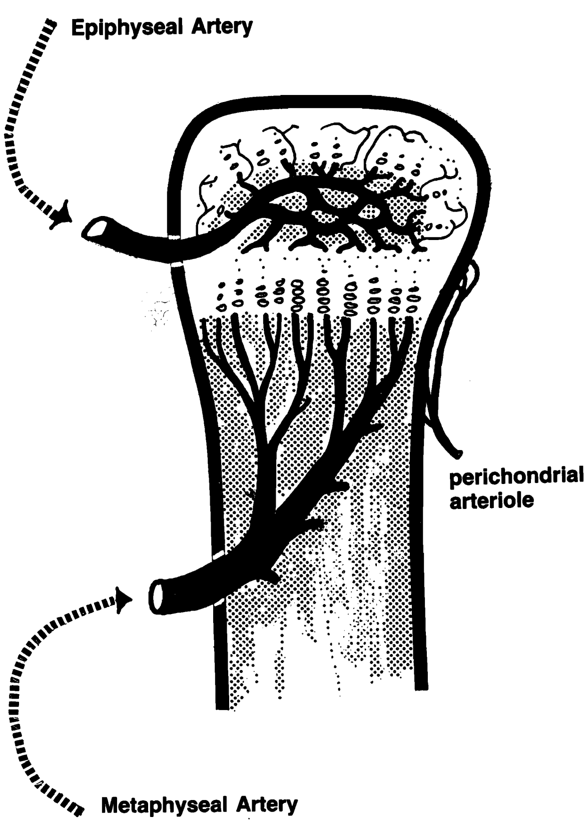


Fig. 2-3. Blood supply of the growth plate. Damage to the epiphyseal artery destroys the plate. Damage to the metaphyseal artery is unimportant. (Siffert RS, Gilbert MD. Anatomy and physiology of the growth plate. In Rang M (ed). The Growth Plate and Its Disorders. Baltimore, Williams & Wilkins, 1969.)

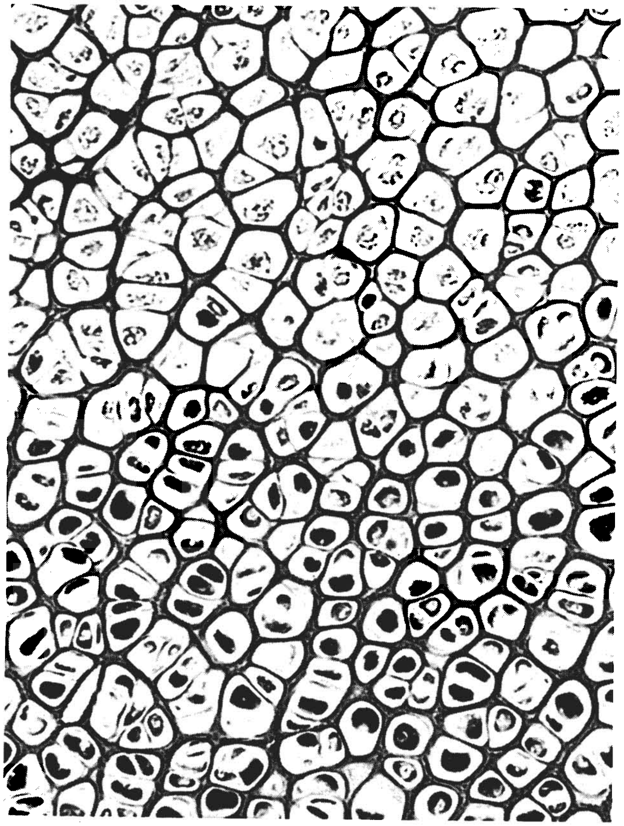


Fig. 2-4. Histology of the growth plate in transverse section through zone of cartilage transformation. The paucity of matrix accounts for the weakness of this zone.

Epiphyses with Soft-Tissue Attachments. When these are separated, the soft-tissue hinge will remain attached to the epiphysis, so that the circulation to the epiphysis remains intact. The germinal cells are not injured, and longitudinal growth continues unscathed.

Healing Reactions of the Growth Plate

Dale and Harris have published the most credible description of growth-plate separation.[5] The plate separates mostly between the calcified and uncalcified layers of the growth plate. For a week or two the hiatus is filled by fibrin. The plate becomes wider, because growth cartilage continues to be produced without invasion by metaphyseal vessels. After about 2 weeks, the vessels begin to invade the cartilage columns again. The plate becomes narrower once more, and the healing occurs without leaving a scar. In this way, the growth plate heals more quickly than a fracture through bone (Fig. 2-6). The repair of an injury at right angles to the plane of the growth plate shows more variation (Fig. 2-7).

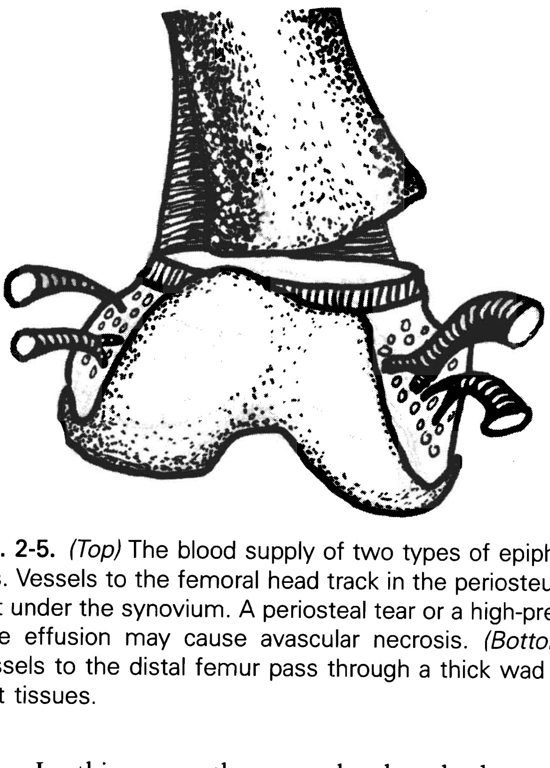


Fig. 2-5. *(Top)* The blood supply of two types of epiphyses. Vessels to the femoral head track in the periosteum just under the synovium. A periosteal tear or a high-pressure effusion may cause avascular necrosis. *(Bottom)* Vessels to the distal femur pass through a thick wad of soft tissues.

Cartilaginous Epiphysis. Both parts of the epiphysis continue to grow interruptedly, producing a double-ended bone, if they remain displaced.[14]

Ossified Epiphysis. If the fracture surfaces are not in contact, both fragments continue to grow for

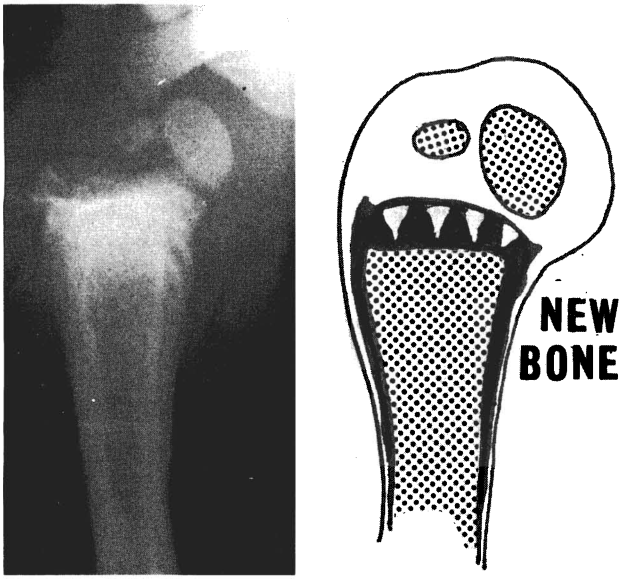
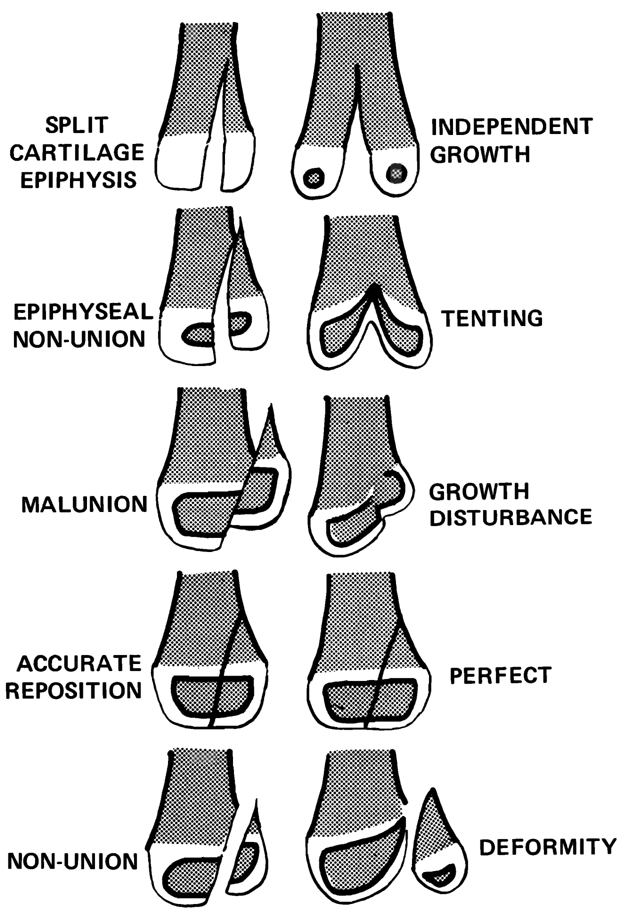


Fig. 2-6. Healing after growth-plate separation occurs by means of new bone formed by the growth plate and by the periosteum. It can be seen clearly 3 weeks after the initial injury.

Fig. 2-7. Healing patterns of Type-IV injuries.



some time. Eventually, premature arrest of growth adjacent to the fracture line takes place.

If the fracture surfaces are apposed without coaptation of the growth plate, a bridge of callus will form between the epiphysis on one side and the metaphysis on the other. This bony bridge is a brake on growth. When the bridge is at the center of the epiphysis, the two outside edges will continue to grow, resulting in tenting of the end of the bone. When the bridge is toward one margin of the growth plate, a progressive, angular deformity develops.

If the fracture is accurately reduced so that there is coaptation of the growth plate, there will be a small scar at the site of growth-plate injury, but this is not sufficient to disturb growth.

Effect of Internal Fixation. Small Kirschner wires passed through the center of the plate do not interfere with growth. If they are passed near the margin of the plate, growth is occasionally disturbed. Threaded pins or screws across the plate act as effectively as Blount's staples.[13]

Repair of Articular Surfaces. Cartilage defects in a joint invite intra-articular adhesions. Salter and associates have shown that continuous, passive motion not only discourages adhesions but stimulates more rapid and more complete healing of full-thickness defects in rabbits.[12] Motion—not immobilization—for injured joint surfaces would seem wise.

Salter–Harris Classification of Growth-Plate Injuries

The Salter–Harris classification of growth-plate injuries is in general usage. Founded on the pathology of injury, the classification is well suited to the accurate verbal description of an injury and provides an excellent guide to rational treatment (Fig. 2-8). Most growth-plate injuries can be easily classified, leaving very few fractures to produce arguments at fracture rounds. The classification should be studied in the original, as it is one of the classic papers in orthopaedics.[11] There have been others. In 1898 Poland illustrated the common variations of separation (Fig. 2-9). Aitkin's classification of growth-plate injuries is widely used, although we have not found it as practical as the Salter–Harris classification.

Type I. In a Type-I fracture (Fig. 2-10) the epiphysis separates completely from the metaphysis. The ger-

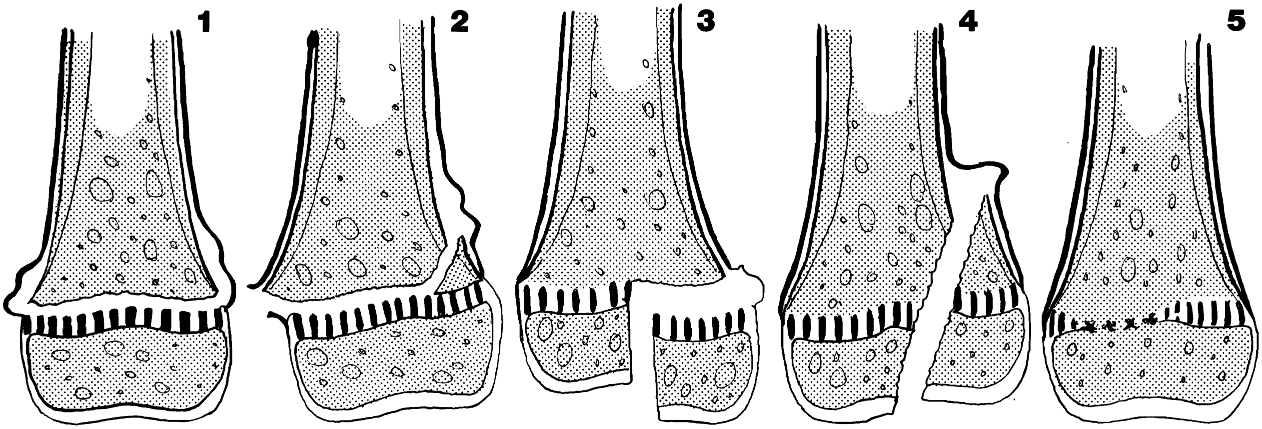


Fig. 2-8. The types of growth-plate injury as classified by Salter and Harris. (Salter RB, Harris WR: Injuries involving the epiphyseal plate. J Bone Joint Surg 45A:587, 1963)

Fig. 2-9. Poland's classification of growth-plate injury.

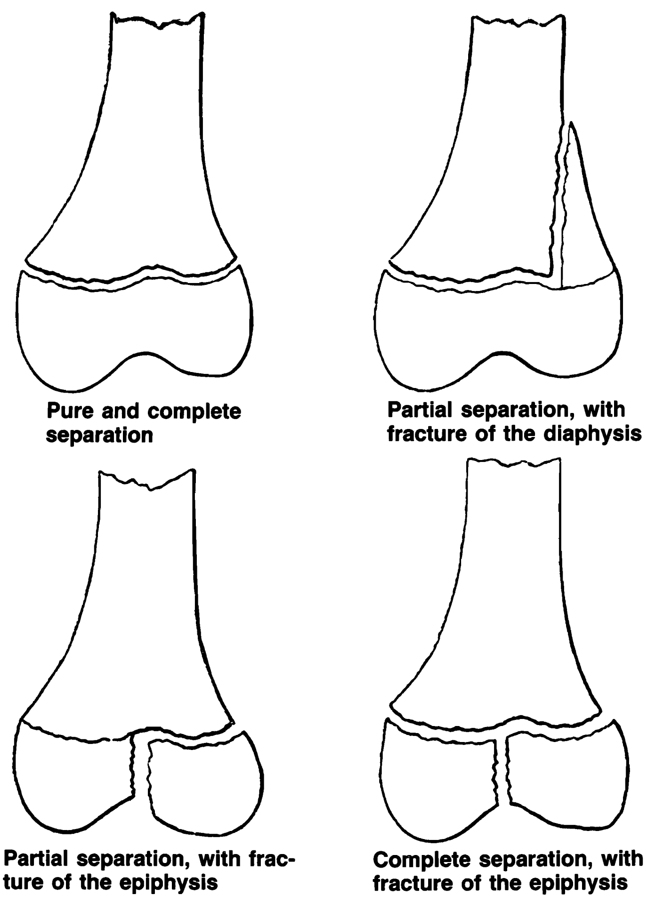
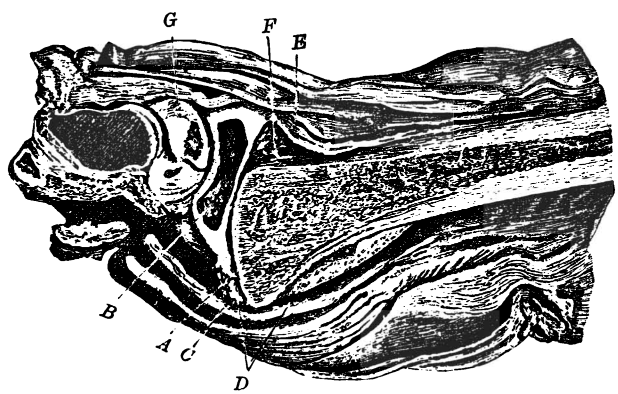


Fig. 2-10. A dissection by Poland of a Type-I injury: *(A)* diaphysis of radius; *(B)* carpal epiphysis of radius incompletely ossified; *(C)* flexor tendons displaced forwards; *(D)* pronator quadratus lacerated by anterior margin of end of radial diaphysis; *(E)* periosteum stripped off dorsal aspect of diaphysis; *(F)* blood clot filling space between periosteum and diaphysis; *(G)* scaphoid.



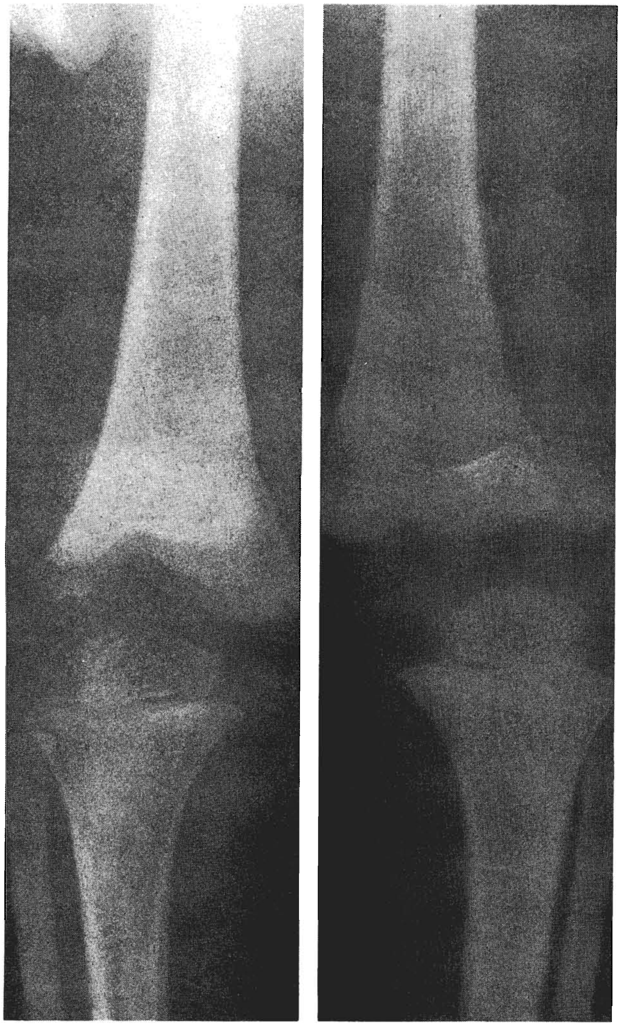


Fig. 2-11. Separation of both distal femoral epiphyses. For 6 weeks this boy, aged 3 years, had been treated with antibiotics and steroids for hectic fever and multiple joint pains. By the time a diagnosis of osteomyelitis was reached, these epiphyses had sequestrated.

minal cells remain with the epiphysis, and the calcified layer remains with the metaphysis. If the periosteum is not torn, there is no displacement. The radiograph in these circumstances may be normal, and the diagnosis is made on clinical suspicion. Most parents look on these injuries as sprains, since there is little swelling and little deformity. You will be alerted to them by tenderness over the growth plate, and you will not be disturbed by the absence of radiologic signs. Stress radiographs may be taken if accurate diagnosis is imperative. Diagnosis of separation of an unossified epiphysis is made on clinical signs and on the presence of soft-tissue swelling observed on the radiograph.

When the periosteum is torn, displacement is easily reduced without any satisfying crepitus or the sensation that the fragment is snapping back into position, because the two fracture surfaces are covered with cartilage.

Type-I injuries are usually the result of shearing, torsion, or avulsion force. Apophyses are usually avulsed.

Pathologic Type-I injuries occur in scurvy, in rickets, in osteomyelitis, and in disorders associated with hormonal imbalance (Fig. 2-11).

Healing occurs within 3 weeks, and problems are rare. Avascular necrosis of the femoral head is the worst problem to be encountered. Nonunion of a separated medial epicondyle is not uncommon; only rarely does it cause any instability. It is difficult to distinguish between a Type-I injury of the growth plate (which has an excellent prognosis) and a Type-V injury, in which the plate is crushed, which has a poor prognosis. The history of injury is the best guide; Type-V injuries are produced by axial compression. In fact, Type-V injuries are exceptionally rare, so the distinction is not a practical problem.

Type II. The plane of cleavage of a Type-II injury (Fig. 2-12) passes through much of the plate before the fracture travels through the metaphysis. The fracture is produced by lateral displacement force, which tears the periosteum on one side and leaves it intact in the region of the triangular metaphyseal fragment.

The fracture is usually easily reduced, and overreduction is prevented by the intact periosteum. The cartilage-covered surfaces usually prevent the sensation of crepitus as the fragment is pushed into position. When the radial head is separated, for example, it may be impossible to judge the success of a reduction by clinical means.

Occasionally, the shaft of a bone will become trapped in the buttonhole tear of the periosteum. This is most likely at the shoulder, if there is a large, metaphyseal fragment poking through a small, periosteal tear. If the degree of displacement is unacceptable, open reduction may be needed on rare occasions.

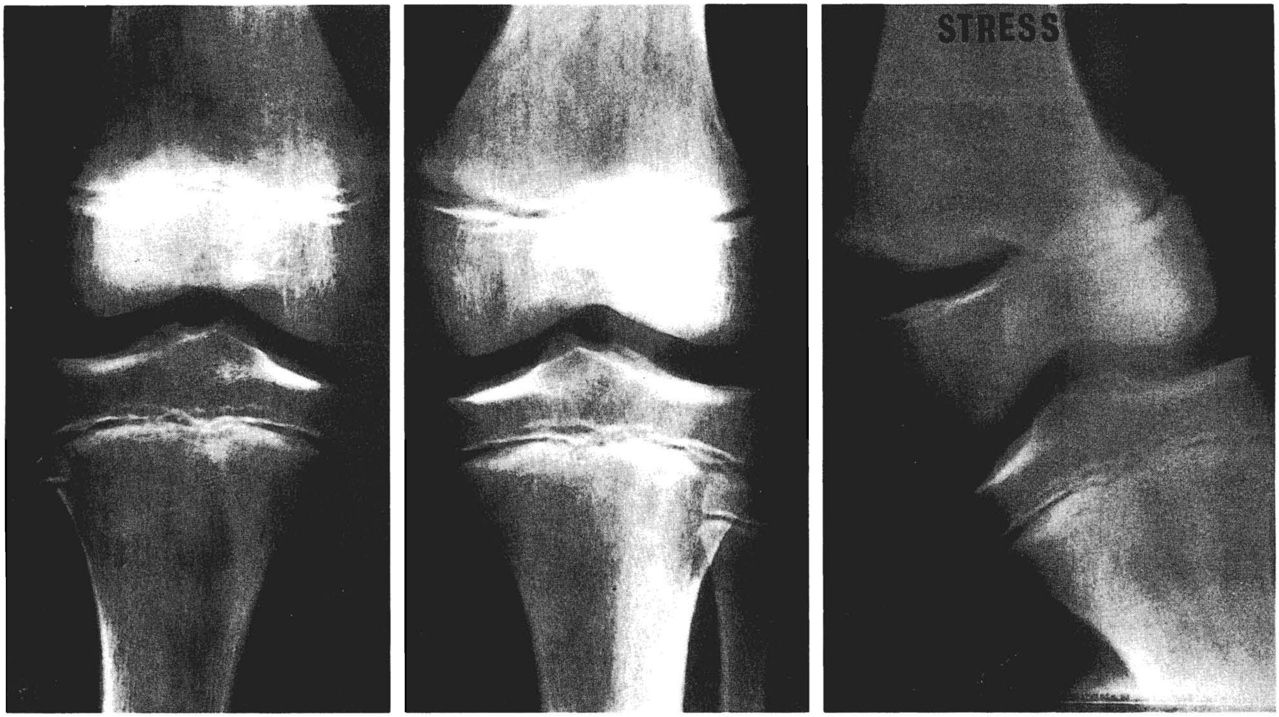


Fig. 2-12. Suppose this 12-year-old boy came in with a swollen left knee that was tender on the medial side. Would you recognize the slight widening of the growth plate? A stress film would have demonstrated a Type-II injury.

Fig. 2-13. Type-III injury of the distal tibia, the Tillaux fracture, in a girl, aged 14. Type-III injuries are most likely to occur when most of the plate is closed.

Type III. Type-III injuries are seen in partially closed growth plates (Fig. 2-13). The plane of separation passes along with the growth plate for a variable period before entering the joint through a fracture of the epiphysis. The fracture is intra-articular and requires accurate reduction to prevent malarticulation. Open reduction may be needed, but the fragment should not be dissected free of its blood supply. The most common site is at the distal end of the tibia, toward the end of growth, when the medial half of the plate is closed. Growth disturbances, therefore, are not a problem.

Type IV. The fracture line in a Type-IV injury passes from the joint surface, across the epiphysis growth plate, and into the metaphysis (Fig. 2-14). The most common example is a fracture of the lateral condyle of the humerus. It is an injury for which the doctor can do a great deal. Left alone, this intra-

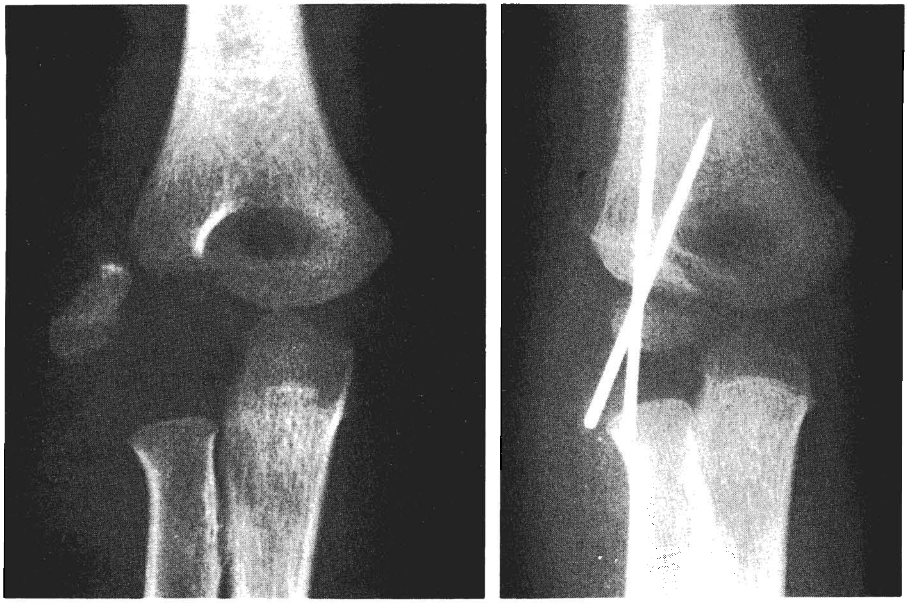


Fig. 2-14. Fracture of the lateral condyle. A Type-IV injury.

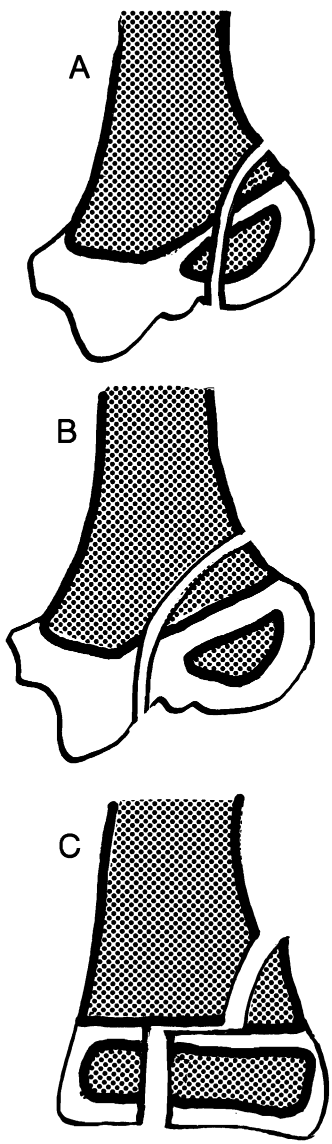


Fig. 2-15. Not all Type-IV injuries are the same. *(A)* When the fracture line crosses a bony epiphysis, the risk of bony callus bridging the growth plate and causing a growth disturbance is great if accurate reduction is not achieved. *(B)* When the fracture line passes through a cartilaginous epiphysis, bridging is unlikely. *(C)* A stepped fracture line permits stable closed reduction.

articular injury will produce joint stiffness and deformity owing to loss of position, nonunion, and growth disturbance. The fracture must be accurately reduced, usually by open reduction and internal fixation, to secure a smooth joint surface, closure of the fracture gap to prevent nonunion, and cell-to-cell apposition of the growth plate to ensure that growth is not disturbed.

At other sites the growth plate cannot be seen clearly, and when there is doubt whether it is accurately reduced, improve the view by removing the metaphyseal fragment. The gap can be filled with fat to discourage bridging. There are several subvarieties of this injury that are not generally known (Fig. 2-15).

Type V. Concepts about Type-V injuries are changing (Figs. 2-16 to 2-18). In the original concept, the plate is crushed, thereby extinguishing further growth. All or part of the plate may be affected. A compression injury of the plate may seem like nothing more than a sprain at first, and only later will the true nature of the lesion be recognized. At other times, a Type-I or Type-II injury is obvious initially;

then pressure from the most prominent corner of the metaphysis produces a crushing injury, to the chagrin of the surgeon and to the detriment of the patient.

Since the work of Langenskiold, Bright, and others on growth arrest owing to bony bridging this classical concept of a Type-V injury needs reexamining.[3,8] When a small area of the growth plate is damaged, there is a race to replace the defect. Either regenerated growth cartilage or bone may win. Growth is threatened if bone forms. Our focus should be on the bridge rather than the crush, if only because the bridge can be treated.

Even when everyone agreed on the nature of Type-V injuries, they were considered rare. Now, there is much to be said for retiring the term altogether. Bony bridging should be regarded as a potential *complication* of any growth-plate injury and not as a special type of injury.

All growth-plate injuries should be followed for 6 months, perhaps a year, because a growth disturbance is a remote possibility.

Fig. 2-16. One of the earliest radiographs of a Type-V injury was published by Poland in 1898. The growth plate of the radius has closed, and the radius has not grown.

Fig. 2-17. Growth arrest of the phalanges of the right hand due to frostbite.

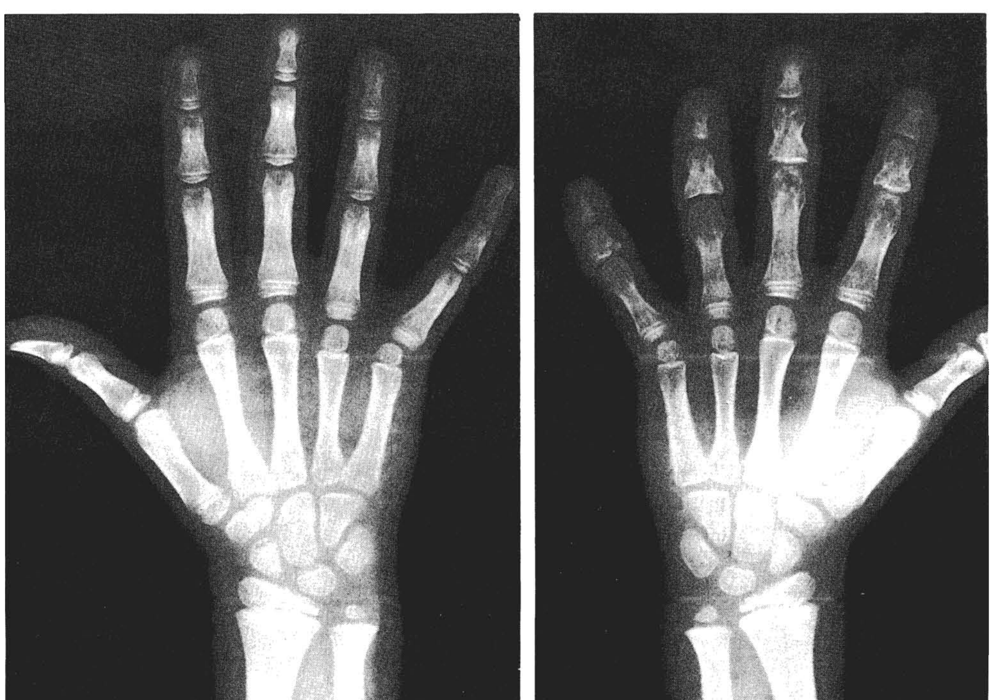


Fig. 2-18. This 14-year-old girl had stubbed her right great toe years before. The toe is short due to an old Type-V injury of the base of the proximal phalanx.

Stress Injuries of the Growth Plate

The concept of stress fracture through the growth plate was introduced by Godshall and others. It is a natural development, from the observation by Bright and associates, that shear cracks in the growth plate are seen when the load applied to the plate is 50% of that necessary to separate the plate.[3] Continued injury could be expected to inhibit healing. Godshall and associates described pain in the knee, inability to run, and circumferential tenderness around the distal femoral growth plate.[6] X-ray films showed widening of one-half of the growth plate with sclerosis. After 12 weeks of rest the lesion healed. The little leaguer's elbow and Osgood–Schlatter disease are further examples.

Guide to the Care of Growth-Plate Injuries

Define the Exact Line of the Fracture. This is usually obvious, but some injuries can be very difficult, particularly in the young child with little or no ossification in the epiphysis. Multiple views, with comparative views of the opposite side, may help. (Remember that humans are made symmetrical for the purpose of comparison.) Stress films should not be omitted, and arthrography may be helpful. Occasionally, when you suspect a displaced intra-articular fracture but cannot prove it, it is wiser to err in favor of exploration than to rely on your small stock of undeserved miracles.

Classify the Fracture. The Salter–Harris classification is a logical guide to problems that accompany different types of injury.

Treat the Child and the Parents. Reduction should be early and gentle. These injuries unite quickly, so that attempts to correct malposition after a week are liable to do more damage to the plate than good. Repeated efforts at reduction may do nothing more than grate the plate away. If problems are anticipated, they should be communicated to the parents without unduly alarming them, preferably preoperatively.

Open or Closed Reduction? It is usually possible to secure closed reduction of Type-I and Type-II injuries. Exact anatomic reduction, though desirable, may be unnecessary, since remodeling will take care of many imperfections (see p. 31 on remodeling). Occasionally, soft tissue is interposed (*e.g.*, at the ankle) or the part is so deeply placed (*e.g.*, the radial head) that open reduction will be necessary. Open reduction is also required for markedly displaced separations of the medial epicondyle. Stability is easily achieved with a few periosteal sutures, and internal fixation is seldom needed. Type-III injuries commonly need open reduction in order to secure a smooth joint surface. Type-IV injuries are commonly unstable, and accurate reduction is mandatory. This applies particularly to the lateral condyle of the humerus; it may be possible to reduce this injury, but it is difficult to be sure that it is stable, and almost impossible to be sure, by examining radiographs of a flexed elbow taken through a thick cast, that the position is maintained. For these reasons, open reduction and internal fixation is much safer.

Chondrolysis. A growth plate may be destroyed by infection. This is a theoretical risk in all open fractures and a more practical hazard when open reduction is carried out. For this reason, all Kirschner wires should be buried below the skin (not left protruding through it) to prevent infection.

Length of Immobilization. Various rules are invoked. The elbow may become stiff if immobilized for more than 3 weeks. For other joints, we allow 3 weeks for union of an epiphyseal separation, and 6 weeks when we are waiting bony union.

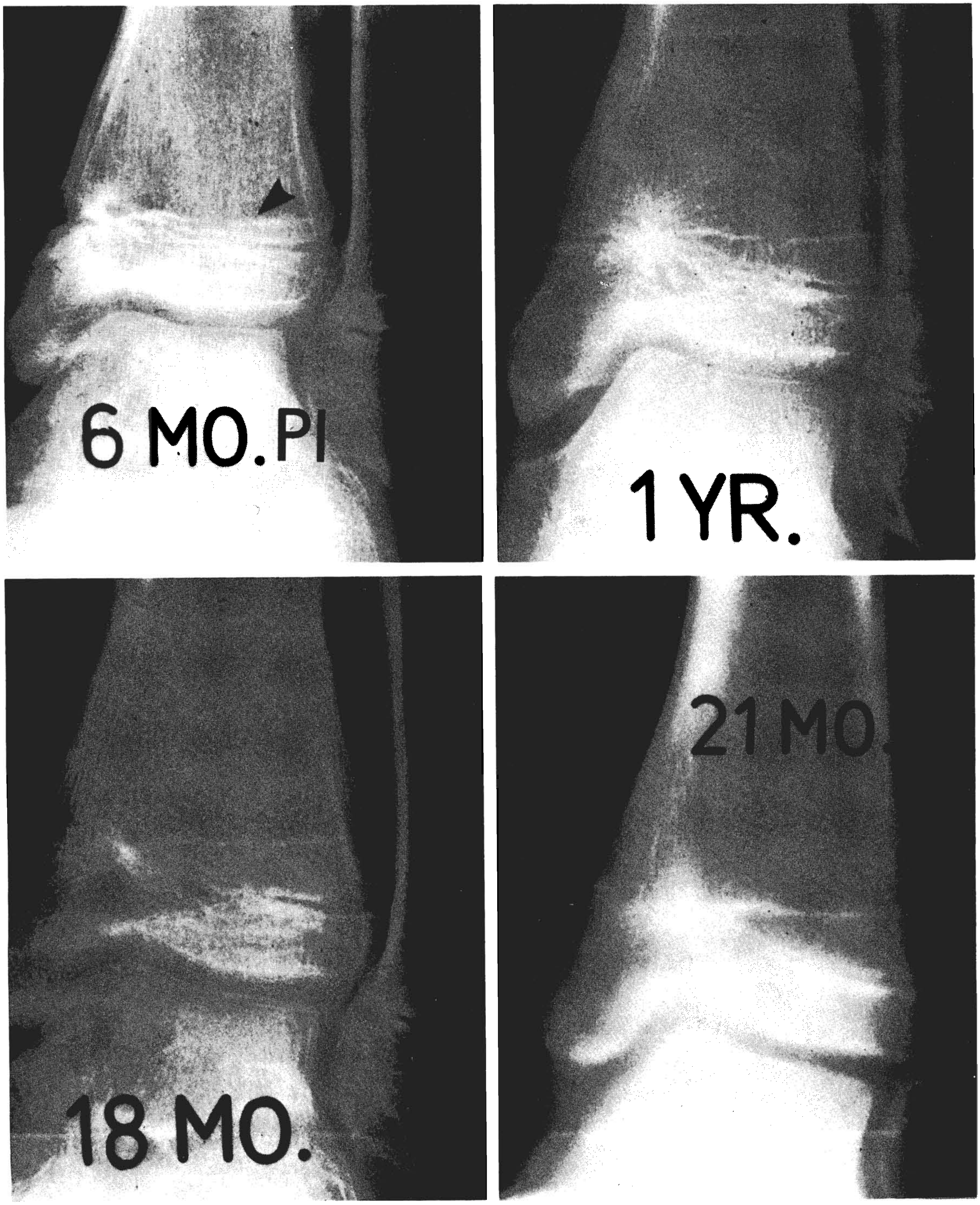


Fig. 2-19. Six months after a Type-IV injury of the medial mallcolus (treated by ORIF) there are signs of a bony bridge. Uncertainty led to inaction. A Harris growth arrest line which converges with the growth plate is certain evidence of partial growth arrest and is much easier to recognize than the bridge itself. Bridge resection should have been performed within the first year.

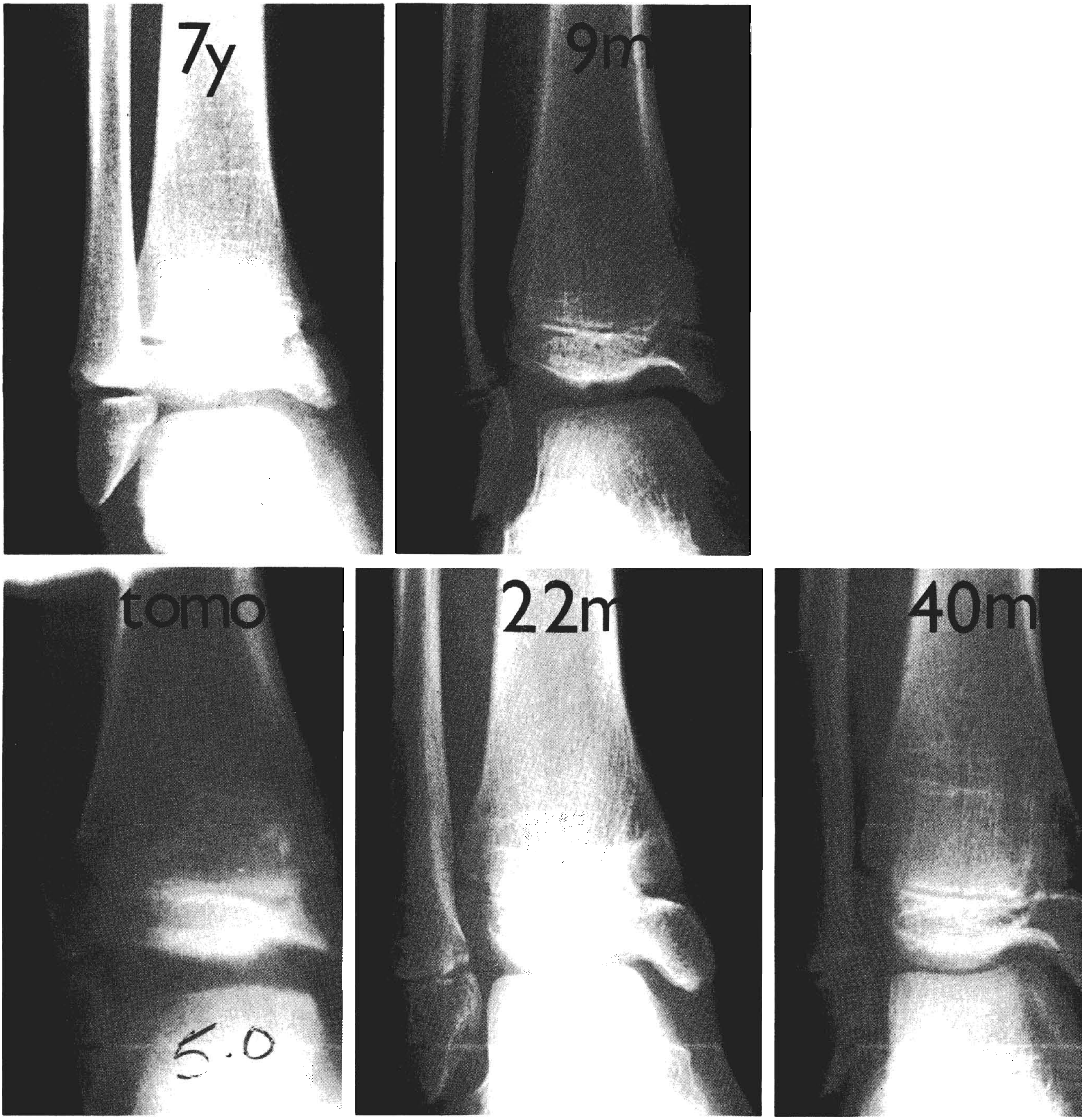


Fig. 2-20. An "undisplaced" Type-IV injury of the medial malleolus. The chance to prevent growth arrest is lost when the cast is applied. Nine months later there is a small bridge confirmed by tomographs. A Langenskiold operation is performed by Colin Moseley, M.D. Later, the bone grows normally. Harris lines mark growth.

The Child from Elsewhere General Hospital. Children presenting late with Type-I and Type-II injuries more than a week old in unacceptable positions should be left with the displacement uncorrected, for fear of damaging the plate. Osteotomy should be carried out later if remodeling fails.

Open reduction of displaced Type-III and Type-IV injuries may be better undertaken late than never. Be careful not to devascularize the fragment at the time of replacement. In order to secure better alignment of a Type-IV injury, the metaphyseal fragment may be peeled off the growth plate and discarded, in order to see that the plate is accurately aligned.

Bony Bridging. Growth stops when a bony bridge joins the epiphysis to the metaphysis. An early sign may be a converging Harris line (Fig. 2-19). In the early stage, the patient is free of deformity and complaints. The orthopaedic surgeon is confident that angulation is beginning and can see a bridge. But often he is put off by the radiologist who cannot be sure and who thereby sets the scene for delay. For one reason or another the majority of children with bridges spend the golden period for treatment with a follow-up appointment card in their pocket. Tomograms should be taken to confirm the diagnosis and to define the size of the bridge.

Since Langenskiold and Bright described resumption of growth after resection of the bridge, there has been much more reason to follow growth-plate injuries carefully. Langenskiold replaces the bridge with autogenous fat, Bright with silicone rubber.[1,2,8,9] The bridge is approached by making a window in the bridge is approached by making a window in the metaphysis. A loupe and a headlamp improve vision. The bridge is pale bone, in contrast to the red bone of the normal metaphysis. The bridge is removed with a burr until the normal plate is seen. The bridge is usually more extensive than expected. Radiographs during surgery may help to localize the bridge so that not too much and not too little is removed. The defect is then replaced with fat or rubber (Fig. 2-20).

Langenskiold reviewed 33 cases in 1978 with excellent results.[10] A second operation for recurrence was indicated in three patients. Deformity has improved in most, but some have required osteotomy.

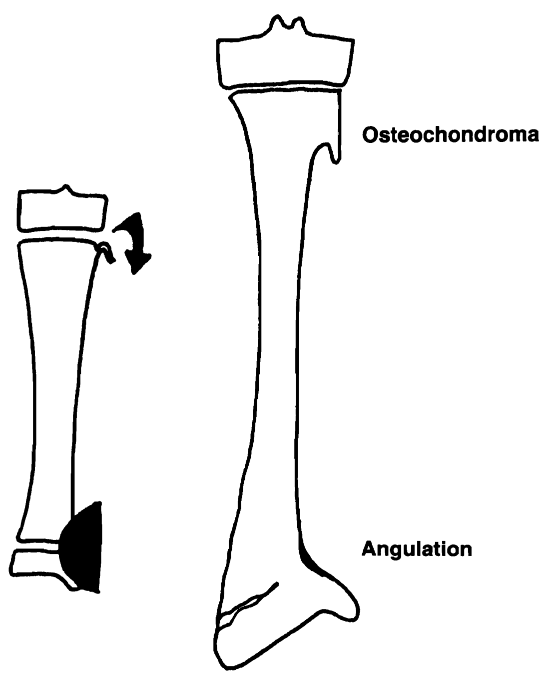
In Conclusion. The majority of growth-plate injuries involve little risk of growth disturbance. In a few, simple surgical intervention can make a great deal of difference to the outcome of the injury. Happily, the number of children who have irretrieveable damage is very small.

INJURIES OF THE PERICHONDRIAL RING

The perichondrial ring encircles the growth plate in the same way that periosteum invests bone. The perichondrial ring appears to regulate the diameter of the growth plate. Injuries are rare but produce characteristic effects (Fig. 2-21).

Displacement of the perichondrial ring produces a traumatic exostosis, clinically and experimentally[10] (Fig. 2-22).

Fig. 2-21. Perichondrial ring injury.



Removal of the perichondrial ring permits bony bridging between the epiphysis and metaphysis. Fracture callus joins the epiphysis to the metaphysis, leading to progressive angular deformity.

The perichondrial ring is most commonly removed by a lawn-mower "scalping" the medial side of the ankle (Fig. 2-23). The surgeon usually replaces the lost skin by split-thickness grafts. The perichondrial ring may be lifted from the distal femoral condyle by the lateral collateral ligament, and this too carries the risk of bridging unless it is accurately replaced (Fig. 2-24).[4] A progressive varus deformity follows because bone replaces the perichondrium. The grafted area must be replaced and the bony bridge removed, as already described.

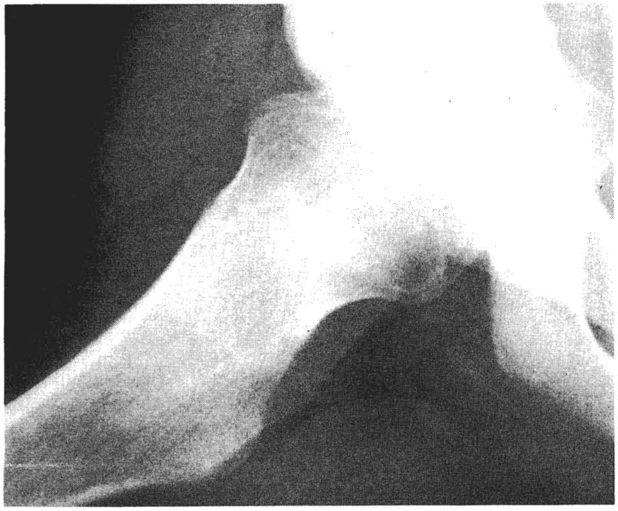


Fig. 2-22. Traumatic exostosis in a boy, aged 18 years. Five years before he sustained multiple injuries. He complained of much pain and stiffness in the hip, but radiographs were normal. He later shows this traumatic exostosis which limited movement and was excised.

Fig. 2-23. A motor vehicle accident at the age of 5 years removed this girl's medial malleolus. Bony bridging occurred, causing growth arrest. Five years after the accident (at age 10) a tibial osteotomy was performed followed by ankle fusion. She was 6 cm short. A tibial leg lengthening has left her 0.5 cm short at the age of 13 years.

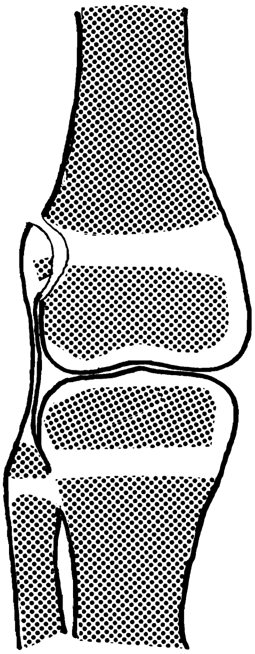


Fig. 2-24. Perichondrial ring avulsion. (After Weber BG, Brunner C, Freuler F: Treatment of Fractures in Children and Adolescents. New York, Springer–Verlag, 1979)

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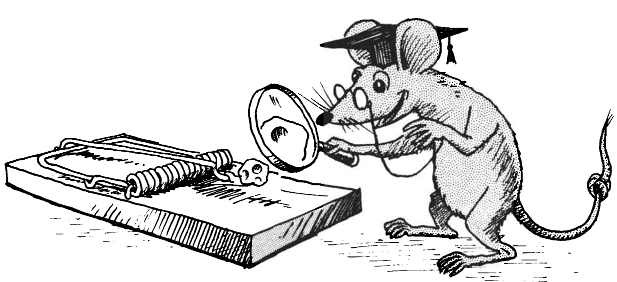
3/ Fracture Care is a Game of Chess

Each fracture type, like each piece in a chess set, can move only in a certain number of ways. Are you going to win or lose? Obviously you cannot win if you do not know the moves of each fracture piece, but even after you have mastered this, and you are playing several games at once, it is easy to be outwitted. In this chapter a few of the obvious traps are identified.

TRAPS TO HAPPY RELATIONSHIPS



The injured child and the alarmed parents are impressed—positively or negatively—by your initial behavior. If you ignore the parents, palpate the fracture directly, and then shout your opinion to the parents above the screams of the child, you have created the wrong impression. Every time you see the child there will be screams; every time you speak to the parents it will seem as if they do not understand what you say.

Remember that even if you have to be convinced that there is a fracture, the child and the parents have already made up their minds. They have dropped whatever they were doing, left children with neighbors, and are trying to remember if they locked the front door. Be gentle, interested, and compassionate. Shake the parents by the hand and introduce yourself. Ask them what happened and ask a few questions to discover what they feel about it all. Then ask the child to point to the painful place instead of discovering it yourself by palpation. Watch the digits being moved actively before touching the child just enough to feel the pulse and test sensation. Splint the limb before sending the child for a radiograph; fractures are painful. Instruct x-ray technicians never to take films of unsplinted fractures (Fig. 3-1). The opportunity to make a good start should not be wasted.

TRAPS TO DIAGNOSIS

Failure to make the correct diagnosis sets treatment off in the wrong direction; a significant proportion of the children who have poor results owe it to this initial error.

Fractures are easily *missed* because of the presence of growth cartilage. There is no tell-tale fracture line to be seen in growth cartilage. Growth-plate injuries that are unstable but undisplaced provide a trap. For example, separations of the epiphyses of the upper tibia, lower femur, and lateral malleolus yield normal radiographs (apart from soft-tissue swelling) if there is no displacement (Fig. 1-1). Stress films will reveal these. Separation of the lateral malleolus is so common that we are content to diagnose this on suspicion.

Fig. 3-1. This child was sent to the radiology department for "AP and lateral of the forearm." The arm was not splinted. The elbow is seen in the AP projection in both views. The technician has twisted the wrist, moving the arm through the fracture site. Peace lovers always splint the arm and move the x-ray machine and not the limb.

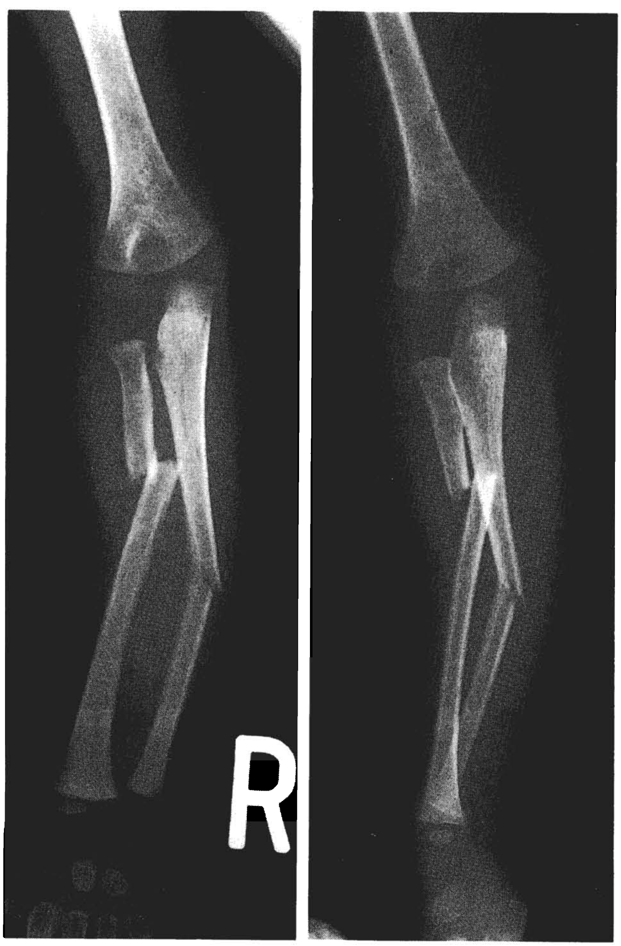


Fig. 3-2. The standard anteroposterior and lateral roentgenograph show nothing more than soft-tissue swelling. Only when an oblique film is produced can the fracture of the medial condyle be appreciated.

Separation of Unossified Epiphyses. In infancy, the upper and lower ends of the humerus and the upper end of the femur may be separated. In older children the unossified epiphyses at the sternal end of the clavicle may mimic a sternoclavicular dislocation. These injuries are easily missed or mistaken for dislocations when the epiphyses is in its preradiographic existence (Fig. 14-10).

When reduction is attempted, soft crepitus will be appreciated. Arthrograms offer a tempting diagnostic aid but usually represent a further source of uncertainty. Arthrography of an unfamiliar joint in a child is not helpful.

Some Injuries Do not Show on Standard Views. Minimal displacements of the lateral and medial condyles may not be apparent on standard anteroposterior and lateral radiographs. Oblique radiographs provide the answer (Fig. 3-2). Oblique radiographs are essential in all ankle injuries.

Always include the joint above and the joint below (Fig. 3-3). Do not miss a dislocated hip for weeks while treating a femoral shaft fracture. Always be certain that the radial head is not dislocated in fractures of the forearm. Remember that two fractures sometimes occur in the same limb; it is the proximal one that is overlooked (Fig. 3-4).

Fig. 3-3. Always include the joint above and below. You will often be tempted to accept the left film. Always insist on the second.

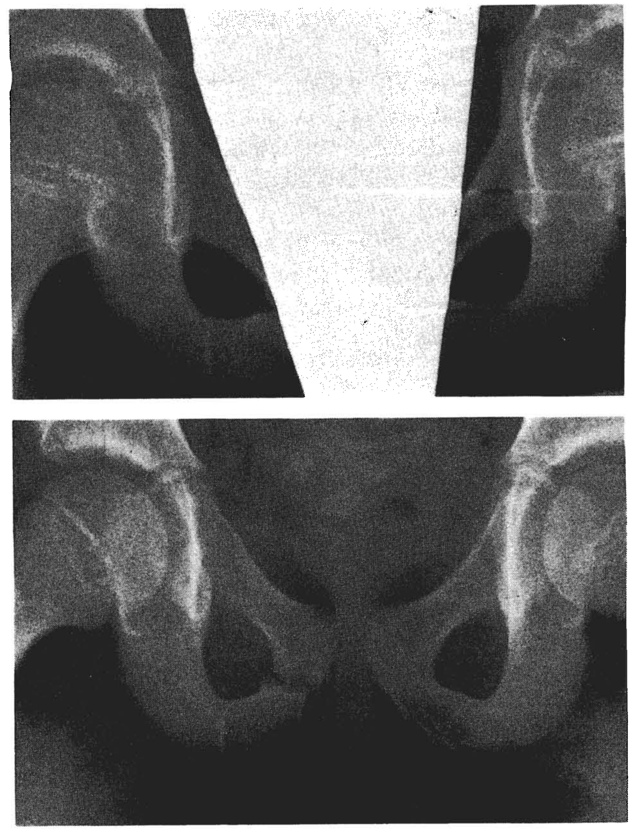


Fig. 3-4. A shield obscured this fracture of the pubic ramus the first time around.

Computerized tomography has revolutionized diagnosis of injury of the spine and acetabulum.

Radiographs May Show the Injury But the Observer Does not Recognize It. Displaced epiphyses may not be instantly obvious when one side alone is radiographed. Separation of the medial epicondyle is the classic example. Always radiograph the opposite limb when in doubt (Fig. 3-5).

The fracture line may be obscured by overlapping bone. Only the observer who has the injury in mind will recognize it. The Tillaux fracture of the ankle is a good example (see Fig. 2-13).

Overdiagnosis. At the beginning everyone mistakes growth plates on radiographs for fractures, but this usually passes. Poorly centered films produce strange appearances (*e.g.*, a radiograph centered on the midhumerus and taken at short distance gives a good imitation of a shoulder dislocation).

Fig. 3-5. A displaced medial epicondyle produces much soft-tissue swelling that is obvious to the clinician. The x-ray film appearances may be much less convincing unless comparison is made with the normal elbow. (Boy, aged 7.)

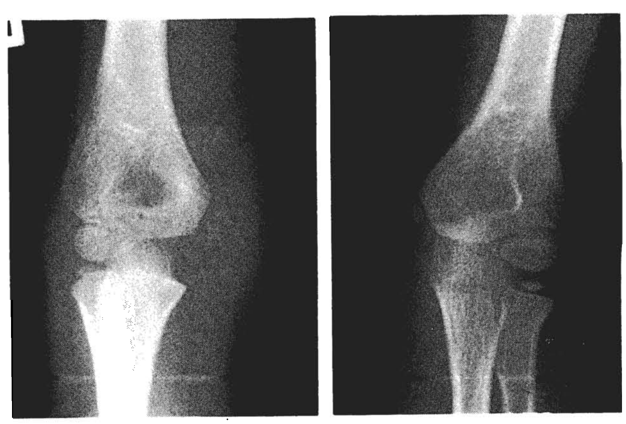


Fig. 3-6. The entry wound was on the medial side of the elbow. Where is the fragment marked with an arrow?

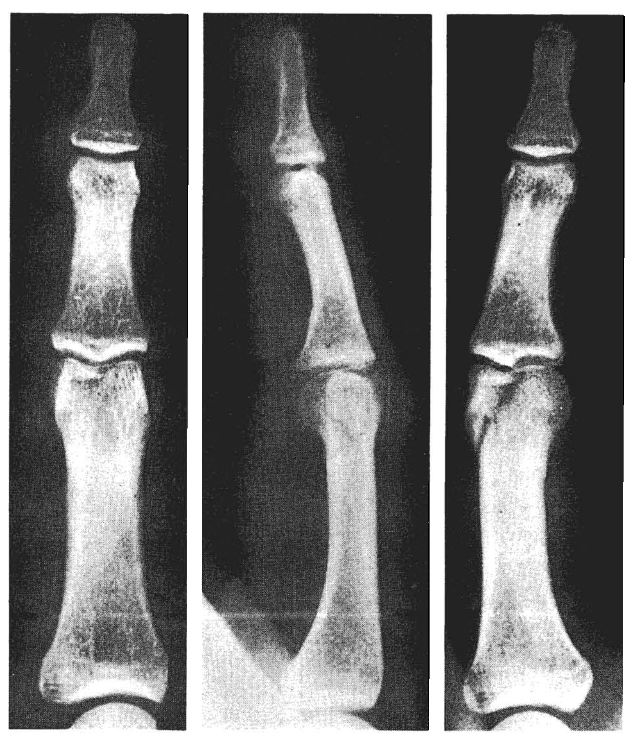
Some Fractures Do not Conform to a Standard Pattern. Occasionally, the nature of the injury cannot be recognized with certainty, especially when the fracture fades into growth cartilage or is of an unusual type. Order additional views (Fig. 3-6). Sometimes postreduction films will clarify things.

Standard Radiographs May not Show the Degree of Displacement. Two radiographs taken at 90 degrees to each other may still be at 45 degrees to the plane of maximal displacement (Fig. 3-7).

Greenstick fractures of the upper tibia commonly appear to have a trivial degree of deformity. Always have an anteroposterior (AP) radiograph of the whole *extended* tibia and femur to determine the degree of valgus; it is usually unacceptable.

Think of the Soft-Tissue Injury. Injuries to blood vessels do occur. Volkmann's contracture rarely follows elbow injuries today because everyone guards

Fig. 3-7. Two views at right angles may not show the maximum degree of displacement. Three views may. The fragment in Figure 3-6 is intramedullary.



against it. Problems are common with high tibial fractures and midtarsal injuries because arterial injury, though common, has not received the same amount of publicity (Figs. 3-8, 3-9).

Clinical Judgment Will Never Be Superseded. If there is every clinical indication of a fracture but the radiographs do not show it, have further appropriate films taken. Talk to the radiologist, and challenge him to demonstrate the fracture. Most radiologists welcome the opportunity to order appropriate films as a change from reading endless films that have been ordered by others.

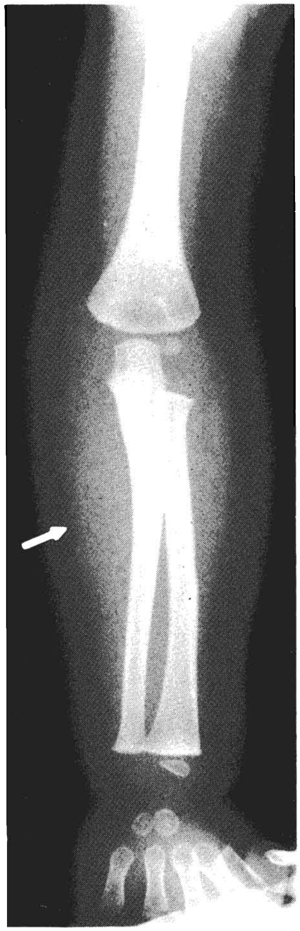


Fig. 3-8. This 1-year-old child sustained a wringer injury. There are no fractures. The swelling and mottled pattern in the soft tissues indicate extravasation of blood.

TRAPS BETWEEN YOU AND CORRECT TREATMENT

When the small number of possible moves is considered, it is a wonder that there is any difficulty in deciding which to select. Yet put a case up at rounds and there will always be somebody who would have done something else. To some extent this is because perfect methods do not exist. Every method has drawbacks; which do you want to take on? Which are acceptable?

The choice of treatment may be difficult because the results of children's fractures, though obviously

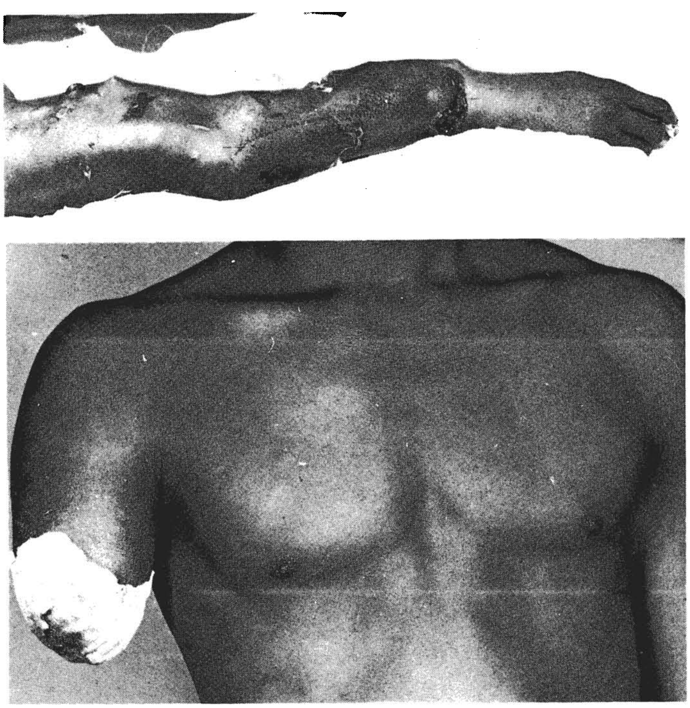


Fig. 3-9. The appearance of this boy's arm after a baby-car fracture tells more than his radiograph. Vascular repair did not help.

much better than corresponding fractures in adults, are not well documented. Children do not usually return to the surgeon more than once after the cast is removed. On many charts at our hospital the last ambiguous note reads "movement returning well, see in 2 months." We are not unique. Few surgeons can produce a good set of films to demonstrate remodeling, though the word is on the lips of all. When ex-patients are recalled for review, all kinds of things come to light that had been either unnoticed or hidden. Children are uncomplaining about minor imperfection; for example, a child with a congenital synostosis of the radius and ulna will pass for normal for several years. It is my impression that a corresponding degree of disability following a fracture easily goes unnoticed.

The key to successful treatment in children's fractures is a clear understanding of what remodeling will accomplish and what it will not.

Remodeling

The scene is a young resident talking to an elderly orthopaedic surgeon:

E.O.S.: But why did you reduce that fracture? It would remodel.
Y.R.: But it is a beautiful reduction. Anyhow, how do you know for sure that it would remodel?
E.O.S.: Seen a lot of them do it, that's how.
Y.R.: What about the child in the clinic today who didn't? She was in my mind when I reduced the child's fracture.
E.O.S.: Knowing who will and who won't is what you learn with experience.

Oscar Wilde said: "Experience is the name everyone gives to their mistakes."

A few general principles may help; remodeling will help:

1. Children with 2 years or more of growth ahead of them
2. Fractures near the end of bones
3. Deformity in the plane of movement of a joint

Remodeling will not help:

1. Displaced intra-articular fractures
2. Fractures in the middle of the shaft of a bone that are grossly shortened, angulated, or rotated
3. Displaced fractures with the axis of displacement at right angles to the plane of movement
4. Displaced fractures crossing the growth plate at right angles

Remodeling is largely a process of rounding off the bones on radiographs. In fractures of the shaft of a bone the periosteum drapes one side of the bone, and this gradually fills in. On the other aspect, the bone is bare of periosteum, and these sharp ends are eroded. The result is that the fracture looks less obvious. This does nothing for the alignment, angulation, and rotation of the fracture site. Near an epiphyses the growth plate can become realigned (Fig. 12-52).

In a supracondylar fracture that has healed with posterior displacement, the shaft acts as an anterior bone block. Movement is restricted until, with growth, the joint moves away from the bone block. The range of movement increases, therefore, with growth.

Most parents are vaguely dissatisfied with the surgeon who puts much faith in remodeling. At the wrist, where this problem comes up most frequently, the bones are just under the skin, and malposition shows. It is our habit to reduce these injuries whenever possible, partly to avoid the risk of further displacement within the cast, and partly to avoid long looks from the parents. There are occasions when it is wiser to await remodeling than to reduce the injury, even though reduction is possible. Metaphyseal fractures and epiphyseal separation about 2 weeks old tend to react badly to attempts at reduction. Heterotopic ossification and growth-plate damage are possible sequelae. Poor anesthetic services constitute another reason for accepting remodeling as a basic treatment. Anesthesia is a definite risk in emergency work. If a child aspirates in the course of reducing a trivial greenstick fracture, it is tragic. There is much to be said for dosing children with these trivial fractures with intravenous diazepam and reducing the fracture quickly while the cast is setting.

Another area in which the extent of remodeling is important is in fractures of both bones of the forearm. Striking remodeling can be seen on radiographs, but it is my impression that this does not help the range of pronation and supination. Any rotatory deformity persists. In other words, remodeling of fractures of both bones of the forearm consists only of rounding off the bone ends on radiographs and is of no clinical value (Fig. 1-18).

Overlap on radiographs becomes less obvious with the passage of time. After fracture, about 1 cm of overgrowth can be expected in a long bone, so that shortening is lost in the remodeling process. The importance of overlap in fractures that are treated in casts is that reduction may be unstable. So long as rotatory and angular alignment have been preserved while the fracture heals, the result will be good.

These principles should help you to decide whether or not to correct deformity in a fracture. But if you accept slight malposition you do not want to lose position any further in the cast—which brings us to the next question.

Casting Without Tears

It may seem callous to you to look at fracture care as a game of chess, but looking at the casts that pass through a clinic make it clear that compassion is not guide enough. Skill is required to avoid common losing gambits such as this: an undisplaced fracture is encased in a lumpy, loose, unmolded cast. A few days later the edge of the cast is digging into the skin and has to be trimmed away; this is a sign that the cast is beginning to slip down. A little later a window is cut because the cast rubs where it touches; the fracture has displaced (Fig. 3-10).

Applying a cast to a conscious child, particularly a small, chubby child, needs cunning. Get everything ready before having the child in the room; we keep scissors chained to the table, since this seems to be the only way to make them constantly available. Bring in the child and mother "to put a bandage on." Most children love to have a bandage on. Don't make the child lie down—he will surely scream and fight. Let him sit or stand. Always use padding. For children who are chubby put on Friar's balsam first to glue the padding and cast on. Roll the padding on evenly and snugly, particularly at the top where the cast always tends to become loose. Don't do this in silence. Use patter like a magician, to distract them from what you are doing. I usually talk to the mother when the child is uncommunicative and ask if she has ever seen a cast go on before, and then recount how the plaster was first mined in Montmartre where there are extensive catacombs you can visit now. I explain that Antonius Mathysen, a Dutch military surgeon, invented plaster bandages in 1851, though the Arabs long before used to put the limb in a box and fill it with liquid plaster. Rather heavy etc., etc. Standard patter has a great advantage over animated conversation, because the quality of the cast is inversely related to the quality of the conversation.

Wrap the plaster around evenly up and down,

Fig. 3-10. An appalling cast. The interior is lumpy and the thickness uneven.

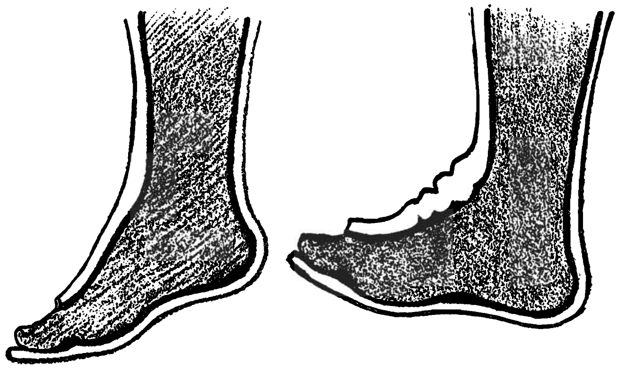


Fig. 3-11. Joints should be held in the correct position when plaster is applied to avoid pressure sores produced by wrinkles in the cast. The cast was applied with the foot in equinus, and then the position was corrected. (Calot R. Indispensible Orthopaedics. London, Ballière, Tindall & Cox, 1914.)

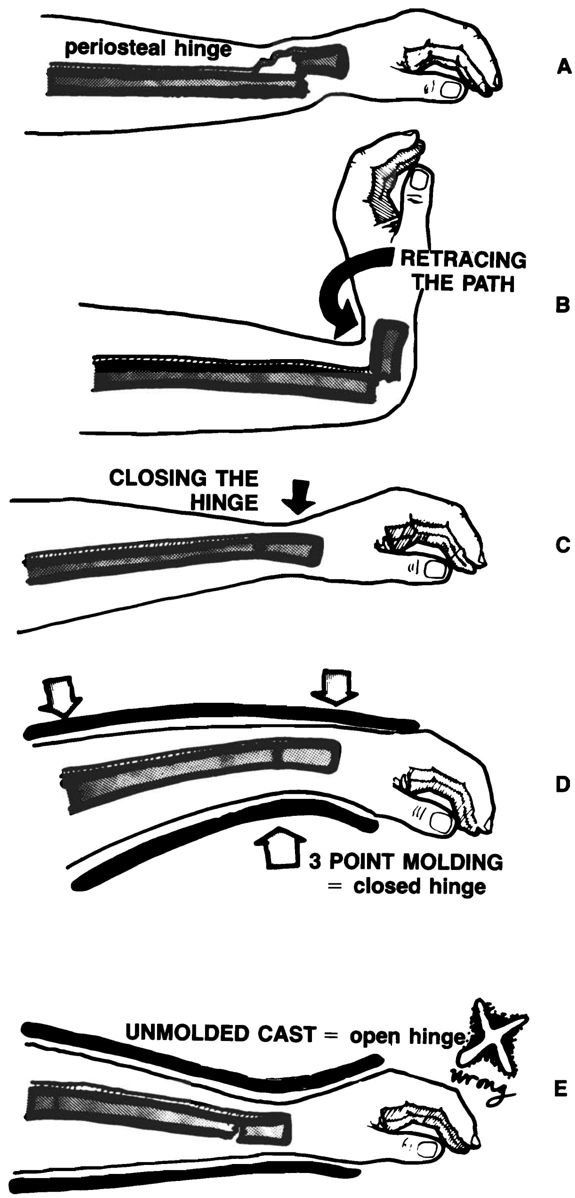


Fig. 3-12. Three-point pressure casting. *(A)* Displaced fracture—the hinge prevents reduction by fraction. *(B)* Retracing the path. *(C)* Reduced—the hinge prevents over reduction. *(D)* A cast with three-point molding holds the hinge closed and the fracture reduced. *(E)* An unmolded cast may make the arm look straight, but it allows the hinge to open.

overlapping by half a bandage width so that the thickness of the cast is even. If you are putting on an above-elbow cast, hold the arm flexed to 90 degrees or 100 degrees. Do not hold it flexed less than a right angle, and then correct the position as the plaster is setting. It produces a ridge first and a plaster sore later. Similarly the position of the ankle and knee must be right before the first turn of plaster goes on (Fig. 3-11).

After applying one or two rolls of plaster the cast should be smoothed and shaped before more reinforcing plaster is applied. In subsequent chapters the details will be considered. As the cast reaches the consistency of wet cardboard the time to mold has come. Use the flat of the hand or the thenar eminence, not the fingertips. The cast should not look like a limb, because you are trying to hold the bones, not the mobile muscle bellies and subcutaneous fat. Use three-point molding, so well described by John Charnley in *The Closed Treatment of Common Fractures* (Fig. 3-12).[2] Many people try to use two-point molding—squeezing the cast at the site of the fracture—which does nothing for the fracture but effectively occludes the circulation.

When the cast has hardened, the edges should be neatly turned back to ensuring that the fingers have a full range of movement at the metacarpophalangeal joints (MPJ), and then enough plaster should be applied, depending on your assessment of the character of the child, to forestall breakage. Draw the fracture and write the date on the cast using an indelible pencil so that, when the notes you have carefully made are lost, treatment can continue. Finally give mother a "plaster care sheet," telling her not to let the cast get wet, how she should recognize swelling of the limb inside the cast, and to make an appointment to come for a cast check the next day.

If your first cast is a good-one, well-shaped and strong, it is unlikely that another will be required.

Should you use plaster substitutes? They are strong, waterproof, and cost several times as much as plaster. But for trivial injuries requiring a below-knee cast capable of bearing weight immediately, they are wonderful.

We have stopped using rubber heels on walking plasters; canvas overboots encourage a better gait and there are fewer repairs.

Did You Call That a Manipulation or a Reduction?

For the majority of children's fractures good alignment may be achieved by manipulation or by traction.

When Should Open Reduction Be Employed? There are situations where an open reduction is indicated *only when a closed reduction fails.* Fractures of both bones of the forearm in teenagers, fractures of the tibial spine, and fractures of the radial neck fall into this group. Some surgeons will operate on overlapping metaphyseal fractures of the distal radius and fractures of the proximal humerus, but it has been my experience that, armed with the correct technique of manipulation, open reduction is unnecessary. Open reduction is said to be hazardous in cases of epiphyseal separations that present late because of the danger of growth-plate damage: osteotomy after healing is preferred.

Open reduction and internal fixation should be the *first choice* in displaced intra-articular fractures such as those of the lateral condyle of the humerus and femur, of the olecranon, and of the patella. Other fractures will also benefit from this approach, (*e.g.*, fracture dislocations of the talus and acromioclavicular fracture dislocations). Children with prolonged decerebrate rigidity and multiple injuries may benefit from nailing a fracture of the shaft of the femur.

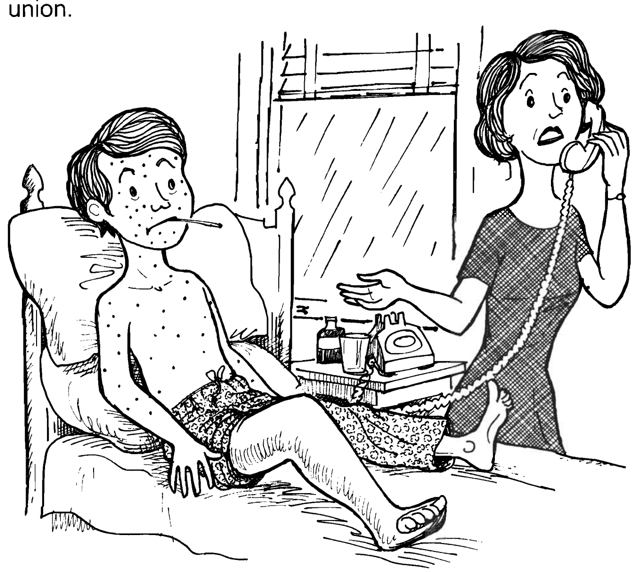
TRAPS ARISING DURING TREATMENT

The general public are curiously stupid about fractures. They will believe, for example, that a nerve palsy first noticed after a cast is applied is due to the surgeon's manipulation and was not merely overlooked before the fracture was set. The public believe that if a fracture slips at 2 weeks and needs remanipulation, that it is the surgeon's poor cast that has permitted slippage. They believe that the calcaneus limp, universal after the cast comes off a child with a fracture of the tibia, represents some error in treatment. They will think these things if you do not tell them about these events before they attract the parents' attention. *Try to tell the parents your plan for the total care of their child at the initial emergency consultation.* Repeat it later.

The wise surgeon should acquaint parents ahead of time with all the problems that are likely to occur—certainly before he himself takes on treatment. In the 18th century, Heister stated that very clearly: "The surgeon should be very cautious offering his prognosis concerning fractures to avoid being called a knave or a fool."[3]

The traps arising during the course of treatment can be avoided by adhering to the following principles.

Fig. 3-13. Poor follow-up is a common cause of malunion.



1. **Use Your Working Knowledge of the Various Complications to Look Deliberately for Them.** Recognize nerve palsies before reduction. Recognize unstable fractures so that you apply casts that are paragons of molding. Recognize situations where your manipulation may fail so that the operating room is prepared for open reduction. Do not allow a child to wake up from a general anesthetic until you have radiographic proof that the fracture is in a satisfactory position. Remember that the acceptability of a reduction is inversely related to the ease with which you can alter the position.
2. **Children are Only Uncooperative When There is Something Wrong.** Regrettably, children are unable to tell you that skin, nerve, or muscle is undergoing necrosis. Instead, they weep or call for their mother or hide their head. Often reassurance works well and aspirin even better. Don't be fooled; split the cast widely or adjust the traction immediately. You do not want to have the experience that will enable you to talk about Volkmann's ischemic contracture at medical meetings.

   Remember that pain goes when tissue dies; if you put your head in the sand until the pain goes away you will be too late. For the fracture surgeon, hysteria does not exist until after the fracture has united.
3. **Ensure that Your System of Follow-up Does not Permit Patients to Be Lost** (Fig. 3-13). Each year a few children do not return to our clinic for about a month after the fracture has been reduced. When they do appear and the radiograph on the viewing box shows malunion, this will be the moment that a colleague will wander into your clinic. Nothing you say will wholly extract you from this situation. Avoid it by calling back all fracture patients who fail to keep appointments.
4. **Recognize a Loose Cast.** A loose cast will allow a fracture to slip. If you can put your hand inside, if the cast telescopes up and down, or if the radiograph shows an air gap (Fig. 3-14), change the cast. Assess the quality of the cast on the radiograph. A cast that only fits in places should be replaced.
5. **Recognize the Earliest Signs of Slip.** When a fracture angulates slowly, it is a sign that the cast

Fig. 3-14. The swelling has subsided and the cast is loose. A black line marks the surface of the skin. Always look at the fit of the cast on the radiograph.

Fig. 3-15. A minimally displaced fracture of the distal forearm. The patient broke his cast and did not attend for follow-up. He heals with angulation. The new bone under the dorsal and radial hinges can be seen. These fractures require carefully molded casts to prevent this problem.

is not maintaining three-point pressures. Change the cast to a better one to avoid gross angulation later (Fig. 3-15).

6. **Talk to the Parents.** If parents are a nuisance, it is always your fault. You have not told them what to do or what to expect. Parents object to insufficient orders and not to too many. If you ask them to check the color of the digits every hour for the first night after reduction, most parents would do this without complaint. But if a child refractures the arm during karate practice 1 day after coming out of a cast, they will blame you. Tell them about cast care and your arrangements for cast repair. Tell them of the likely problems at the outset: the likelihood of remanipulation, stiffness, deformity, bumps of obvious callus, hair legs in teenagers, limp. Warn them about growth arrest and avascular necrosis if these are real hazards, but do not tell everyone with an epiphyseal separation that this is a hazard, because it is not.

Talking is especially necessary when a child is in an ICU. The family needs information, they want to be with their child, and they want to feel useful. Feelings must be expressed and they need emotional support. A meeting dispels family turmoil and defuses family/staff conflict.[1]

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2. Charnley J: The Closed Treatment of Common Fractures. Edinburgh, Livingstone, 1980
3. Heister L: Medical, Chirurgical and Anatomical Cases and Observations. Wirgman G (trans): London, Reeves, 1755

4 / Fractures with Vascular Damage

On the battlefield arterial injuries come quickly, and the decision to expose the artery is already partly made. The amputation rate is only 13% because of prompt expert repair. For *closed* fractures with arterial damage the amputation rate is up to 50% because of late diagnosis.

The maximal permissible interval between injury and repair is about 6 to 8 hours, depending on the degree of arterial occlusion, the state of the collaterals, and shock. These 6 to 8 hours may pass quickly while the patient is given narcotics and a doctor is found to split the cast. The doctor *always* realizes there is trouble but seems unable to act immediately and decisively, hoping that the situation will miraculously improve. Slowly he comes to appreciate that hope is not enough and calls for an arteriogram or transfers the case to another hospital. Every minute should count, because invisible changes are taking place in the muscles and nerves of the limb. Yet in all the patients we have cared for, hours have been frittered away. Successful care comes from a high index of suspicion and early arterial repair. Successful care produces a normal limb; delay, a Volkmann's contracture or a gangrenous limb.

PHYSICAL SIGNS

Unfortunately, in the emergency room, a child with a fracture with ischemia is not startlingly different from a child with a simple fracture. A crying child, with his limb swathed in splints and bandages, and surrounded by distraught relations is not easily viewed with cold, clinical detachment. A quick squeeze of a protruding digit or nail bed for capillary filling is often considered sufficient to demonstrate an intact circulation. Demonstrate the fallacy of this sign next time you operate. Inflate the tourniquet before the limb is exsanguinated. Squeeze the digit: capillary return is still present. This test only indicates that blood is present in the limb, and not that it is circulating.

In the past 5 years the guesswork has been taken from these problems by direct measurement of compartment tissue pressure and by the use of Doppler pulse meters.

THE THREE FACES OF ARTERIAL OCCLUSION

If occlusion is not recognized on admission there is usually a considerable delay before anyone notices it. A child's ischemic pain may be borne stoically by the staff and attributed to fracture pain or clouded by opiate. Pulses are hidden by cast or traction so that observation is difficult. Remember that a splinted limb should be painless. *Pain after reduction should be attributed to ischemia until proven otherwise.* A special trap is painless ischemia in a child with a nerve palsy. Whenever a child is genuinely unable to move the fingers, there is always someone around who says the fingers were moving 5 minutes before.

Complete Occlusion

The pulse is absent, the veins are empty, and in the course of an hour or two the limb becomes white and cold. Failure of nerve conduction produces glove and stocking anesthesia and paralysis. After a few more hours, rigor mortis results in the muscles shortening, and attempts to overcome this are painful. Pain is extreme. Later the skin becomes marbled, and gangrene follows.

Incomplete Occlusion—Compartment Ischemia

Ischemia of muscle, called Volkmann's ischemia (Fig. 4-1), is compatible with an intact pulse and adequate peripheral circulation. The first signs are pain in the muscle and pain on stretching the muscle. For this reason, we do not give any analgesic to children with fractures that have a reputation for vascular problems. Compartment ischemia may be a sequel to an arterial injury (Holden Type I) or to direct compartment injury (Holden Type II) (Fig. 4-2). Frequently there is sufficient arterial flow to maintain a pulse and distal circulation, but the muscles and nerves become hypoxic and damaged. The outcome of muscular ischemia is a Volkmann's contracture. Compartment syndromes will be described in more detail later.

Compensated Occlusion

Not uncommon is the child with a supracondylar fracture who has an adequate distal circulation but no pulse (Fig. 4-3). The extremity may be a little cool, but there are no signs of nerve or muscle ischemia. Despite occlusion of the major artery, the collaterals maintain an adequate circulation. (The same effect is seen after a Blalock operation.) Apart from worrying and ordering an hourly check on sensation and movement, there is nothing special to do. Arteriography and exploration are meddelesome. Within a few weeks the pulse returns, and I have yet to see a child with claudication.

Sites of Fracture Associated with Vascular Damage

While any fracture carries the hazard of vascular damage, the problem is most likely in supracondylar fractures, elbow dislocations, fractures of the shaft of

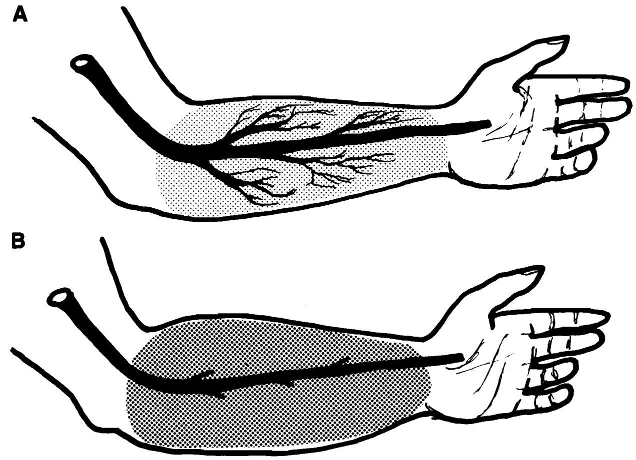


Fig. 4-1. Volkmann's ischemia. *(A)* Normally the pressure in the brachial artery is 120 torr. Muscle is perfused at a pressure of 30 torr. *(B)* Muscle ischemia. If the pressure within the muscle compartment is raised above 30 torr, muscle will not be perfused, but the radial pulse is *not necessarily* occluded.

Fig. 4-2. Compartment ischemia may be due to arterial injury or to increased compartment pressure.

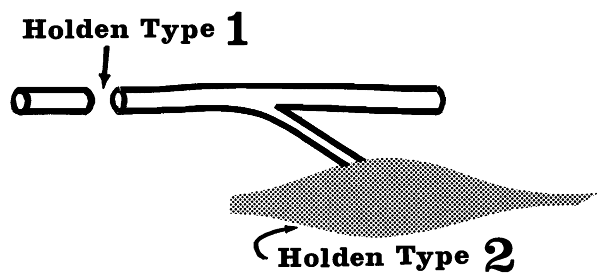
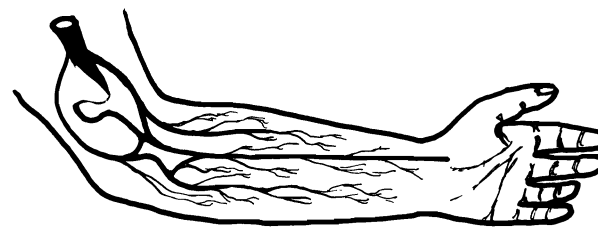


Fig. 4-3. Compensated occlusion. Anastomotic channels maintain perfusion at low pressure and sufficient to sustain the tissue but insufficient to produce a pulse at the wrist. The pulsations have been abolished, but the flow remains. If an eponym had been attached to this condition it would be diagnosed frequently.



the femur, especially the distal one-third (Fig. 4-4), dislocation of the knee, fractures of the proximal tibia, grossly displaced fractures of the ankle and talus, and midtarsal dislocations.

The Nature of the Arterial Lesion

The incidence of arterial damage, as distinct from ischemia, in fractures is not known. As one mother of a child with arterial damage put it, perhaps all children with fractures should have an arteriogram. Only by this radical experiment would we know the incidence of arterial damage.

Lesions in Discontinuity. There is complete transsection of the vessel.

Lesions in Continuity. *Intimal Lesions.* Intimal tears and contusions can only be diagnosed with confidence by arteriotomy. The distal part of the vessel is empty and stringlike. The condition is indistinguishable from spasm until intima is inspected.

Spasm. Traction has been shown experimentally to produce spasm. Application of this observation has reduced the incidence of Volkmann's ischemia in fractures of the femoral shaft (see p. 273). However, the past, the importance of spasm has been greatly overplayed at the cost of many limbs.

Compression. The most common causes of ischemia are undoubtedly tight casts and deformity at the fracture site. Release the cast or align the limb, and the circulation comes bounding back. Kinking and stretching of vessels has been convincingly demonstrated after high tibial osteotomy.

Thrombosis. Prolonged occlusion owing to any cause will produce propagating thrombosis.

Aneurysm. After a few days or weeks the site of fracture becomes painful, red, swollen, and warm—like an infection—but when it is drained, there is a gush of blood. The aneurysm may be caused by a partial tear of the artery at the time of fracture; by the end of a pin, drill, or screw; or by a mycotic infection. Small vessels may be tied off, but major vessels require a graft (Fig. 4-5).

Whenever you embark on releasing a hematoma, bear in mind that it may be a false aneurysm. Listen for a bruit; consider an arteriogram. Check on the whereabouts of your vascular surgeon before you start, just in case you will need help.

Fig. 4-4. In the hour that followed this injury the leg became cold, white, anesthetic, and weak. The pulse was absent. After the fracture was reduced under general anesthesia the veins became full, the foot warm and pink. The pulse did not return for several weeks. The femoral artery passes through the adductor opening at this site, where it is liable to injury.

MANAGEMENT

Prevention

Traction, tight casts, excessive flexion of a swollen elbow, and hypotension all produce ischemia in the absence of an arterial injury at the time of fracture. Be vigilant, be quick, and be decisive. If you are lucky, removing bandages, bivalving the cast, and placing the limb in a dependent position may be enough to improve circulation. If you are the resident, get on and do this; don't call your chief first, however precious the patient or the reduction.

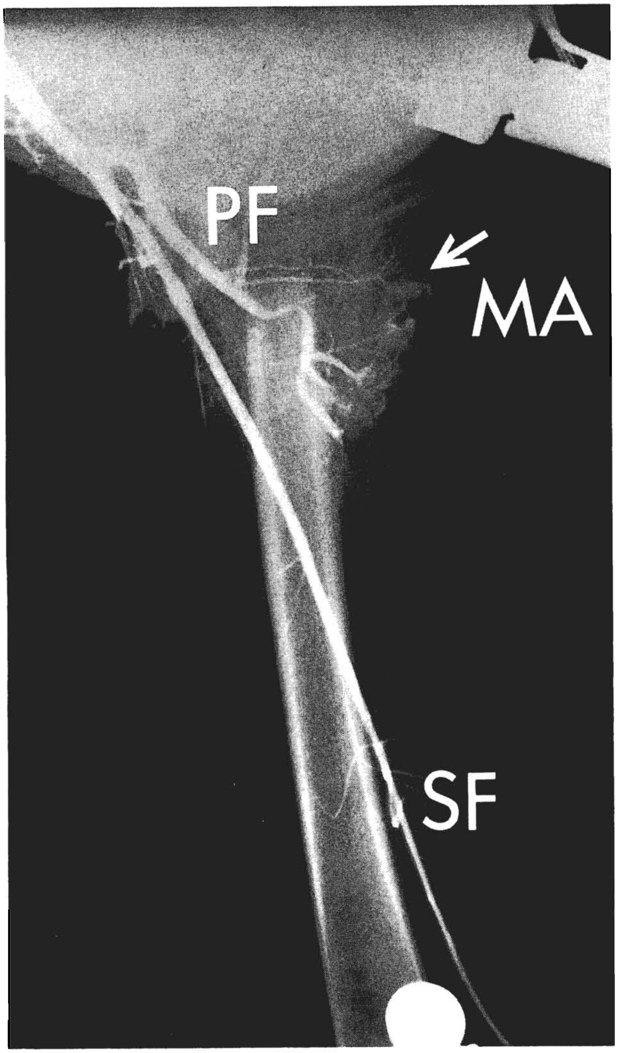


Fig. 4-5. Mycotic aneurysm of profundus femoris. Doris, aged 7, was hit by a truck. She sustained a fracture of the femur (treated by 90–90 traction) and a severe head injury, which resulted in her being unconscious for a month. During this time she was pyrexial at times and then developed multiple staphylococcal abscesses, which required drainage. The mycotic aneurysm attracted attention because of swelling and repeated hemorrhages. Embolization failed and the vessel was tied off. Infection is a risk in multiple injuries because of poor nutrition and a plethora of needles and tubes. Antibiotics are wise. (*PF*, profunda femoris; *MA*, mycotic aneurysm; *SF*, superficial femoral artery)

Treatment of Limb Ischemia

If the circulation does not improve in 5 minutes, you must make very many preparations to take the child to the operating room immediately. As soon as diagnosis of ischemia is reached, it is obviously a matter of extreme urgency, and you must not be put off by any other service commitments nor by anesthetists telling you that the child has a full stomach. You should carry out surgery with the help of a vascular surgeon. However, in civilian practice vascular surgeons do not have much experience with this problem, and you should not look to him to make all the decisions. His greatest experience is in the treatment of vascular disease in the elderly. The new group of microvascular surgeons may be your best ally.

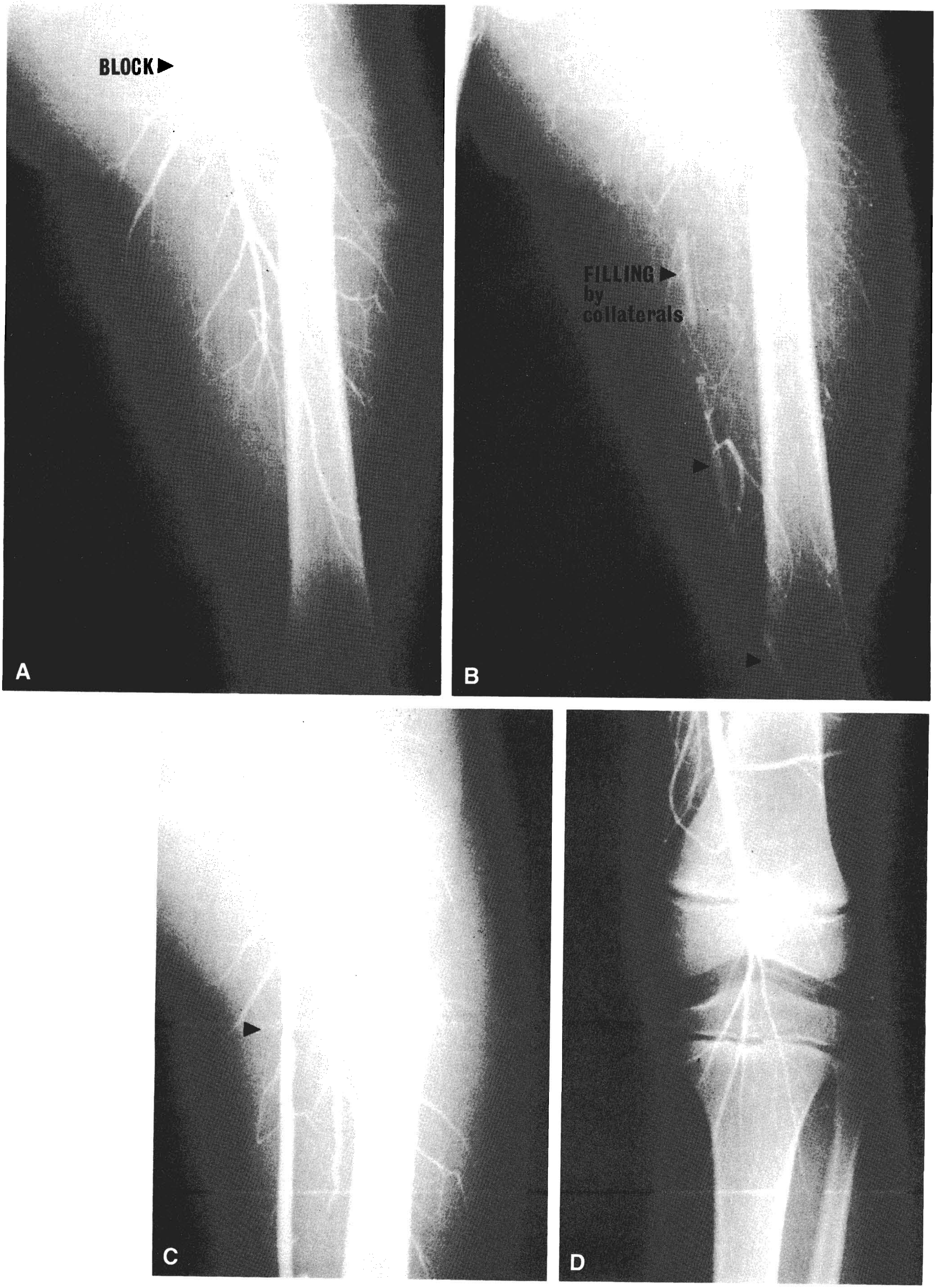
Treatment may include:

Arteriography. Arteriography is only of value if it can be carried out immediately: do not waste time rounding up staff. Arteriography always takes at least an hour, whatever you are told, and in most cases *this time could be better spent relieving ischemia*. It will demonstrate the site of occlusion, although it will probably not disclose the type of lesion. The site of occlusion is usually opposite the fracture site. Arteriography may be of medicolegal value. In one case, I suspected that the cause of ischemia may have been tight bandaging; however, the arteriogram showed an intimal tear opposite the fracture site.

Jim, aged 8, was used to bicycles with "back-pedal" brakes. He went down the hill on his friend's bike so quickly that he was unable to master the brakes on the handlebars. Jim hit a truck, fracturing the left femur. The circulation was unremarkable and he was placed in traction. The following morning the leg was found to be white, anesthetic, and cold. An arteriogram showed obstruction of the superficial femoral artery (Fig. 4-6A). At a later phase the distal part of the artery filled slowly through collaterals (Fig. 4-6B). Had distal runoff been better, the artery would have filled better through the collaterals. The appearances indicated a block in the femoral artery with a distal compartment syndrome.

A femoral arteriotomy in the groin was carried out; Fogarty catheters were passed beyond the pop-

Fig. 4-6. *(A)* Initial arteriogram made 15 hours after injury shows a complete block in the superficial femoral artery. *(B)* At a later phase, the superficial femoral artery fills slowly through collateral arteries. *(C)* A second arteriogram shows an intimal tear at the site of the arrow. *(D)* Ischemia is due to a clot at the popliteal trifurcation.


BLOCK
A
FILLING
by
collaterals
B
C
D

liteal artery, and the clot was removed. Subcutaneous fasciotomy of three compartments of the leg was carried out. The skin became warm and pink, but the pulse did not return.

Thirty-six hours later the circulation deteriorated and the leg looked like white marble. It looked like the end. Another arteriogram (Fig. 4-6C) showed an intimal tear at the fracture site and a block at the popliteal trifurcation (Fig. 4-6D). The leg was laid open through a Henry approach from groin to ankle. The medial head of the gastrocnemius and the tibial attachment of the soleus were divided to reveal the entire vascular tree. After excision of the damaged section of the femoral artery, Fogarty catheters were passed under vision to the ankle through the anterior and posterior tibial arteries.

The artery was anastomosed. All four compartments were decompressed (revealing the inadequacy of subcutaneous fasiotomies). The skin was left open. The circulation was no better. Myringotomies were carried out, and the boy began a series of dives in the hyperbaric chamber. Heparin was administered. After each dive the color of the foot improved.

The back of the leg was closed with skin grafts at 5 days. The fracture was managed in a hip spica throughout because it was longitudinally stable. At 8 weeks the fracture was united and the cast was removed. Dressings were still needed because dead muscle was extruding. He began walking in running shoes.

Six months after injury Jim had anesthesia from midcalf downwards and about 30 degrees of equinus. A year later sensation had returned but paresthesia were a problem. A posterior release was performed and neurolysis of the posterior tibial nerve. The skin grafts were excised. The paresthesias disappeared immediately. He walks normal distances but with a marked limp, because most of the muscle below the knee has been destroyed.

This is a typical story. Ideally arterial damage should be recognized early and repaired before irreversible complications occur.

Treatment of the Arterial Lesion. Direct inspection is the only certain way to determine the nature of the lesion. For this reason, we expose the vessel widely through one of Henry's extensile exposures. The effectiveness of repair can be judged, the extent of muscle damage can be discerned, and wide fasciotomy may be carried out (Fig. 4-7).

Lesions in Continuity. When the artery is constricted at the level of the fracture an intimal tear or contusion is most likely. A segment of artery is excised between bulldog clamps. The proximal end is flushed out. The distal part is dilated and cleared of thrombus with a Fogarty catheter, which is pushed down to the wrist or ankle through each major branch of the artery. These vessels are flushed with heparinized saline to clear any loose thrombus. Backflow should be seen. End-to-end suture is undertaken if this can be done without tension; otherwise, insert a reversed saphenous graft.

When an artery remote from the fracture site becomes narrow, spasm is the cause. Insert a Fogarty

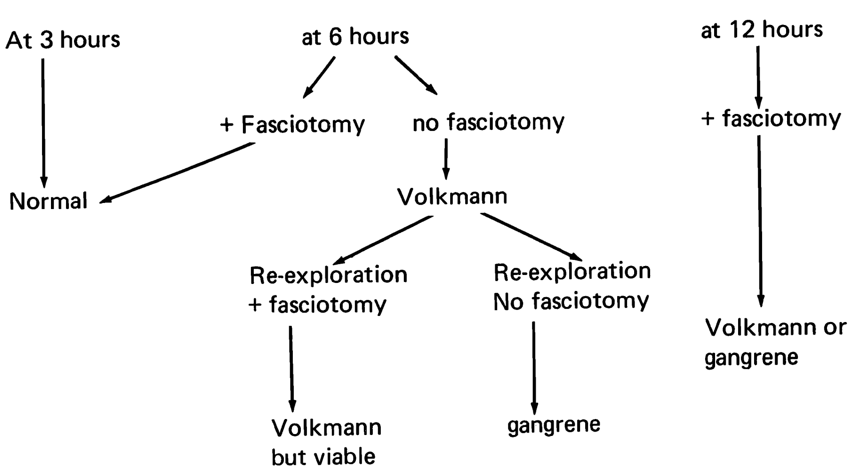


Fig. 4-7. Expectations of arterial repair for complete ischemia.

catheter through a proximal arteriotomy to dilate the artery and to remove clots. Wash out until backflow is seen, and then close the arteriotomy.

NOTE: Papaverine and segmental dilation are ineffective, outmoded, and a waste of time.

Lesions in Discontinuity. Excise the segments, wash out, and anastomose or graft.

Fasciotomy. Subcutaneous fasciotomy is quick and easy. It leaves little scar but does not decompress the deep flexor compartments (Fig. 4-8). For this reason open fasciotomy is mandatory. In the leg, all four compartments must be opened—anterior, peroneal, superficial, and deep posterior. In the arm the deep flexors and extensors require decompression.

Do not excise any muscle at this time. It is impossible to distinguish the sick from the dead. After arterial repair and fasciotomy, distal pulses should become palpable and the veins should fill. The skin can never be closed after fasciotomy, because the muscle has swelled. Cover the extensive wound with tulle, and rejoice that compression is relieved.

Care of the Fracture. Is internal fixation the ideal method? The Vietnam experience suggests that it only adds to morbidity because of infection and nonunion. Our experience is very small, but for children who have not been injured on the battlefield we favor internal fixation whenever possible, because traction may pull the anastomosis apart. A cast, which prevents examination of the entire limb, is contraindicated. External fixation works well and may be the best choice.

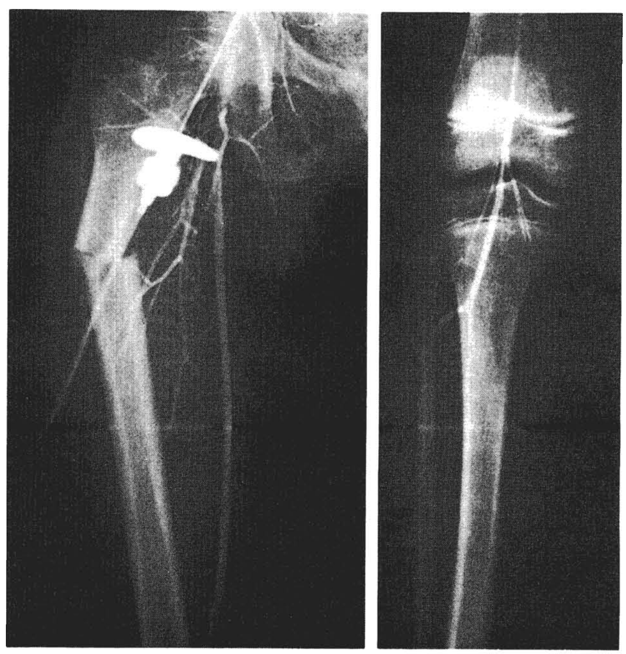
Postoperative Heparin. Subsequent thrombosis may ruin an initially good result; use heparin. As the circulation improves, the ends of severed vessels may begin to bleed and require tying off. This is more likely than bleeding owing to carefully controlled heparin administration.

Complications. Because thrombosis affects 20% of repairs, the circulation must be closely watched in the intensive care unit. At the first sign of failure, the vessel must be explored once again and the thrombus removed.

Note-Keeping and Public Relations. Parents of children in whom ischemia is noticed late usually believe that this catastrophe is somebody's fault, and often they are right. These cases usually go to litigation. Keep scrupulous notes; every time you see the child, record your findings and note the time. Put down everything; nothing is too insignificant to note. In all probability, you will rely on these notes in court. You or your colleague will need all the help that only pages and pages of notes will provide.

At every stage you would be wise to take photographs, and to request your colleagues' advice. Not only may this be helpful, but their written notes may be useful as well. If the case is referred to you, you should keep in touch with the original doctor. Do not jump to the conclusion that it is all his fault. Do not write inspired opinions about the quality of his care. If you do, you will usually be wrong, and certainly damage not only his reputation but also your own. If the question of negligence arises in your

Fig. 4-8. This girl fell out of a tree. She almost died during the next 12 hours because of hypotension from a ruptured spleen and a hemothorax. The fractured femur was placed in skin traction. The combination of muscle hypoxia owing to hypotension and somewhat tight bandaging produced a white, anesthetic leg. Arteriogram shows no damage at the fracture site but complete vascular occlusion caused by compartment compression. All compartments were opened, and the arteries were dilated with Fogarty catheters.



mind, you will be wise to notify your Medical Protective Society.

The Aftermath

In a few days, you will know whether a normal limb may be expected or whether amputation or reconstruction will be required. The reward of early repair will be a normal limb. Wet gangrene usually requires early amputation and secondary suture. In children it is worth skin-grafting a stump in order to preserve length, and, in particular, to save a knee joint.

RECONSTRUCTION OF A DAMAGED LIMB

After a week the fasciotomy bed is formed by young granulations on living muscle; a skin graft should be performed to cover the defect. When there is much necrotic muscle, this must be removed by dressing changes and excision before a skin graft is used to cover the defect. Usually necrotic muscle separates through a sinus in the graft for several weeks.

While the limb is anesthetic and the fracture ununited, it is wrong to try to correct contracture very energetically. Pressure sores and screams are the only results. Discourage the effects of gravity aggravating the contracture, and allow the physiotherapist to prevent joint stiffness, but no more. As sensation returns, painful, tingling hyperesthesia may be a problem. If the incident of ischemia is short-lived, producing only neuropaxia, sensation returns within a week or two. Severe ischemia may result in axonotmesis, so that sensation returns at the rate of 1 inch a month, or not at all.

Leg. When the fracture is united, a below-knee brace with a sheepskin liner in the boot may be needed to control the paralyzed ankle, discourage contracture and protect the anesthetic foot. Walking definitely wards off contracture. If the child is laid up in bed for any reason, the contracture will increase dramatically in a few days if frequent stretching is not carried out.

Arm. Keep the fingers and wrist splinted to prevent flexor shortening as much as possible.

In the succeeding months reconstruction will be required. In the arm, excision of the infarct and tendon transfers are indicated. The leg is simpler because contractures can be released by tendon lengthening.

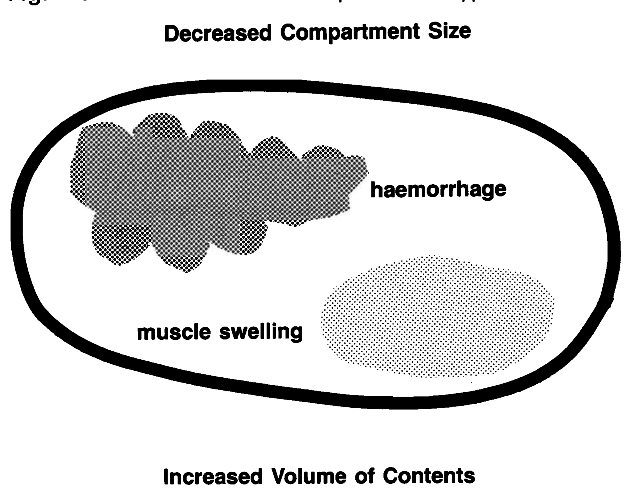
A triple arthrodesis may be necessary later to stabilize the foot. However, in children, I have been surprised by the remarkable degree of muscle power that can return, even when large volumes of muscle are known to have been destroyed. Some children come to amputation late because a stiff, deformed, anesthetic foot is heir to repeated trophic ulcers. The amputation flap should be specially fashioned to preserve the area of skin with sensation. This should be mapped out accurately, using a pen, immediately before operation.

COMPARTMENT SYNDROMES

A rise in pressure within a closed compartment may tamponade the muscles and nerves so that they become ischemic. Muscles are normally perfused by blood at a pressure of about 30 torr in a compartment with a tissue pressure of 3 torr to 4 torr. If the compartment pressure exceeds 30 torr, the muscle will receive no blood, but the main arteries will not be compressed, the pulse will get through (Fig. 4-9).

In everyday life compartment pressure often exceeds 30 torr for a few minutes at a time. When making a fist, the muscle becomes hard, the pressure rises, and the muscle loses its circulation for a time.

Fig. 4-9. Mechanisms of compartment hypertension.



You may have noticed the effects when applying a cast on a leg. Have you noticed how your assistant, who is grasping the toes, always drops the leg just before you have finished? This is because your assistant's forearm muscles are ischemic all the time he grips; when they reach their limit, he drops the leg.

The science of compartment syndromes has been much advanced by experimental models. The anterior compartment of a dog's leg can be injected with blood to raise the pressure. Studies of nerve and muscle show that irreversible changes begin after 6 to 8 hours of ischemia. After 24 hours the muscle shows only slight histologic changes, despite the fact that it is dead and will undergo necrosis later. Muscle damage is related to the *duration* of ischemia. Nerve damage is related to the compartment *pressure*. At first there is loss of conduction, which quickly returns when the pressure is lowered, but prolonged compression causes nerve degeneration.

Compartment pressures may be measured by several techniques Figs. 4-10, 4-11. We use Mubarak's wick catheter and have found this very satisfactory. We make our own. Others prefer Whiteside's technique because it requires no special equipment. But, whichever you choose, you should become familiar with one technique before you are confronted by a problem case. Practice on an orange. We usually measure pressure in children under general anesthesia, but it can be done using local anesthesia. Do not inject a local anesthetic into the muscle.

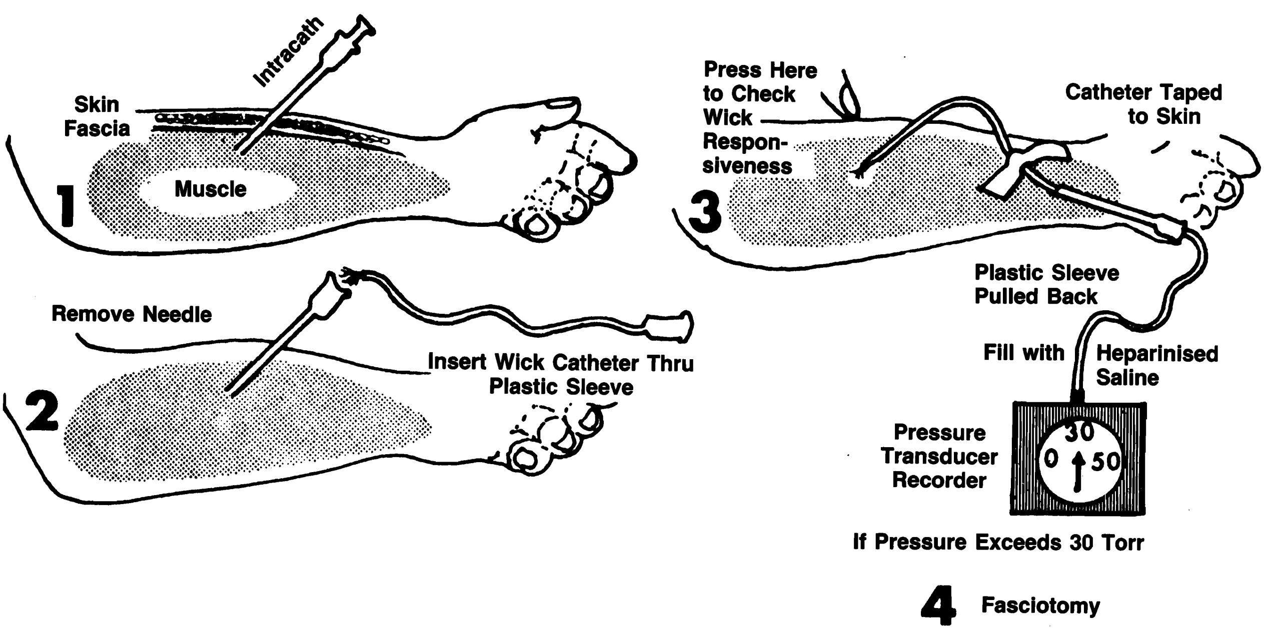
Why Measure the Pressure? If you rely on clinical signs alone, you will do fasciotomies too late and too infrequently. Numbers galvanize you into action and will carry weight in your struggle to get into the operating room quickly.

What should you do if you believe that a child has a compartment syndrome, but the pressure in both deep and superficial compartments are normal? Check the equipment. Repeat the test in an hour or two. If technology continues to contradict common sense, do a fasciotomy.

Differential Diagnosis of a Compartment Syndrome

Fracture pain, a lonely child, an arterial injury, and a nerve palsy may each resemble a compartment syndrome. A Doppler and a pressure measurement will

Fig. 4-10. Mubarak's method of measuring intracompartmental pressure. The "wick" end is being replaced by a "slit" end.



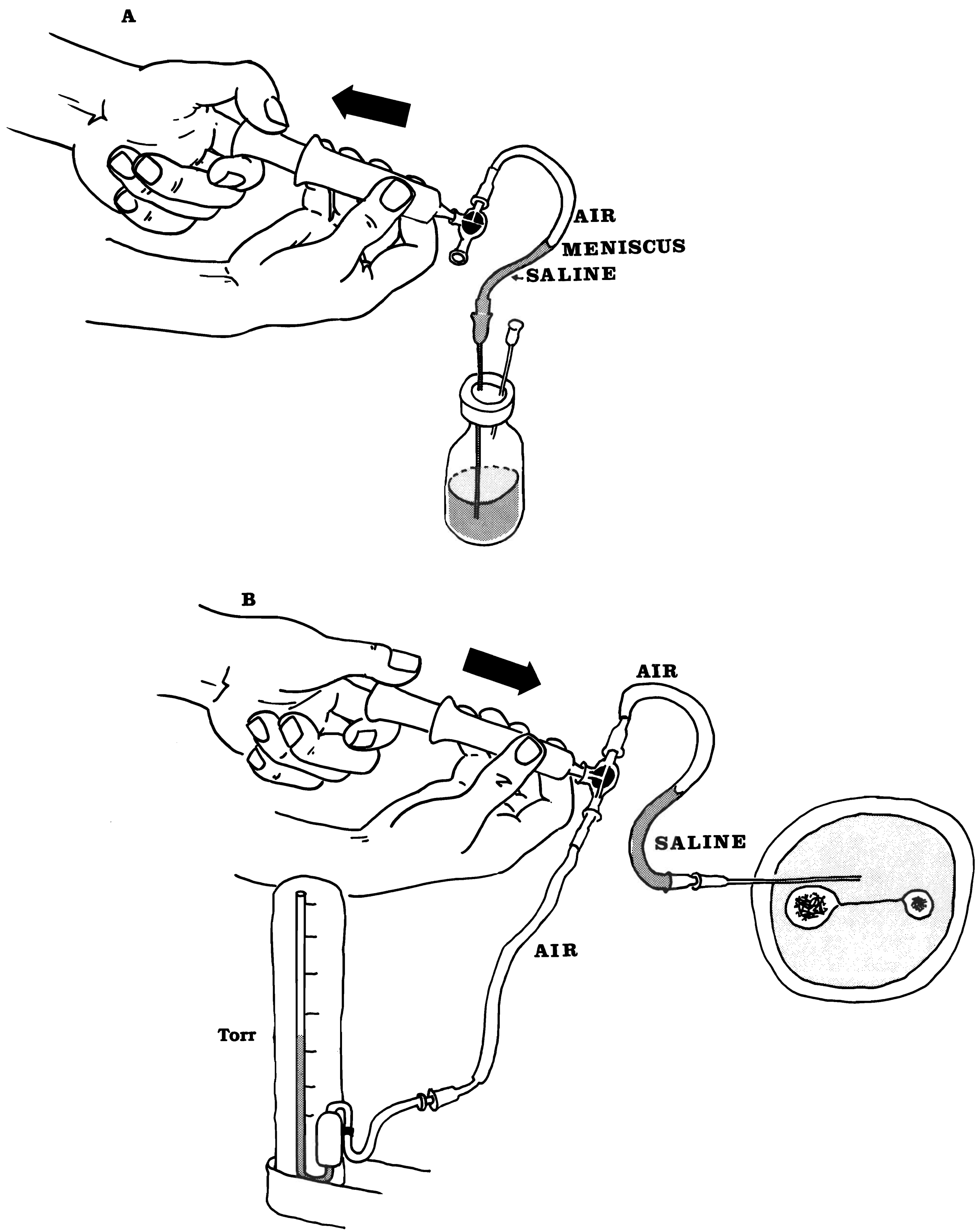

A
AIR
MENISCUS
SALINE
B
AIR
SALINE
AIR
Torr

Fig. 4-11. Whiteside's technique for measuring compartment pressure. *(A)* Use a 20-ml syringe, a three-way tap, and an IV connecting tube. Assemble the syringe with the plunger at the 15-ml mark. Draw up saline to fill about half the tube. Turn the three-way tap so that saline is not lost. *(B)* Push an 18-gauge needle into the muscle of the compartment. By all means inject local anesthetic into the skin, but do not inject the muscle or fascia. Connect and open the three-way tap. Increase the pressure SLOWLY by pushing in the plunger. The mercury manometer will rise. When the tissue pressure is exceeded, the mercury will move a millimeter or two. Stop and read the pressure on the manometer. *Do not* inject too fast; it will push into the muscle and give a false high. *Do not* draw back on the plunger; it will suck muscle into the needle and produce a false high.

distinguish these. A nerve stimulator has been described as helpful, but we have not had one available. Consider a child who is unable to dorsiflex the toes. There may be a question about bruising of the lateral popliteal nerve at the fibular neck; a nerve stimulator will help. If the nerve is damaged, stimulation above the neck will be ineffectual, but stimulation distally will produce a response. If distal stimulation produces no movement in the toes, suspect a neuromuscular block owing to ischemia.

Care of a Compartment Syndrome

On suspicion, the cast and padding should be split to the skin and spread apart widely. There is a lot to be said for taking the front of the cast off to be 100% certain that there are no edges digging in. An acutely flexed elbow should be straightened. This is a time to forget the reduction. Contact the parents so that you do not have to hang around waiting for a consent for the next stage. Elevate the part to the level of the heart, but not above. Does the compartment feel hard? If after 15 minutes there is any decreased sensation or pain on stretching muscles, plan to measure the pressure preferably under general anesthesia.

Carry out a fasciotomy if the pressure measured by wick catheter exceeds 30 torr. Whiteside advises fasciotomy if the pressure comes within 10 torr to 30 torr of diastolic pressure.[1]

Upper Limb

The deep flexor compartment is usually affected. The extensor compartment is affected in 20% of cases. Measure the pressure in the extensor as well as the deep flexor compartment. The fasciotomy should extend from above the elbow into the palm; always open the carpal tunnel. Expose the median nerve and the radial artery. Open the fascia over profundus and flexor pollicis longus. Decompress the extensor compartment by opening the interosseous membrane. Do not try to close the would—little stitches just cut in. The edges can be drawn together with Steri-strips if you wish. Pull the edges together with strips at 1, 2, and 3 weeks, by which time closure succeeds. Stitches cut out or leave railway-track scars; the strips are much better. Skin grafting is generally unnecessary.

Lower Limb

Use the catheter to decide which compartments need opening—peroneal, anterior, superficial posterior or deep posterior. There are several techniques available. All the compartments can be opened through the fibular bed. The periosteum is lifted off the fibula and then incised to open all compartments. It is difficult to see much, and there is not much room for swelling. I prefer a medial and lateral incision; the medial incision opens the posterior compartments between the tibia and the gastrosoleus; the lateral incision opens the anterior tibial and peroneal compartments. They should be opened widely.

Early and Late Fasciotomy

Fasciotomy within 8 hours of the onset of a compartment syndrome means that full function returns almost immediately. This is how it should be done.

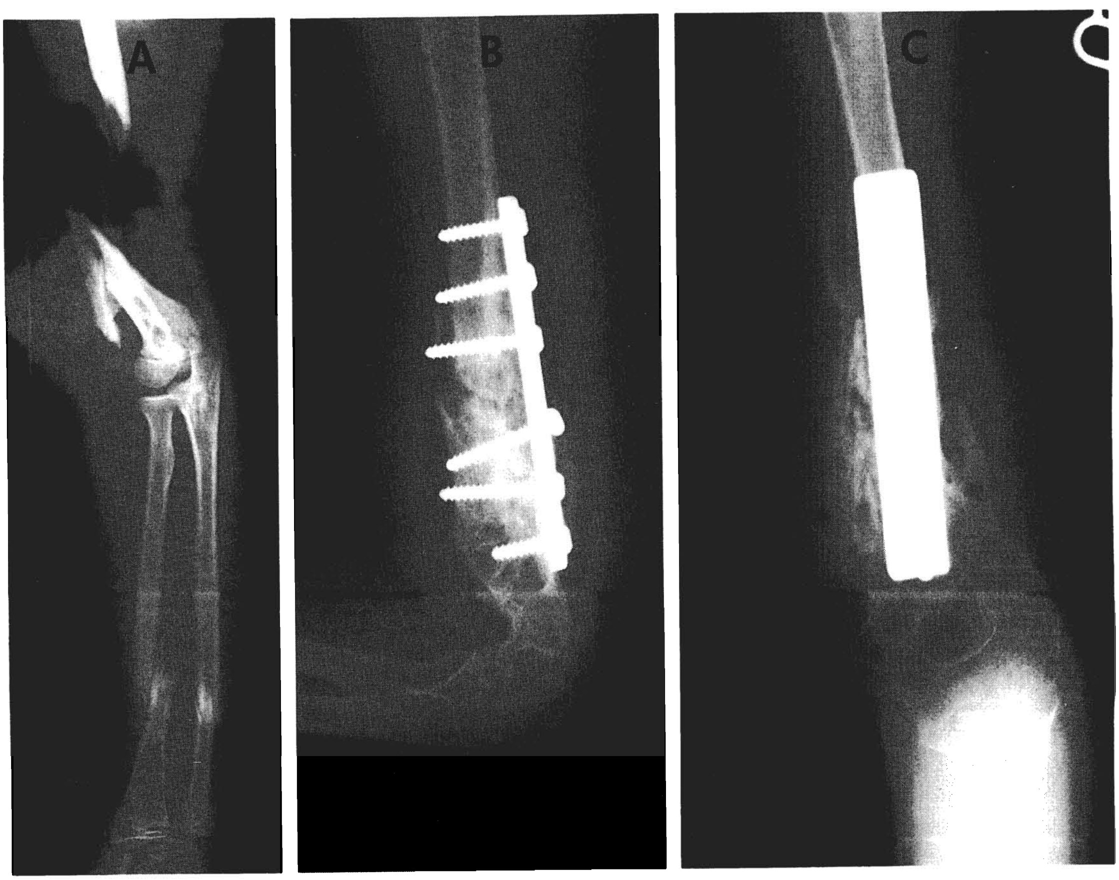
When cases present after days or weeks of a compartment syndrome, fasciotomy is still worthwhile. All tissues will be pale and friable because they have broken down without a circulation to provide repair. Leave the wound open but covered with tulle gras.

Administer antibiotics. Inspect the wound after a week. Some muscles may not look bad, though they may still not contract when pinched; leave these. If muscles are liquifying, they should be removed. Use a front slab to hold the fingers extended, but be careful not to produce sores on the anesthetic fingers. Some muscle regeneration is possible, but when the finger flexors are totally destroyed, we have removed them and labeled the anterior interosseous nerve. This avoids contracture. After the median nerve has recovered, it is worth replacing the muscle. A free transplant of gracilis can be made by microvascular anastomosis of the nerves and vessels.

THE SEVERED LIMB

A partially severed limb is a challenge requiring teamwork. My only experience was with a boy who twisted his arm off in a laundry wringer, perhaps the most common cause of this injury today (Fig. 4-12). Four hours after the accident, he was admitted to the hospital with the arm hanging on by three bruised nerves and a strip of skin. He had a circumferential wound around the elbow at the site of a humeral fracture, and fractures of the radius and ulna. His vessels were completely severed. The vascular, orthopaedic, and plastic surgeons joined together to repair the arm. The distal vessels were flushed with heparin and saline until they ran clear. This helped identify the vein. The humerus was shortened slightly and fixed quickly with a plate. Next the large veins were repaired with a saphenous graft. The artery was repaired with saphenous graft, and blood flow was established again about 6 hours after the injury. The radius was held with an intramedullary Kirschner wire, and this provided the opportunity to

Fig. 4-12. *(A)* A spin drier in a laundromat produced this injury. *(B, C)* Two years later. (See text.)



carry out a fasciotomy. The skin was partly closed with sutures and partly with "silon" sheet. The boy was transferred to the hyperbaric oxygen chamber on anticoagulants. To our surprise, he moved his fingers the following day and had no edema. He showed no sign of ischemic contracture; indeed, the hand became perfect. The humeral fracture required grafting for nonunion, and then he regained full elbow movement.

The results of replantation of limbs depends particularly on nerve regeneration. The procedure is more likely to succeed in children than adults and if the limb is only partially severed, as in the case described above. Reattachment is worthwhile for uncrushed injuries up to about 6 hours from time of severance.

Replantation of the completely severed limb or digit has become a standard procedure in the last 5 years. Most large centers have a replantation team, who are producing some wonderful results in this rapidly expanding, new, exciting field.

In closing, remember that some limbs with vascular damage are so severely injured initially that immediate amputation is the right answer.

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5/ Fractures in Special Circumstances

Most fractures run a predictable course. Sometimes there are special circumstances that cannot be ignored. In this chapter, a potpourri of these conditions will be described.

THE BATTERED CHILD

Although assault has been a criminal offense for centuries when directed toward adults, it has only in the last hundred years been considered an offense when directed against children. The first action brought on behalf of a battered child took place in New York City in 1870. Mary Ellen was being beaten daily by her parents. Attempts to correct this situation by appeals to the police and to the District Attorney's office were unsuccessful. Eventually an action was brought by the American Society for Prevention of Cruelty to Animals, which succeeded because Mary Ellen was certainly a member of the animal kingdom and was being cruelly used.

Today child abuse is a major pediatric problem. Physical abuse affects about 225 children per million of population. Two to 3 percent of abused children die; the mortality rate of battering is equal to that of leukemia.

Each year The Hospital for Sick Children in Toronto treats about 100 battered children. The frequency of child battering is three times as great as that of congenital dislocation of the hip, or of clubfoot.

Recognition of Battering

Battered children may come to the hospital with head injuries, with visceral injuries, fractures, with bruises, or with all of them. The special features are as follows:

Multiple Injuries Over a Period of Time. Some fractures are new and some are old. Infants commonly sustain Type-I epiphyseal separations. If these are manipulated every day, a characteristic appearance is produced (Fig. 5-1). A skeletal survey is mandatory; it may show healed rib fractures with more recent limb injuries. A bone scan may show fractures easily overlooked (Fig. 5-2).

Though these radiographic appearances are diagnostic and much used as illustrations, it should be realized that they are unusual. *Most* battered children have fractures indistinguishable from those produced by a motor vehicle (Fig. 5-3).

Evasive Explanations. "He must have fallen out of his crib." "He fell downstairs three days ago." Considerate parents bring their children right away when they are hurt, and they are sure of the cause of injury. In fact few children who fall do themselves any

Fig. 5-1. The corner fracture, the ring of new bone at the growth plate, and subperiosteal new bone are characteristic of child abuse of the chronic variety. Boy aged 18 months.

harm. Levin studied 100 infants who fell (and these were only the falls that alarmed mother) and not one gave cause for concern.

Admission Desired. Mother is generally the guilty party, and father has known about it. When the child is obviously hurt, father wants the child admitted.

Lack of Tenderness. Parents are gentle as they handle an injured child. "Battering" parents handle him like a sack of potatoes and are oblivious of his cries. Once in an interview I asked the parents, "Is he a good boy?" "No, he is very bad." "What do you do when he is bad?"

Father grabbed the boy's arm—his thumb fit exactly a large bruise on the boy's arm—and shook his fist at him.

History of Previous Obvious Injuries. Some children are already known to the Children's Aid Societies because of family problems. Others have been seen in emergency departments before. This information is difficult to obtain but sometimes emerges later.

Management

A high index of suspicion is warranted. Statistics indicate that 10% of all injuries in children under the age of 2 years are due to battery, and 25% of all fractures in children under the age of 3 years. The doctor should approach all fractures in this age group as examples of battery until he has been convinced otherwise. In Ontario and many other places the doctor is required by law to inform the Children's Aid Society whenever he has a *suspicion* of child abuse. This law protects not only the child and siblings from further injury but the doctor from legal proceedings.

Whether or not the injury itself demands admission, the child should be admitted for protection and to provide time for investigation. The family must be understood; the child must be examined and tested to exclude scurvy, rickets, bleeding disorder, leukemia, pseudarthrosis of the tibia, and bone fragility. The doctor may find himself in a strange position, that of acquiring evidence against the parents as well as trying to provide them with counsel. The social worker has much to offer in these circumstances but needs support from you. She will be able to alleviate the strains in the family by using community resources, will educate them in child rearing, and may put them in contact with Parents Anonymous, an organization of reformed child abusers. In the future parenting courses at school may go some way to preventing child abuse in future generations.

If a child has been seriously injured, the parents may be charged with child abuse and the child put in a foster home; but judicially the view is usually taken that the child is better with his own parents, even in an indifferent home, than with foster parents.

Social workers constantly complain that doctors

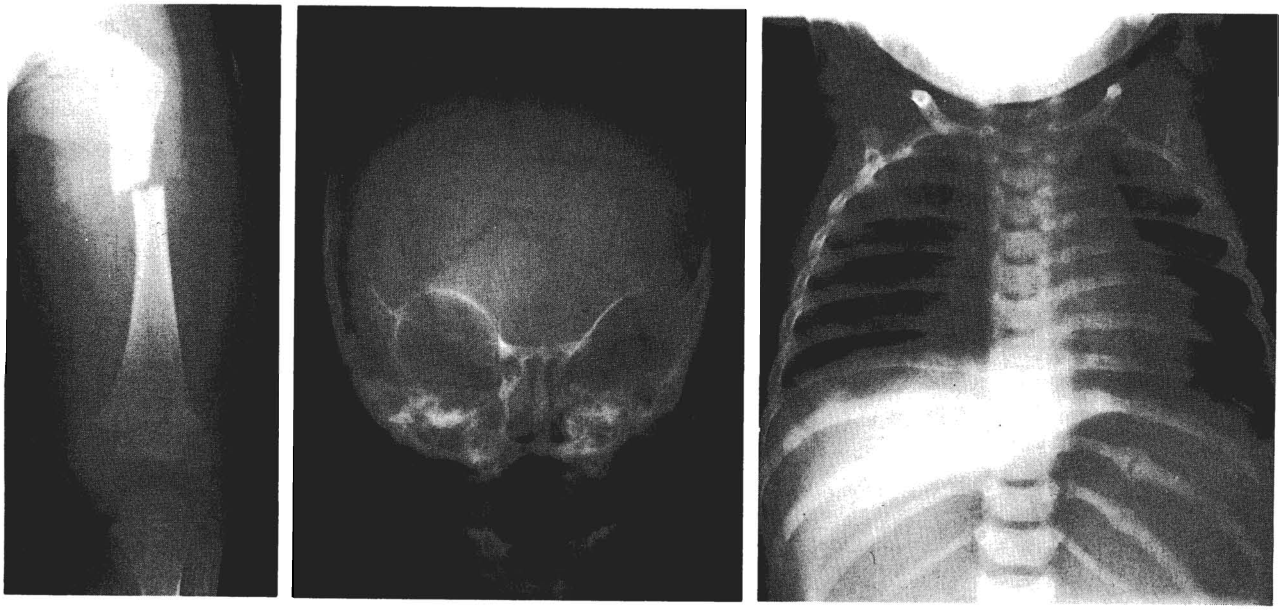


Fig. 5-2. The femoral fracture is fresh. If it were the only injury it would not raise the radiologist's suspicion. However, skull and healing rib fractures make the diagnosis of child abuse certain.

fail to refer cases, and courts give parents the benefit of a doubt. At The Hospital for Sick Children we refer all cases to the Child Abuse Team, who deal with the social and legal problems while we tend the injury. Lately we have had fewer cases. Hopefully the massive media publicity is dissauding abusive parents.

The Battering Child

A 6-week-old child was brought to the Emergency Department with symmetrical spiral fractures of the humerus. The parents thought the arms had been caught in the sides of the crib—an immediately suspicious explanation. Instead, the babysitter's children were the culprits; whether in play or in malice I never found out (Fig. 5-4). Adelson has recently described cases where infants were killed by children. Some of these killings were due to sibling rivalry.

OPEN FRACTURES

Children's open fractures are as hazardous as adults. The main aim is not to placate the parents by telling them that you have sewn everything up; it is not a

Fig. 5-3. Separated upper femoral epiphysis. Knowledge of the family background raised the family doctor's suspicions. Boy aged 11 months.

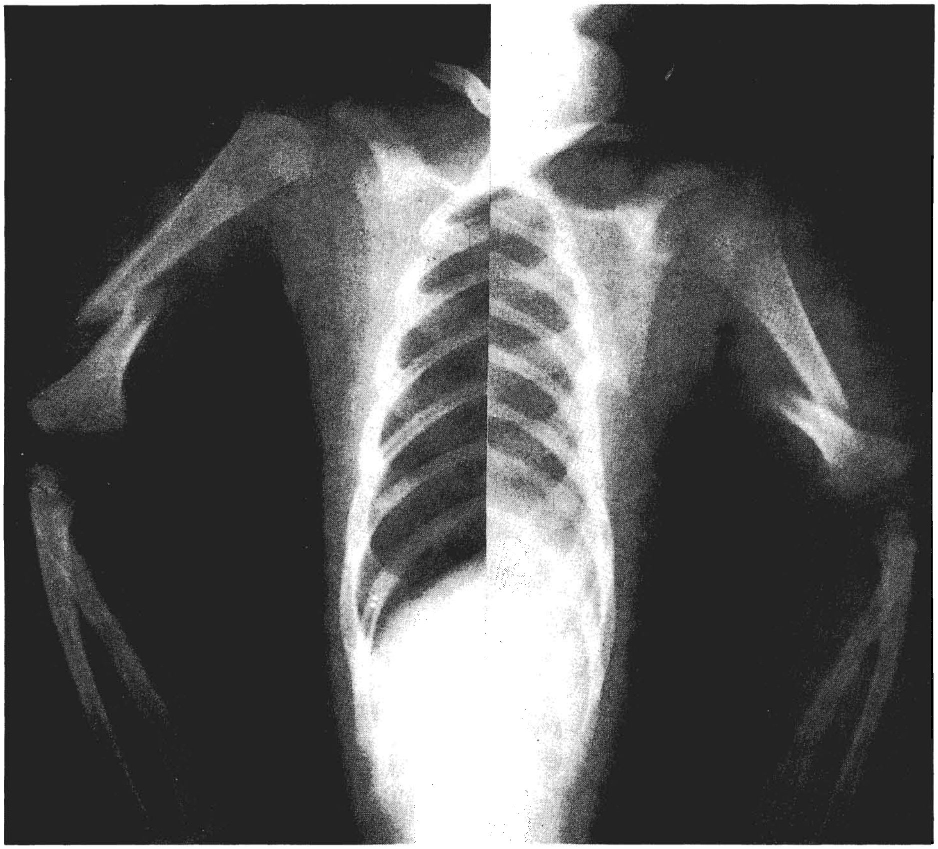


Fig. 5-4. The babysitter's children, aged 7, 5, and 2 years, had produced these symmetrical fractures.

cosmetic scar or internal fixation hidden under muscle. The main aim is the prevention of gas gangrene, tetanus, and pyogenic infection. These may sound like distant threats, but in the past 4 years we have had two patients referred with gas gangrene Fig. 5-5. Both sustained small wounds from forearm fractures; the wounds had been cleaned and closed, and both came to above-elbow amputation. The literature has many others. Beware of pinhole wounds.

Open fractures include motherhood and fatherhood issues; the latter are contentious.

Motherhood Issues

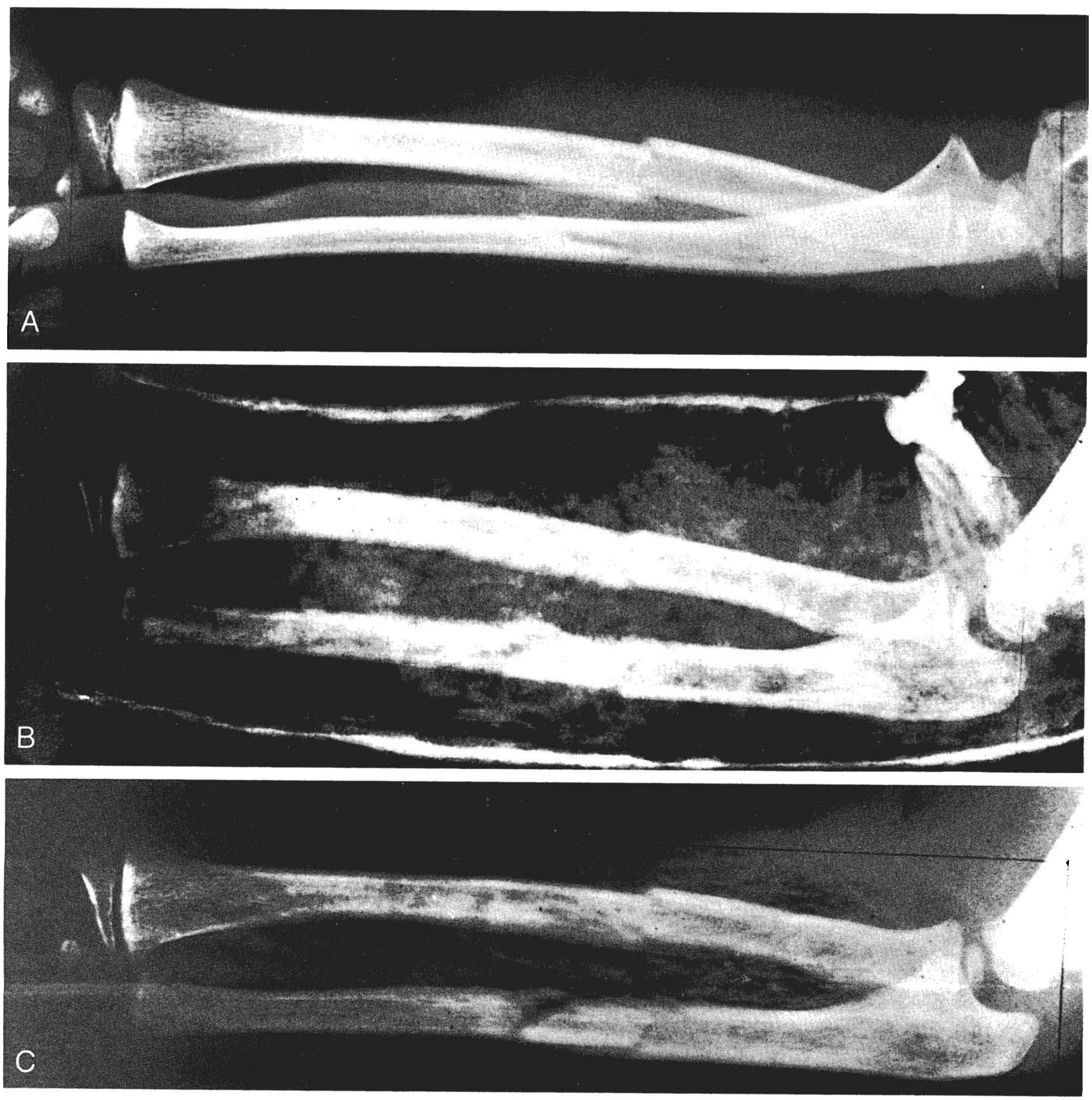
1. ***In the Emergency Department.*** Take a culture and cover the wound with a sterile dressing to protect it from all the people who want to peek and introduce nosocomial infection. The person who applies the dressing should put a sketch of the wound and its measurements on the chart for others to see. Tetanus prophylaxis is administered and IV cephalosporin (*e.g.*, cephalothin 200 mg/kg/24 hr divided into four doses) begun while the operating room is readied. Wounds should be explored within the golden period of 6 hours from injury.
2. ***Irrigation.*** With the patient under anesthesia, take a culture and clean the skin *around* the wound with an iodophore. Irrigate the wound with 10 liters to 20 liters of Ringer's solution. Jet lavage is much more effective than just pouring on fluid. When the surface dirt is removed, redrape and explore the wound.
3. ***Explore the Wound.*** Tracing the connection between the wound and the bone may be difficult. In one recent medicolegal case about gas gangrene in an open fracture, the surgeon missed the connection and thought he was dealing with a simple fracture. He closed the wound and the court closed the case against him. Always enlarge the

wound to establish the anatomic extent. Look for nerve and vessel injury. Look for intramedullary and subperiosteal foreign bodies.

4. ***Debride the Wound.*** In olden days wounds were cauterized or totally excised—like cancer. Today debridement always includes:
   a. Removing tags of tissue—send some for culture
   b. Removing tissue tattooed with dirt
   c. Removing foreign bodies

   Debridement usually includes:
   d. Excising 1 mm to 2 mm of the wound edge, where the skin is probably crushed
   e. Removing some tissue which remains attached but is presumed devitalized, particularly muscle that does not contract when pinched
5. ***Further Irrigation of the Wound.*** Irrigate again using fluid containing antibiotics. If the wound is contaminated with manure, you may consider installing a closed irrigation system for a few days.

Fig. 5-5. *(A)* A playground fall produced this fracture of the forearm. There was a pinhole wound over the ulna. The wound was cleaned without anesthesia, and a cast was applied. *(B)* The next day the forearm was painful. The cast was split. *(C)* The next day there was gas in the tissues, producing a mottled appearance. The arm was dead and was amputated quickly as a life-saving measure.



Fatherhood Issues

Three questions are constantly brought up and are the subject of much discussion.

Should Antibiotics Be Routine? Bacteria can be cultured from two-thirds of open fracture wounds. If wounds are more than 3 hours old before debridement, even a few bacteria will have multiplied sufficiently to result in infection. Wounds contaminated by soil may contain "infection-potentiating factors."

These are the theoretical reasons for giving antibiotics; the practical reasons are that effective antibiotics lower infection rates. Most organisms are penicillin resistant, so that early studies using penicillin showed no benefit. With cephalosporins, Patzakis and associates were able to lower infection rates from 14% in patients treated without antibiotics to 2.3% in those given cephalosporins.[6] Gustilo and Anderson cut the infection rate from 12% to 2.5%.[4] There are strong arguments in favor of routine cephalosporins. The drug should be started in the Emergency Department. A further dose should be given during surgery and then for 3 to 7 days. If the wound remains open, it will become secondarily infected, usually with Pseudomonas. Closure becomes desirable. Further cultures will dictate the most appropriate antibiotic.

How Should Open Fractures Be Fixed? Plates, nails, casts and external fixators each have their proponents for adults. The case is not settled. Decisions are made on the basis of previous experience and testimonials, rather than science. My choice in children depends on the size of the wound: when the wound is small, it is debrided, and the fracture is treated as if there was no wound. When the wound is large, a cast should be avoided because the position is lost when the wound is tended. Epiphyseal injuries are held with pins, and diaphyseal injuries with an external fixator. Open forearm fractures may be plated immediately or after the wound has healed.

Should the Wound Be Closed? The theoretical *advantages* of closure are that secondary invaders are kept out and normal anatomy is restored. The *disadvantages* are (1) the tension in the wound, which may cause sloughing; (2) the lack of drainage; and (3) the increased risk of gas gangrene.

Viewpoint 1: Some Open Fractures Should Be Closed. In a large prospective study, Gustilo and Anderson divided open fractures into three groups (Table 5-1).[4] Primary internal fixation was used only for fractures requiring vascular repair, and they successfully closed the majority of wounds. Their results are outstanding, without any cases of gas gangrene. It may be significant that clostridia were not cultured from any wounds at the time of debridement.

Viewpoint 2. Paul Brown has made a telling comparison between the number of cases of gas gangrene during the Vietnam War and a similar period in met-

Table 5-1. Gustilo and Anderson's Classification of Open Fractures

TYPE	DEFINITION	TREATMENT	INFECTION RATE
I	An open fracture with a wound less than 1 cm long and clean	Oxacillin, ampicillin, and primary closure	0/78
II	An open fracture with a laceration more than 1 cm long without extensive soft-tissue damage, flaps, or avulsion	Oxacillin, ampicillin, and primary closure	2/181
III	Either a segmental fracture or an open fracture with extensive soft-tissue damage or a traumatic amputation; special categories were gunshot injuries, any open fracture caused by farm injury, or an open fracture accompanying vascular injury requiring repair	Oxacillin, ampicillin, and delayed closure	6/67

ropolitan Miami.[1] In Vietnam all wounds were left open; 22 cases of gas gangrene occurred in 139,000 combat casualties. In Miami there were at least 27 cases during a comparable period; presumably there were few injuries. All had had their wounds closed. The conclusion was that open fractures should be left open. If gas gangrene develops in a wound that has been closed, you have no excuse.

Consensus. Closing an open fracture is like crime—fine, unless you are caught. Delayed primary closure is the ideal, either by suture, or skin graft.

Fig. 5-6. Bone cyst of the humerus with a pathologic fracture.

PATHOLOGIC FRACTURES

By definition, a pathologic fracture is one through weak bone of abnormal composition. There are several causes of pathology.

Local Bone Lesions

Simple Bone Cyst. Most pathologic fractures in the upper humerus are caused by bone cysts. Minimal displacement is the rule. Diagnosis can be confidently made on the radiologic appearance alone (Fig. 5-6).

The presence of the cyst does not interfere with healing, and the fracture is treated as if the cyst is not present. However, if nothing is done, refracture is likely.

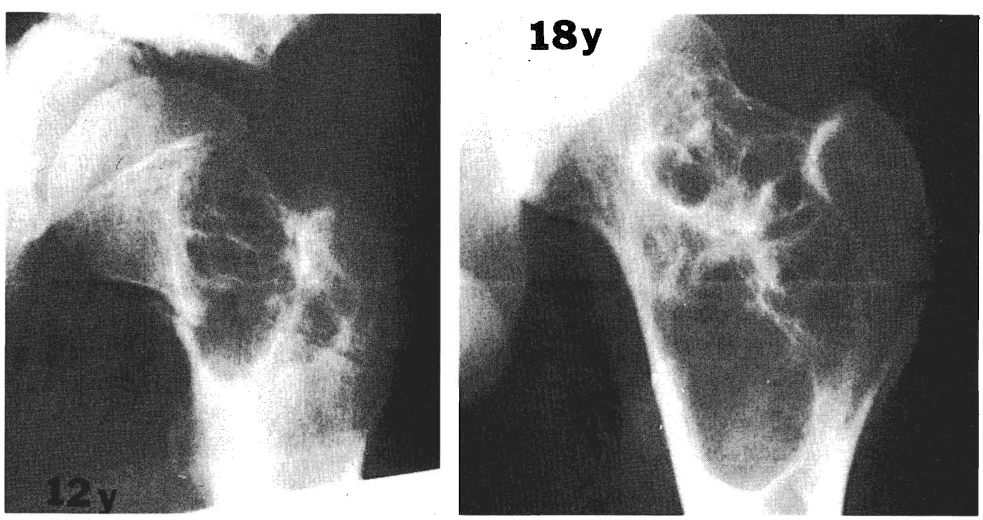


Fig. 5-7. Pathologic fracture through a bone cyst. Child aged 12. Despite curettage and bone grafting twice, this cyst has recurred. Though the bone has not fractured again the cyst remains a threat.

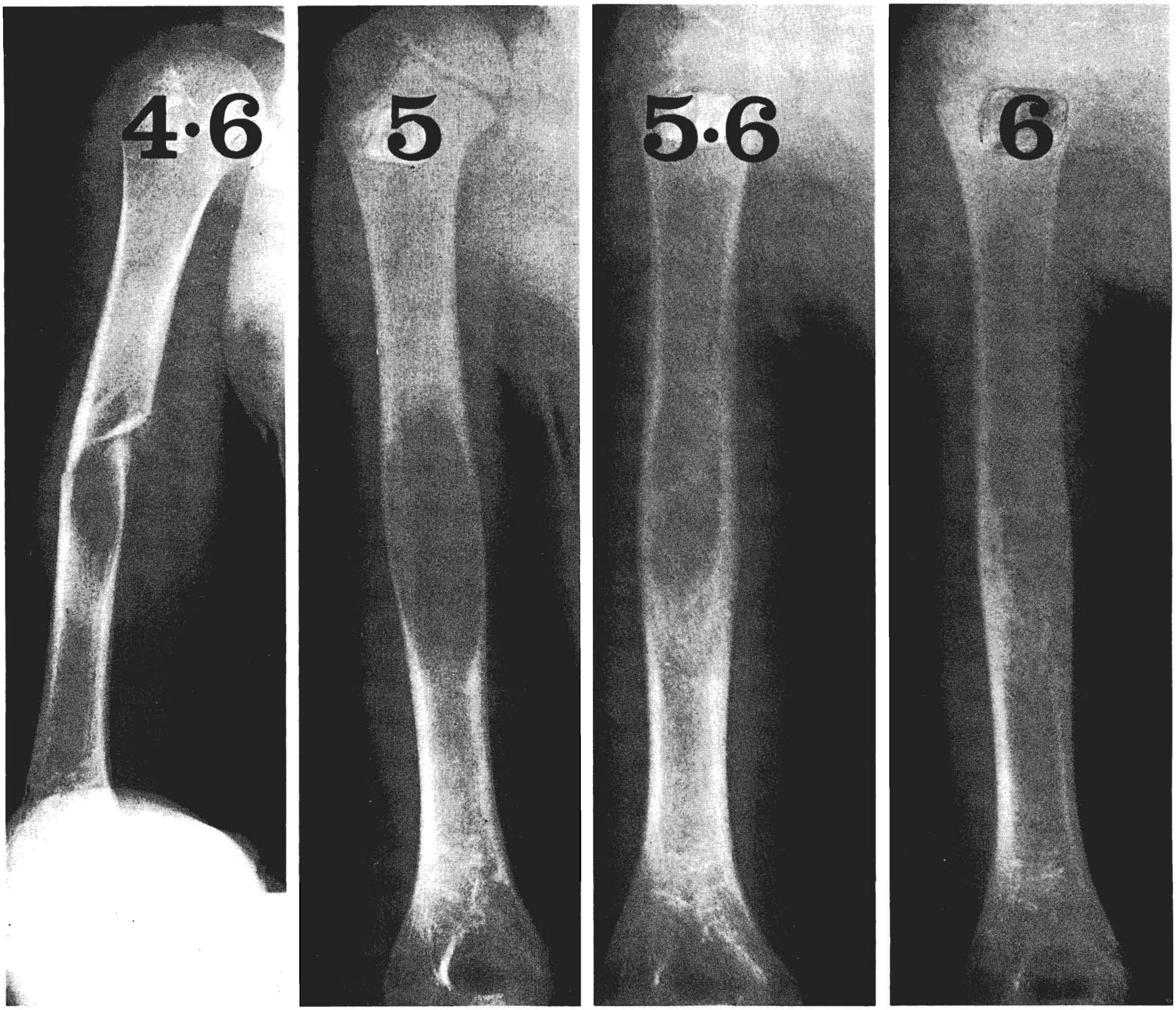


Fig. 5-8. At the age of 5 years the cyst was injected and went on to heal.

Neer found that 80% of children had one to three refractures after the initial injury and 10% had some deformity as a result.[5] Only 1 patient out of 42 did not, at that time, come to surgery. For this reason he advocated treating all cysts.

Bone cysts occasionally produce fractures in weight-bearing bones such as the neck of the femur. Deformity is likely Fig. 5-7. Bone cysts may breach the growth plate. Dr. Raimundo Gonzales of Monterrey showed this by injecting Hypaque into a cyst. Growth disturbance and even collapse of the femoral head may follow.[2]

The treatment of cysts has been transformed by the discovery that injection with methylprednisolone will produce healing (Fig. 5-8). Scaglietti, Marchetti, and Bartolozzi consider it important to use two cannulated needles to enter the cyst under radiographic control in order to avoid hemorrhage.[7] The exit of clear, yellow fluid confirms the diagnosis, so that biopsy is usually unnecessary. Forty mgm to 200 mgm of methylprednisolone acetate (Depo-medrol) is introduced, depending on the size of the cyst. We have usually done this under anesthesia. If the cyst is showing no signs of healing at 3 months, the injection is repeated and may be repeated again. In 72 cases Scaglietti followed for more than 18 months the results ranged from complete healing in 36% to a clearly positive result in 96%. Surgery for bone cysts is moving into history.

Nonossifying Fibroma. The distal tibia, followed by the distal femur, are the most common sites of the fracture through cortical nonossifying fibromas. Centrally placed lesions do not weaken bone (Fig. 5-9).

Most of these fractures are spiral and little displaced. Healing is accompanied by partial obliteration of the fibroma. Since the diagnosis is obvious, biopsy is not required. Refracture is very unusual. A small series of large fibromas has been reported. Some of these were grafted initially because of their size and because of doubts about the diagnosis. Obliteration was more rapid.

Miscellaneous. Every type of "fascinoma" has been associated with pathologic fracture (Fig. 5-10).

General Bone Weakness

Neuromuscular Disorders. In children the major cause of pathologic fractures is osteoporosis resulting from neuromuscular disorders. Fractures are especially common in these patients after operation and cast immobilization (because of joint stiffness and disuse atrophy).

Poliomyelitis. The fractures are typically metaphyseal, and minimally displaced. Every attempt should be made to treat these in weight-bearing casts, in order to avoid the real risk of more osteoporosis and further fractures.

Muscular Dystrophy. Since we adopted a policy of keeping children with Duchenne dystrophy on their

Fig. 5-9. This 9-year-old twisted her leg while skating. The fibrous cortical defect obliterates first at the fracture line, and later the whole defect becomes filled with new bone.

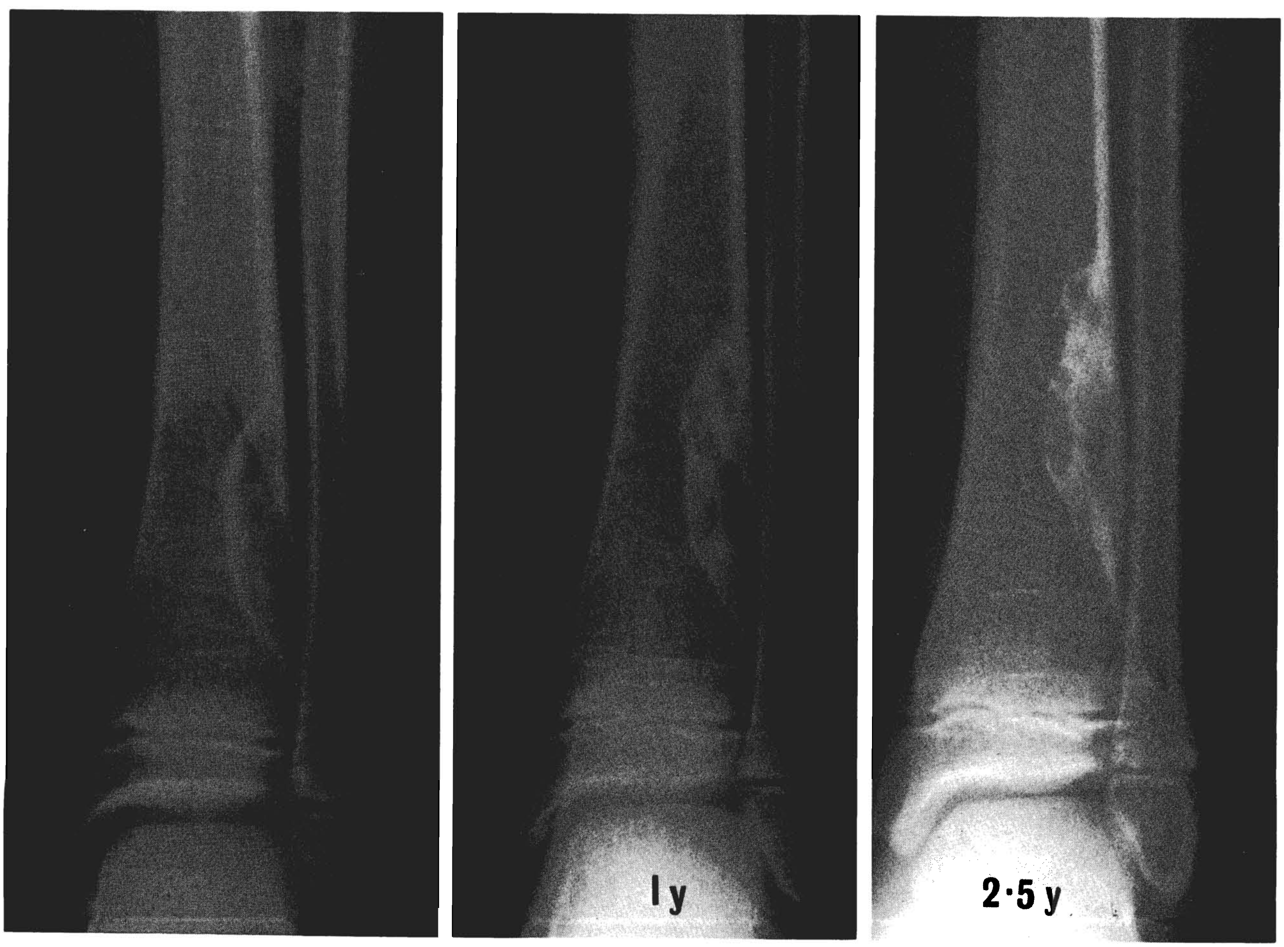


Fig. 5-10. Healing osteomyelitis should be protected to prevent fracture. Girl aged 3½ years.

Fig. 5-11 At 10 years of age John was barely able to walk because of muscular dystrophy. He was seen 2 weeks after sustaining this fracture. It had not displaced and he was nursed at home. The fracture healed *in situ,* but he did not walk again.

feet as long as possible, by means of surgical releases and bracing, we have encountered more lower-limb fractures in this group. Fractures occur at *all* sites and require no special care. The fracture usually spells the end of ambulation, however (Fig. 5-11).

Cerebral Palsy. Fractures in children with cerebral palsy are uncommon. Their bones are strong. It is only after immobilization in the cast that they become weakened enough to fracture. Routine care is generally effective. However, in bedfast patients, particularly those with contractures and convulsions, there are frequent fractures. Very simple methods of treatment are needed for these patients, because pressure sores are difficult to avoid.

Spina Bifida and Paraplegia. Diagnosis is often delayed when a fracture occurs in an anesthetic part of the lower limb. The surgeon is confronted with a swollen, hot, red limb in a child with a slight fever—symptoms that simulate acute osteomyelitis. This clinical picture is not peculiar to spina bifida; it may occur in a battered child or in a stoic who walks

Fig. 5-12. Hyperplastic callus in paraplegia from meningomyelocele in a child aged 1 year.

on a fractured ankle. Fracture is very common after operation and cast immobilization; supracondylar and trochanteric fractures of the femur are so common after hip surgery that I warn the parents to expect them. The incidence is reduced by insisting that the child stand for a few hours every day while in the postoperative cast.

Rapid healing is the rule. Commonly, hyperplastic callus is seen (Fig. 5-12). There is no single explanation for the massive volume of callus; repeated movement, unspecified neural influence on bone formation, and hyperphosphatemia are possible reasons.

Treatment should be simple and carefully supervised. Remember that a child with a shunt should not be put head-down in traction. Overriding is seldom a problem because of flaccid paralysis. It is important to maintain alignment and rotation correctly. We generally use bulky dressings for a period of 2 weeks, in order to avoid the problem of pressure sores. An early return to brace-wearing for the tibia, or a well-padded weight-bearing cast, is advised in order to prevent further disuse osteoporosis and a succession of fractures. Growth-plate injuries may present a diagnostic challenge. Wenger and associates noted premature growth arrest occurred in five of the nine patients.[9] They should be kept immobilized and nonweight-bearing.

General Bone Disease. Fractures in osteopetrosis and osteogenesis imperfecta are common. Displacement is usually slight, and there is much to be said for simple splinting. Air splints have been advocated for osteogenesis imperfecta (Figs. 5-13, 5-14).

FRACTURES IN SPECIAL GROUPS OF PATIENTS

Head Injuries with Long Bone Fractures

When a child is hit by a car, Waddell's triad of injuries is commonly produced. A child's femur is at the level of the bumper; his trunk is at the level of the

Fig. 5-13. Fracture in osteopetrosis in a girl of 8 years. This family of affected children sustains frequent fractures.

Fig. 5-14. An extreme example of hyperplastic callus in osteogenesis imperfecta. This phenomenon has only been noted in association with dislocation of the radial head.

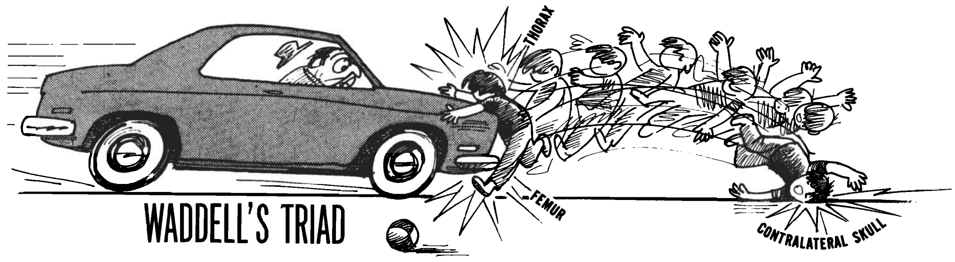


Fig. 5-15. Waddell's Triad of injuries in children.

hood; he may receive a blow to the head on landing on the road (Fig. 5-15).

Fractures of the femur and the shaft of the humerus can be difficult to manage in restless, recumbent children. If the head injury is minor and expected to clear in a day or two, the fracture should be immobilized by simple splinting in a Thomas leg or arm splint until routine methods may be employed. Fat embolism may be blamed for prolonged unconsciousness if this is not done.

When decerebration is likely to be prolonged beyond a few days, we use 90–90 traction for the femur, or intramedullary fixation, depending on the degree of restlessness and the extent of other injuries. Fracture of the shaft of the humerus is treated by vertical skeletal traction through the olecranon.

Fluorothane "shakes" when anesthesia is discontinued make the bones overlap. If you add extra weight to the traction to prevent this, be sure to remove them in a short time, so that a traction injury to the nerves will be avoided when the shakes stop.

Fry, Hoffer, and Brink noted 39 children with a fractured femur in 292 children with a severe head injury—about 1 in 10.[3] There were many problems in the care of these fractures—malunion, more than 5 cm of shortening, fractured bone ends eroding through the skin, and disruption of knee ligaments aggravated by tibial pin traction. Tibial pin traction and skin traction were ineffective methods of management. Internal fixation was preferred in those fit for anesthesia, and 90–90 traction for the rest (Fig. 5-16).

Fractures in the Newborn

The literature is full of birth injuries of every type, a sad reflection on obstetric care. We see very few nowadays, except in babies with fragile bones or with contractures. Any injury may be produced: long bone fractures are easily recognized, but separations of unossified epiphysis present a challenge to diagnosis. There may be difficulty distinguishing between birth fracture and child abuse. Callus appears within 7 days to 10 days around a birth fracture. Truesdall, in 1917, analyzed 33,000 deliveries for skeletal injury and found 85 injured children.[8] These were no greenstick fractures, and only 10% were epiphyseal separations. The humerus and clavicle were most commonly fractured, and a Velpeau bandage controlled these well. Fractures of the midshaft of the femur accounted for 12% and traction was required to prevent gross overriding and anterior angulation (Fig. 5-17).

Spinal cord injury may be produced by longitudinal traction, resulting in "floppiness." Radiographic changes are usually absent. This is discussed further in the section on spinal-cord injuries.

Hemophilia

A well-controlled hemophiliac today is free of crippling deformities and can lead quite an adventurous life. Fractures present no special problem if cryoprecipitate is administered. Fractures heal at the normal rate.

The child should be admitted and a careful watch kept for a few days. While the fracture may produce no problems, the neighboring joint may have been injured slightly at the time of fracture; one boy with no circulating Factor VIII had repeated hemoarthrosis of the knee following cast immobilization for a fracture of the tibia.

A greater risk than fractures, which provoke immediate attention, is a slow bleed into a closed compartment, which results in Volkmann's contracture. This obviously demands urgent decompression.

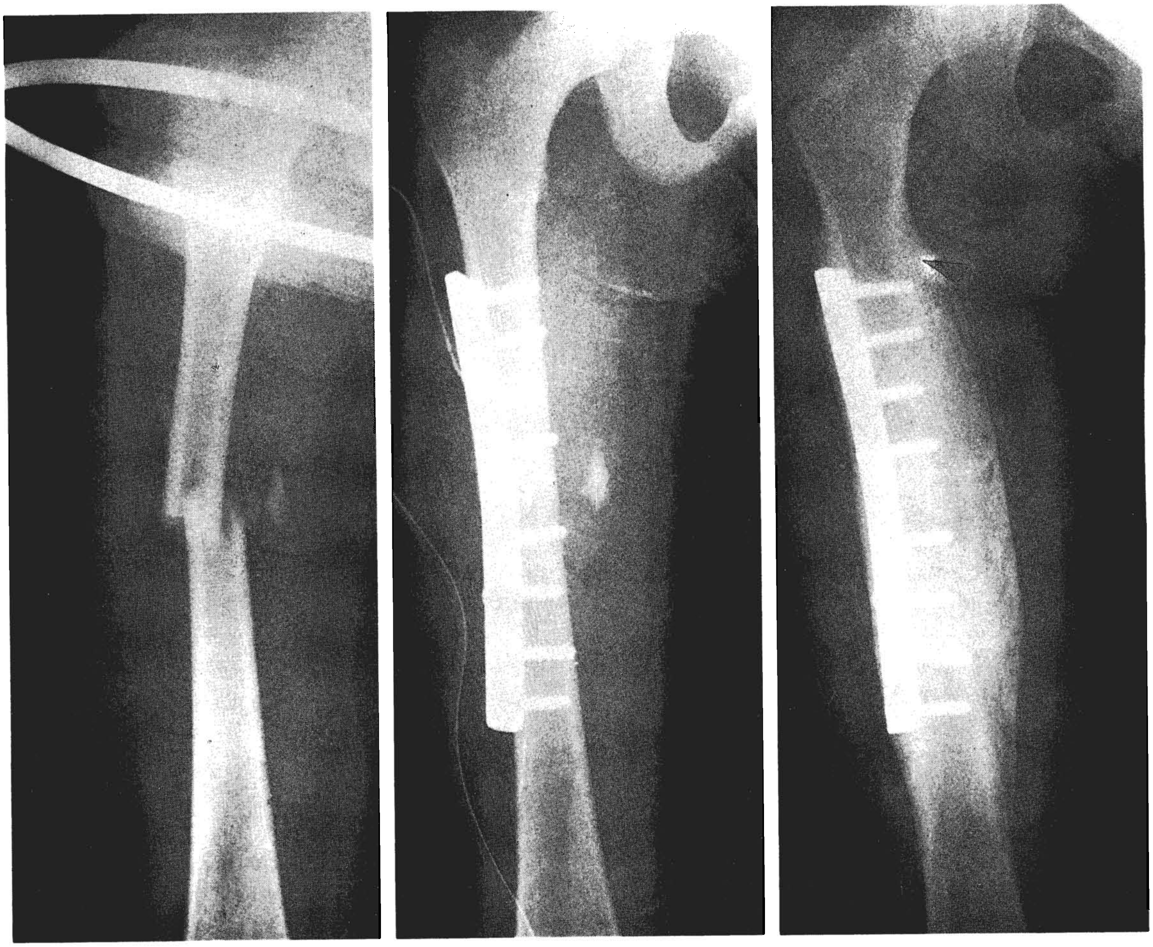


Fig. 5-16. This fracture was uncontrollable owing to a severe head injury. Plating avoids the risk of producing avascular necrosis of the femoral head from damage of the epiphyseal arteries. Antibiotic cover is wise because poor nutrition and multiple tubes increase the risk of infection in these patients.

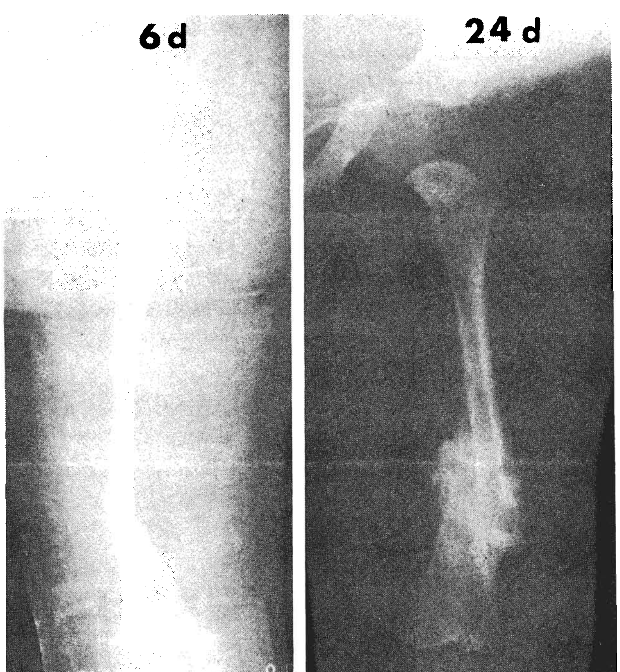


Fig. 5-17. There was difficulty bringing down the leg in this breech delivery.

Renal Osteodystrophy and Rickets

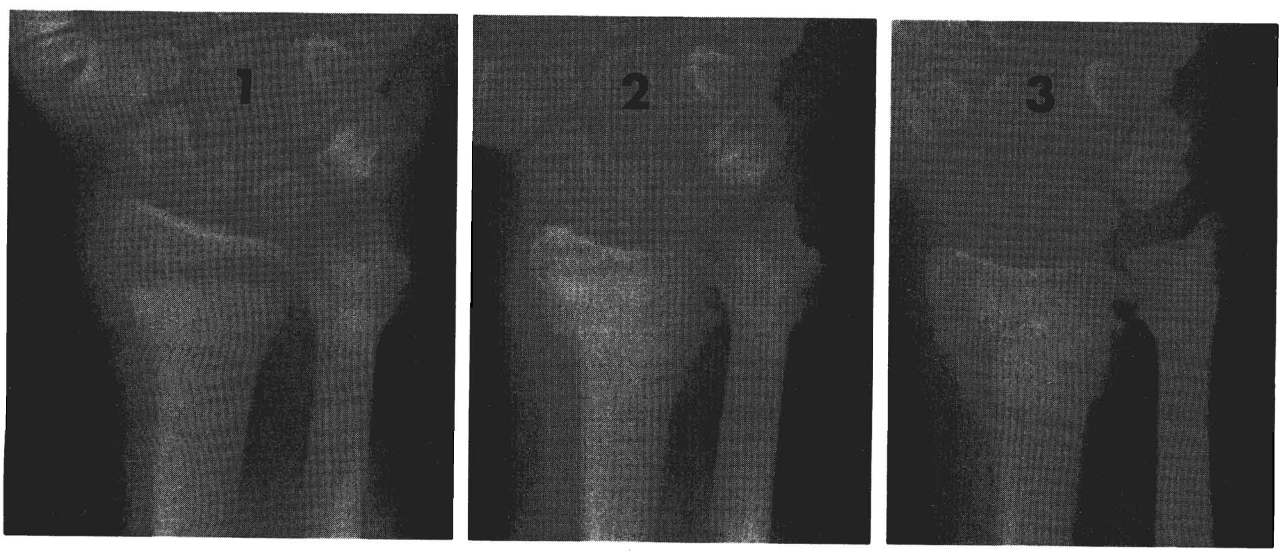
Children waiting for a kidney transplant may develop profound osteodystrophy. A slow slip of the upper femoral epiphysis should be pinned as soon as it is noted. Dialysis is no bar to anesthesia (Figs. 5-18, 5-19).

STRESS FRACTURES

The most common sites of stress fracture in children are the upper third of the tibia, the lower half of the fibula, followed by metatarsal, rib, pelvis, femur,

Fig. 5-18. John, at the age of 10, had been on dialysis and after one failed transplant now had a functioning kidney. His main complaint was knocknee. His slipped epiphyses were treated by pinning *in situ* and intertrochanteric osteotomy.

Fig. 5-19. *(1)* Vitamin D-resistant rickets. This child was receiving insufficient vitamin D. *(2)* A slight fall produced a pathologic epiphyseal separation. The dosage of vitamin D was increased. *(3)* At 2 months the separation has healed.



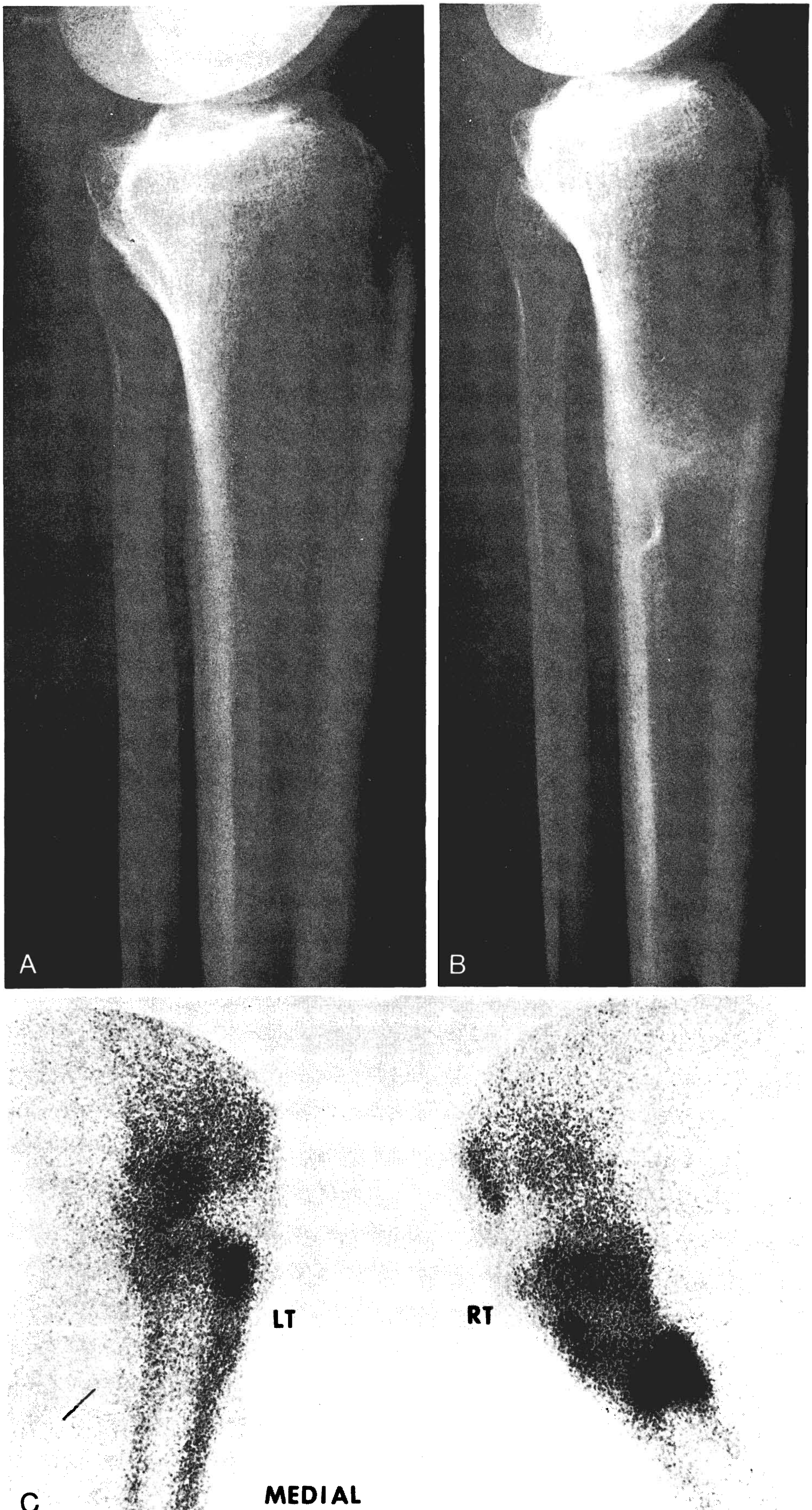

A
B
LT
RT
C
MEDIAL

Fig. 5-20. This runner had recently increased his mileage to 30 miles per week. One day the right upper tibia became tender and the patient began to limp. *(A)* The x-ray film at this time was normal. *(B)* Bone scan showed a hot transverse bar—the typical first sign of a stress fracture. Later, periosteal new bone forms and the hot area becomes more diffuse and less characteristic. *(C)* After 3 weeks, the diagnosis can be made radiographically. Two years later, the patient developed the same symptoms in the other leg. The radiograph was normal at Elsewhere General Hospital and the patient was told there was nothing the matter. When his request for a scan was turned down he went elsewhere. (Courtesy of David Gilday, M.D.)

Fig. 5-21. A lucky break: the buckle fracture of the distal radius brought to light this 11-month-old child's rickets.

and humerus. They are particularly common in the spring, when children become active after a winter of inactivity. The radiographic appearance may be confused with a neoplasm or an infection, but the distinction is usually clear. If the diagnosis is in doubt, serial radiographs should be obtained over a short period of time (Fig. 5-20). A bone scan will demonstrate a stress fracture earlier than a radiograph.

Stress fractures through the distal femoral growth plate have been described in athletes. Abstinence from sport may be sufficient treatment, but a cast is helpful if a child is wild, if pain is marked, or if the fracture looks as if it may become complete. All stress fractures of the femoral neck should be immobilized.

LUCKY BREAKS

In a child with fixed deformities a fracture will sometimes provide a serendipitous opportunity for straightening the limb (Fig. 5-21).

SECOND-HAND CASES

Both mother and father come in. "We are very concerned, doctor. Joe broke his arm and we took him to Elsewhere General Hospital, where they set it. He came out of the cast last week. Now look at it. He can't move it, and it is not straight."

The care of a healing fracture is quite different from that of a fresh fracture. You will need the tact and delicacy of a diplomat—qualities not usually first in the orthopaedic firmament—and the skill of a technocrat. The choice lies between awaiting natural improvement, late osteotomy, or immediate correction.

Diplomatic Considerations

Everyone treating fractures will leave some patients with crooked limbs (though some doctors have more than others). Therefore, do not deride the other doctor; rather, communicate with him. Seek the reason. Perhaps the child was not brought for follow-up examination, or he may have repeatedly broken the cast.

Most parents have no concept of the difficulties of fracture care, and when these are explained they may lose their anger, especially if you offer a positive course of future action.

Technical Considerations

When a limb comes out of a cast, muscle wasting and stiffness detract from its appearance. Ask yourself: will it improve, stay the same, or get worse? Several factors should be taken into consideration.

Age of Patient. In the young, remodeling is more effective, but the effects of growth disturbance are more harmful.

Age and Site of Fracture. Between 6 weeks and 3 months after the accident, when most of these problems present, it is not difficult to refracture the bone, either by closed means or by drill osteotomy. Secondary changes are few, and normal anatomy can be restored.

Angulation. Angulation in the plane of joint movement will improve spontaneously. Valgus, varus, and rotatory malunion should be corrected, but generally, there is no urgency about this, and osteotomy may wisely be postponed to the school vacation. However, a forearm angulation should be corrected as soon as possible, because remodeling and secondary joint changes adversely affect late repair.

Shortening. Excessive shortening is most common in the femur, owing to overlapping or angulation. One inch of discrepancy is dramatic in a 3-year-old, but improvement can be expected because of post-fracture overgrowth, and increase in height. If the final discrepancy will be more than 1 inch, drill osteotomy should be performed and the child put in steep traction to bring the leg out to length.

Growth-Plate Disruption and Joint-Surface Irregularity. It is difficult and dangerous to try to shift a Type-I or Type-II injury after a few days. Remodeling is very effective, and if this is not sufficient, a late osteotomy is indicated. Malunited, displaced, Type-IV injuries only become worse with time and should be replaced at open operation at almost any time. Callus must be removed, and the joint surface realigned without depriving the fragment of its blood supply. Ununited lateral condylar fractures at the elbow are probably best left alone after a few months.

THE GRIEF REACTION

Not everything you do will go perfectly well. There are a million gremlins working against you; you know the names of some of them—shortening, angulation, and plaster sore; "late for dinner," "the X-ray department was so slow that we skipped the last film," "it seemed acceptable at the time," "but the fingers were pink" "we are out of stock." These are foreboding phrases. With luck you can sense danger mounting and change course. But when disaster strikes unexpectedly, you will experience the grief reaction. In other words, you will go to pieces without realizing it. You should know about it because it is counterproductive.

1. ***Denial.*** You will deny the presence of complications. This is a feature of all vascular problems that have serious consequences.
2. ***Disbelief.*** You will not believe what you are told. Phone messages from nurses and parents can often be interpreted as leaving room for doubt.
3. ***Despair.*** All you can think about is the trial.
4. ***Delegation.*** As soon as the reality is inescapable, you put all your effort into seeking a culprit.
5. ***Desperate Acts.*** Faced with a problem seldom encountered, there is a temptation to do an operation you have never done before. This is the time to seek the help of a colleague who is not so emotionally involved.

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6 / Soft-Tissue Injuries

Hugh G. Thomson

An orthopaedic surgeon should know how to manage soft-tissue injury. Orthopaedics is more than the treatment of a specific condition involving bones; it is the care of a patient with a bone problem in a soft-tissue envelope.

Sometimes a consultation with an associate is necessary in the treatment of your patient. Indeed, Sir Harold Gillies believed that the sign of a good consultant was that he was prepared to consult!

It is the purpose of this chapter to outline the detailed management of some soft-tissue injuries. The excellence of fracture treatment or the outcome of an orthopaedic operation could be considered proportional to the excellence demonstrated in the management of the overlying soft tissue, be it an open or closed injury.

The soft-tissue envelope is subject to various types of injury. Assigning the wound to the correct category is the most important single step for you to take. For example, a clean laceration produced with a scalpel does not damage the margins of the laceration and will heal by primary intention after suture; whereas a laceration produced by heavy pressure with a blunt object devitalizes skin edges, destroys some soft tissue, and requires more elaborate treatment. Soft-tissue injuries may be classified in many different ways, based on the elements of cutting, abrading, burning, crushing, and tearing.

HEMATOMA

A hematoma, whether produced by blunt trauma or by a fracture, seldom requires more than cleaning of the overlying skin and masterful inactivity. But a loculated hematoma within the subcutaneous or deep tissue, while unusual, should alert the surgeon to the risk of local or diffuse infection; avascular changes in the skin, nerves, and muscles; and the possibility of an underlying blood dyscrasia. All these influence a program of treatment. Conservatism, observation, and investigation are the keynotes of the treatment routine.

Small Hematoma

A small hematoma is unlikely to require treatment. It may give rise to a zone of regional fibrosis with skin tethering or puckering for as long as 6 to 12 months after the injury. The parents should be warned of this possibility, because it will temporarily compromise the cosmetic appearance of the clinical result.

Large, Tense Hematoma

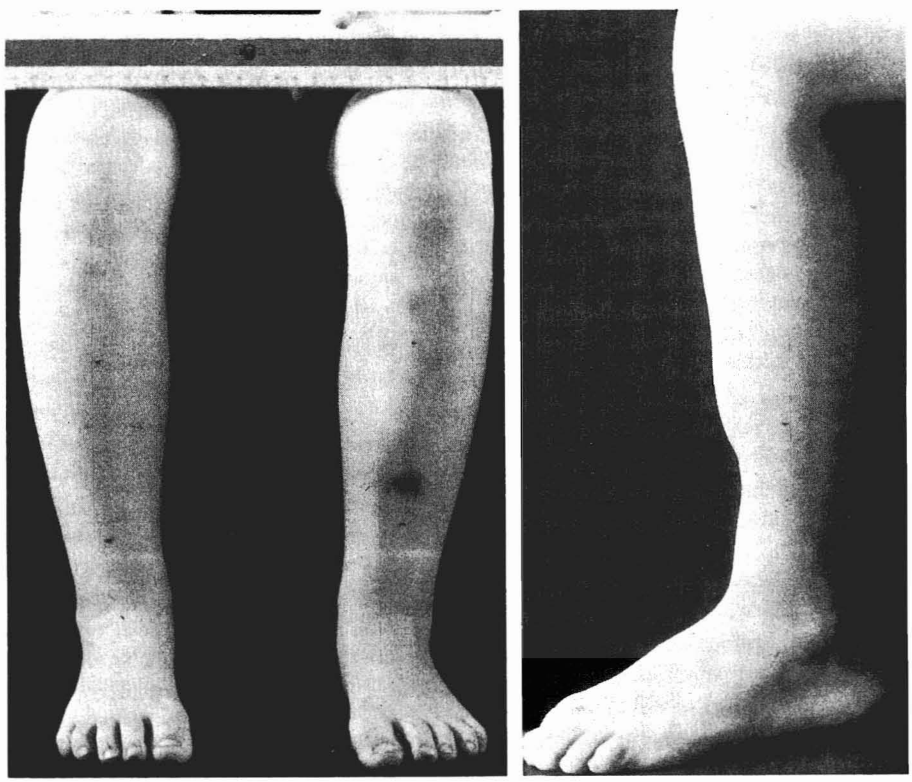
A large, tense hematoma may require evacuation if there is impending skin necrosis or impending Volkmann's ischemia. Otherwise, it may be left to resorb, or it may be aspirated after it has liquefied. When surgical evacuation is necessary, the incision should be placed as far from the hematoma as access will permit and preferably just off and parallel to a skin flexion crease. The hematoma can then be approached subcutaneously or subfascially and evacuated. A modified pressure dressing over tulle gauze should be applied. There is controversy about whether drainage, irrigation, or both should be used; what type of tube and for how long? A flat compressible, malleable, silastic catheter without irrigation has served me well. The catheter should be removed 36 to 48 hours after incision and drainage. Antibiotic treatment prior to drainage is certainly worthwhile in the pressure of a fracture, but is less strongly indicated for an isolated soft-tissue injury.

FAT FRACTURE

The most common cause of a fat fracture is a sharp, nonlacerating force; it can overlie a bone fracture (Fig. 6-1). The phenomenon is rare and usually late to appear, with an interval of several months between injury and initial observation. It is almost impossible to foresee this clinical entity, and this causes more problems than anything else. The patient and his relatives cannot be prepared for this phenomenon.

A fat fracture is probably due to shearing through the fat, superficial fascia, and (on occasion) deep fascia. This creates a diastasis in the fat compartment and a degree of fat necrosis owing to the original compression–contusion force. As resolution occurs, the proximal edge is elevated, and the distal edge is usually flattened. This unsightliness is difficult to improve. It can be attempted with fat, fascial, and even muscle rotation flaps through a curved, marginal incision. This and other types of local augmentation are fraught with potential complications. Therefore, it is important to assess accurately the functional and esthetic disability the patient is experiencing. For example, there is relatively little disabil-

Fig. 6-1. Anteroposterior and lateral views of lower tibial fat fracture 2 years after injury. Notice the gravitational fullness of the proximal portion!

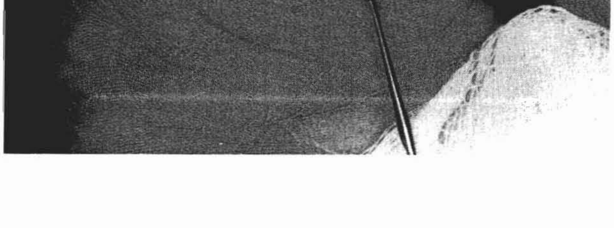


ity when this problem involves the buttock, whereas involvment of the anterior tibia of a girl is a different matter. You must remember that for most reconstructive surgery the patient and surgeon always must make a trade, and here the trade is a large incision in a previously unscarred area. Is it worth it to the patient?

FOREIGN BODY PENETRATION

From time to time surgical procedures are frustrating to the operator. However, very few can appear so simple yet result in such overwhelming frustration as the removal of a foreign body. The presence of a foreign body is usually heralded by a simple puncture would and is therefore disarming. Its absence cannot be assumed from a negative roentgenogram. The history, location, wound appearance, and palpation are usually enough to assist in the presumptive diagnosis. Conservative management and wound observation are appropriate when a puncture wound exists alone and when the history and clinical and roentgenographic examinations are negative and there is no other indication to explore the area. If the index of suspicion is higher and one or more positive findings are present, then wide exploration of the wound is necessary. Don't try to probe the wound. It is useless! Don't pull out the foreign body. This is a convenient trap. Even if it is smooth metal, it may have carried clothing or other foreign material with it (Fig. 6-2). The area must be operatively and adequately explored. In most cases this requires fluid and mechanical debridement followed by primary closure of the wound. An image intensifier can be very helpful if the initial roentgenograph is positive.

Fig. 6-2. A hardwood-floor splinter located in the thenar eminence. After 6 days with local reaction, it could be removed with ease, and the tract was irrigated with antibiotics. This is not the usual situation, and it is more common to open the tract for adequate removal.



LACERATION

Is it a tidy or an untidy wound? Your management depends on this easy distinction. A wound is tidy if: (1) it is to be repaired within 8 hours after injury; (2) it was made by a sharp object, whether from within or without; and (3) it has no gross evidence of contamination by bacteria or foreign bodies. In other words, a tidy wound resembles a surgical wound. An untidy wound has ragged edges, disrupted soft tissues with areas of impending necrosis, and obvious foreign-body contamination. Any wound that has remained open for more than 8 hours should be considered untidy.

At the initial examination, look for signs of divided vessels, tendons, and nerves. Then cover the wound with a sterile dressing. While the patient is still awake, inquire about allergies to antibiotics that you may want to administer while the patient is anesthetised. Either tetanus toxoid or immune globulin should be used to protect against tetanus.

Simple Tidy Laceration

Initial care of the wound requires regional antiseptic preparation up to its margins and profuse fluid irrigation (normal saline, Ringer's solution), with or without antibiotics, in its depth. Almost without exception I prefer to irrigate the wound at this point with a dilute solution of bacitracin (10,000 u in 500 ml saline). Surgical debridement should be relatively conservative but influenced by site, depth, and type of injury. Judicious excision of skin and subcutaneous margins, necrotic tissue, and previously unseen foreign bodies should be carried out.

It is often difficult to determine if a wound on an extremity is deficient of skin and soft tissue. As a matter of fact, almost all lacerations on the extremities give this appearance (Fig. 6-3A). This is due to the circumferential tension the skin exerts around a cylinder and the important sheathing effect of the

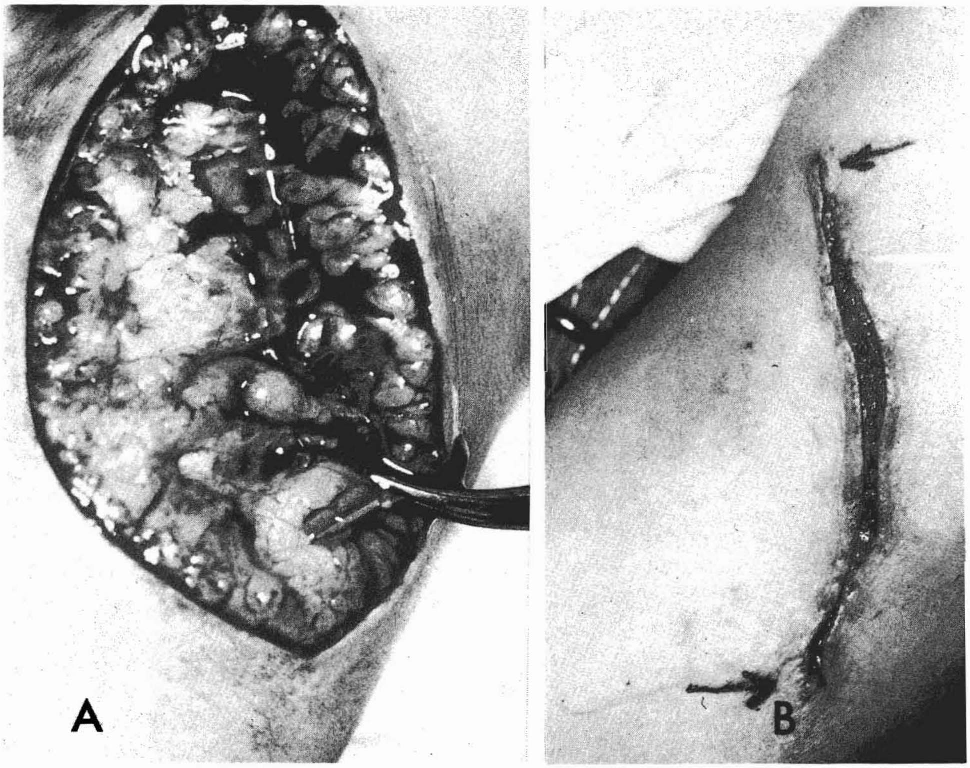


Fig. 6-3. *(A)* Simple laceration of upper extremity. Note the widely spread wound, which gives the appearance of tissue loss! *(B)* Subcutaneous closure of superficial fascia and fat with absorbable suture. If using subcuticular suture, a two-layer closure of this zone is necessary, as shown.

superficial and deep fascia, which is lost when lacerated. These factors, coupled with local wound edema, complicate the clinical picture. If a wound is closed under undue tension, ischemia of the wound margins is assured, with obvious complications. Therefore, a decision must be made early. Is there tissue loss, or is the wound edema so great that primary direct closure is unwise? Must some other means of closure be considered? Using two skin hooks crossed on each other can be helpful in this decision. If slight tension on the hooks approximates the edges, the primary direct closure is unlikely to be a problem. Don't test this tension using toothed thumb forceps. They do not provide the proper perspective, and at the same time they tear the skin margins.

Direct Closure. The deep closure should be carried out with absorbable, interrupted, and inverted sutures. Polyglycolic-acid sutures provide excellent support to the deep structures owing to their prolonged tensile strength (Fig. 6-3B).

Prior to actual skin closure, it is important to anticipate the late contracture of the mature wound. If the wound lies at right angles to any flexion crease, it will create a significant contracture problem. Therefore, anticipating this problem may save your patient another operation. This can be accomplished with a simple **Z**-plasty, or **Z**-plasties in tandem. Remember: the angles of the arms of the **Z** should rarely exceed 60 degrees. (This principle must also be remembered when closing elective incisions.)

The best way to close the skin margins continues to be a matter of controversy (Fig. 6-4). Remember that the patient will always have a scar, and your responsibility is to provide the least noticeable scar. Should you use interrupted cuticular sutures or continuous subcuticular sutures? This is a matter of personal preference. The major advantage of subcuticu-

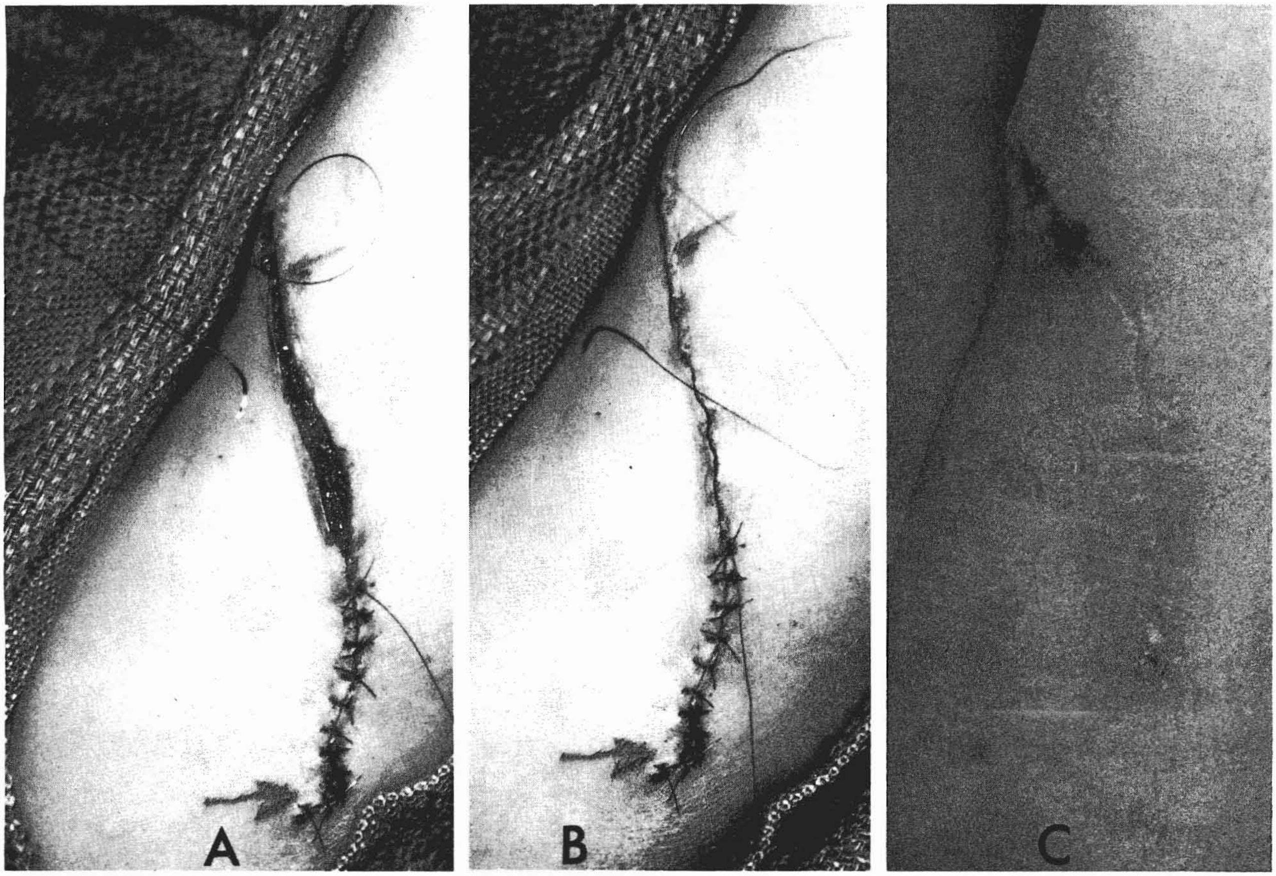


Fig. 6-4. *(A)* Use of interrupted and subcuticular closure for the wound shown in Fig. 6-3. *(B)* Closure complete. *(C)* Three months later; scar showing "railroad tracks" in area closed by interrupted sutures.

lar suture is the elimination of "railroad tracks," which are so common with interrupted sutures. Wound infection is almost inevitable if interrupted sutures are left under a plaster cast for weeks or months; removal always causes some discomfort. Subcuticular sutures usually overcome these problems. On the other hand, interrupted sutures are suited to irregular wounds, to wounds that have been grossly contaminated, and to areas such as the face, favoring early suture removal. When a wound becomes infected unexpectedly it may be necessary to remove a few sutures, which is impossible with a subcuticular stitch.

Skin-Graft Closure. Direct edge-to-edge closure of wounds is not always possible. The most useful alternative is a skin graft. The thickness of the skin graft depends on the needs of the recipient site (Fig. 6-5). A free full-thickness skin graft is rarely used to close a tidy traumatic defect. It is usually reserved for an elective procedure under more optimal conditions. The thinner the skin graft, the better its chance of survival in any environment. Therefore, use a split-thickness skin graft to replace traumatic skin deficits. Although a split-thickness graft is more likely to "take," it is more susceptible to contraction, to hyperpigmentation, and to instability. It does not provide insulating skin coverage. A full-thickness graft provides stable cover and is less liable to create a contracture and a pigmentation problem.

A skin graft can be obtained with a variety of instruments ranging from a basic straight-bladed knife

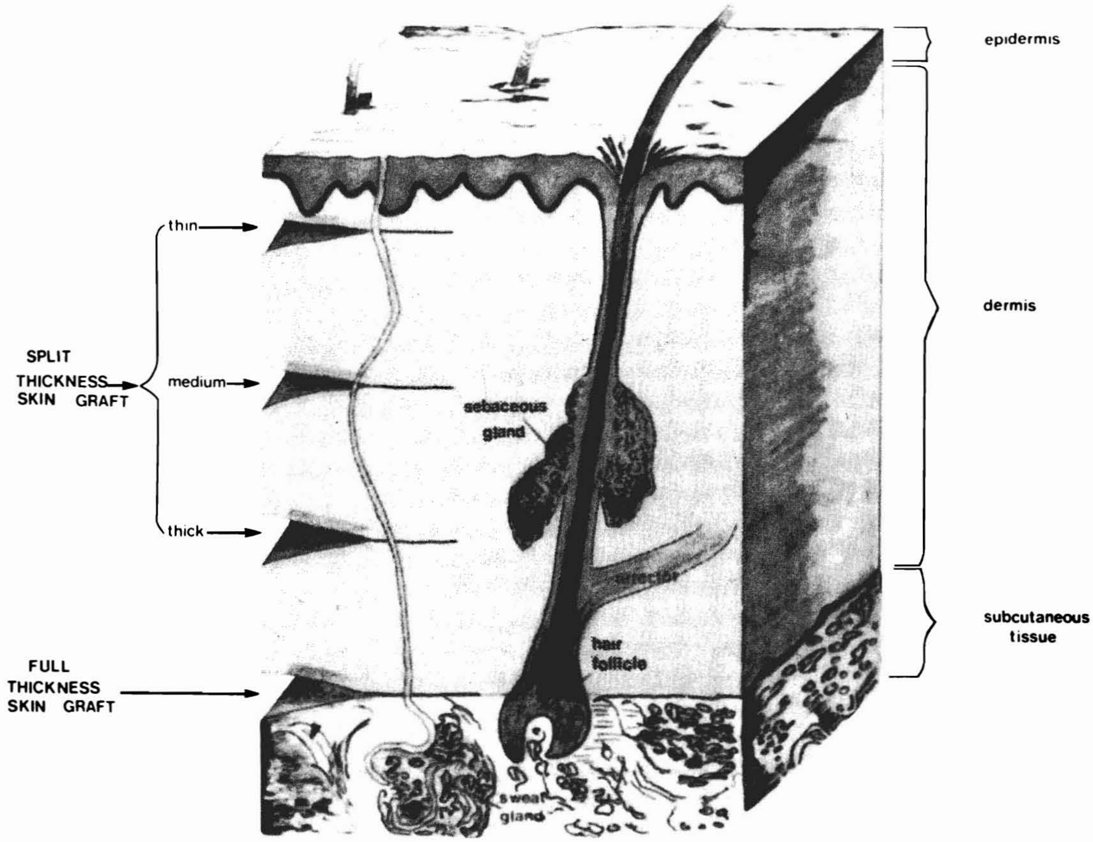


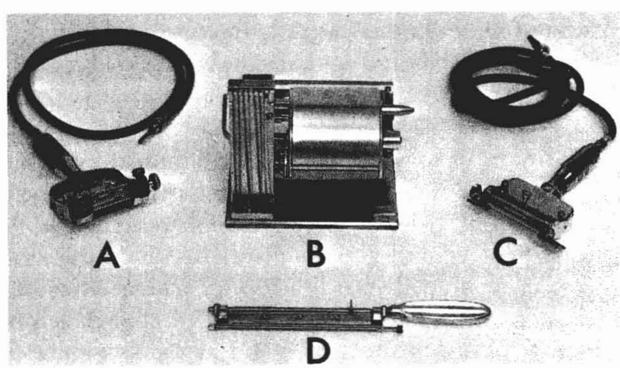
Fig. 6-5. This drawing demonstrates the levels at which different skin grafts are cut.

to a rapidly oscillating gas turbine blade (Fig. 6-6). This latter type of dermatome has more universal application, because it requires relatively little experience and because the thickness of the graft can be readily changed any time during its operation. Try to become adept with one instrument only!

The care of the skin graft and the donor site is critical:

1. Place the skin graft in a gauze moistened with Ringer's lactate. Store it in a separate basin to lessen the chances of it being discarded!
2. Place Ringer's lactate sponges over the donor site, which will be covered by a petroleum jelly tulle gauze at the end of the operation.
3. When wound toilet has been completed and the recipient site prepared, the graft is laid, glistening side down, into the defect.
4. Long marker sutures attach the periphery of the graft to the margin of the skin defect. These sutures should hold the graft under even tension,

Fig. 6-6. Dermatomes: *(A)* Brown electric, *(B)* Reese drum, *(C)* Hall turbine, and *(D)* Cobbett knife.



which is comparable to the tension of the skin prior to its removal from the donor site. This is why you must insert the marker sutures on one margin first and then stretch the graft before inserting the other marker sutures (Fig. 6-7).

5. Noncutting quilting sutures are placed through the graft into the bed (when anatomically possible) and tied over a piece of silence cloth (moleskin) to tether the skin graft to the recipient bed (Fig. 6-8).
6. Hematoma from nonspecific oozing can be prevented by making small incisions in the skin graft using a No. 11 blade (Fig. 6-9A).
7. The long marker sutures are tied over a bolster of cotton waste with tulle gauze as an interface between graft and bolster. The use of elasticized material held in place with staples is a very fast and efficient method of applying diffuse pressure to the skin graft (Fig. 6-9B).
8. Immobilization of the part for 5 to 7 days is important to lessen hematoma and shearing of the graft, and permit maturation of the new endothelial channels.

If these principles are followed carefully, skin graft coverage should never pose a difficult hurdle for you.

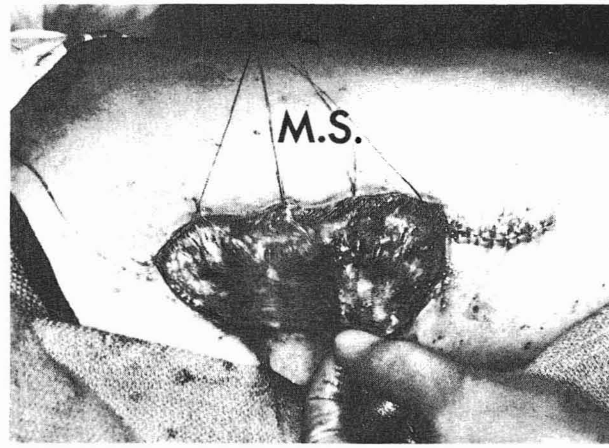
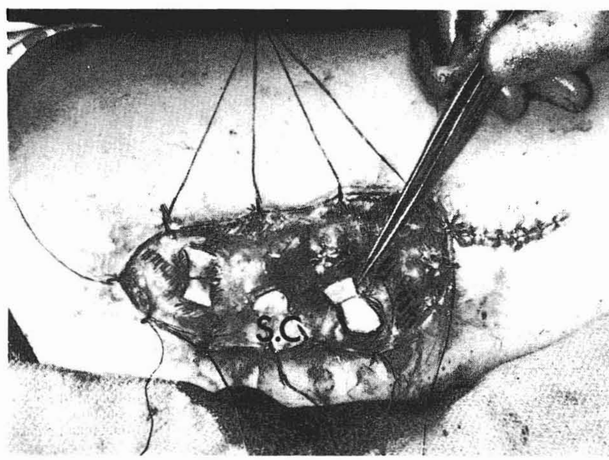


Fig. 6-7. Skin graft techniques. Marker sutures (M.S.) in place with traction applied to the skin graft.

Fig. 6-8. Bolsters of silence cloth (S.C.) to hold graft tightly to recipient bed.



Simple Untidy Laceration

It is sometimes difficult to determine with complete accuracy whether a wound has been created from within by bony fragments or from without by a lacerating missile, which might have carried contaminating foreign bodies into the fracture site. Initially, these wounds should be considered untidy, regardless of the degree of severity.

By definition, wounds in this category have a post-injury history of greater than 8 hours, evidence of gross contamination, plus extensive soft-tissue disruption or a degree of impending necrosis. With this type of wound you are justified to be somewhat more aggressive in your fluid and mechanical wound debridement. It is very worthwhile to begin the mechanical or surgical debridement at the skin surface and work into the depth of the wound. Traumatic tattooing should be adequately cleansed of the foreign bodies, using dry sponges. Sharp excision of the skin edges is undertaken, and all deeper foreign material and necrotic tissue is excised. I emphasize edges first, because, if they are left until the problem in the depth is treated, this step may be forgotten on the way out, as you will be tired and possibly hurried. Remember that skin continuity is all-important for wound-depth continuity. Each step is as important as every other one.

There is usually no strong contraindication to primary closure of an untidy wound, provided that (in the judgment of the surgeon) it can be converted into a tidy wound. As with all the clinical situations discussed in this chapter, there are exceptions to the rule, and only experience can determine those exceptions (Fig. 6-10).

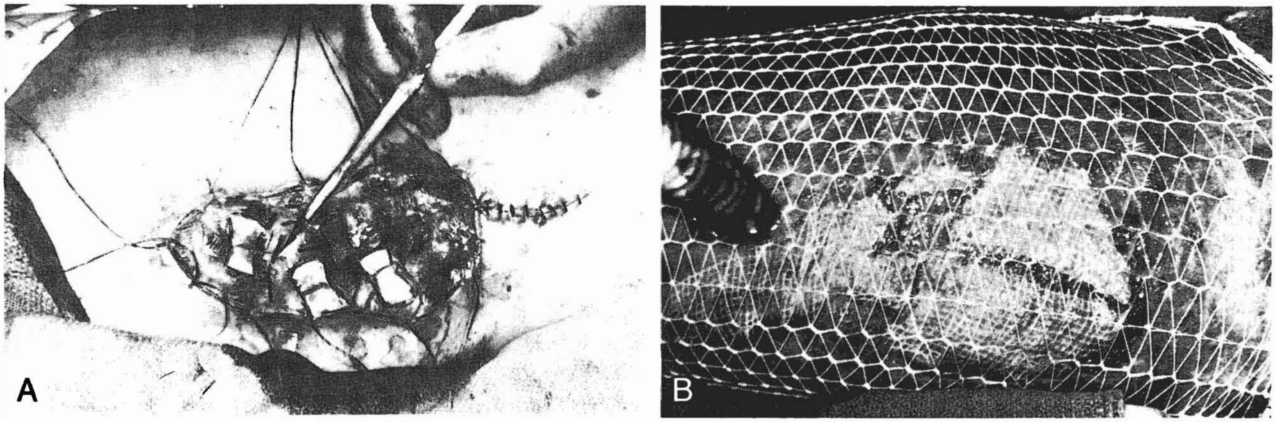
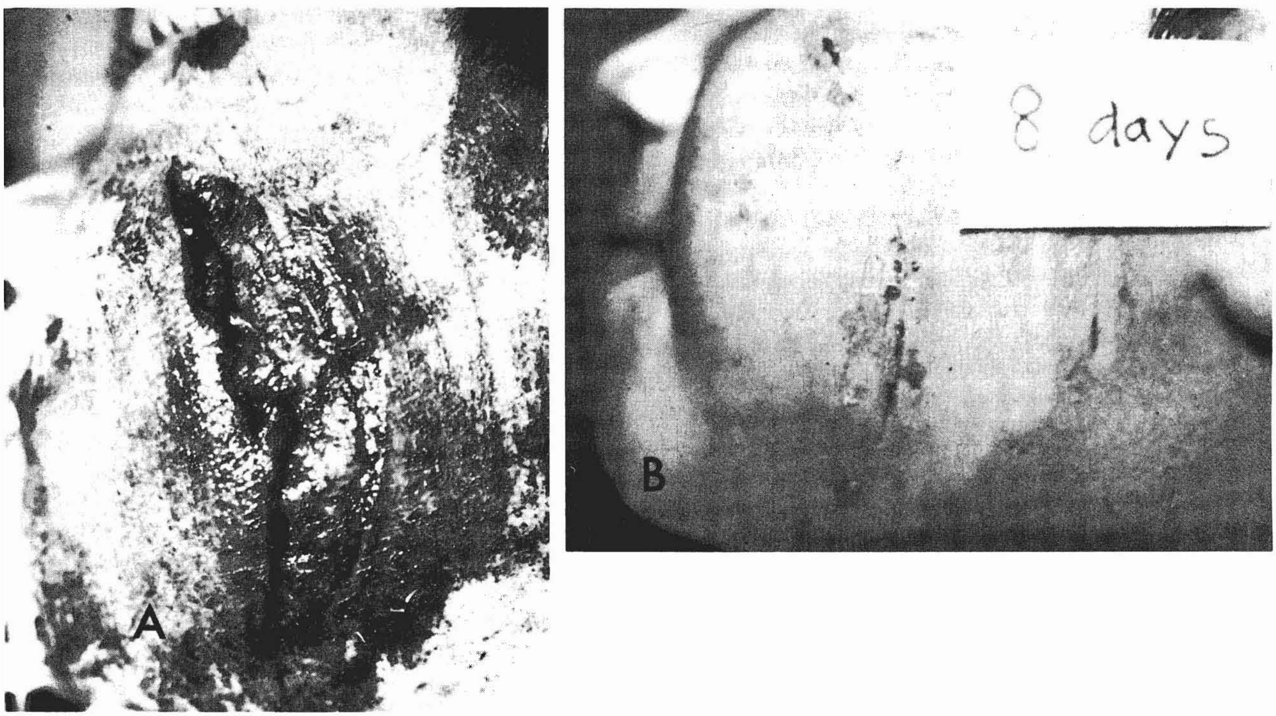


Fig. 6-9. *(A)* "Pie cuts" made in the graft with a No. 11 blade to permit free oozing and to lessen hematoma formation. *(B)* Retelast (Nordic Pharmaceuticals) held smoothly over bolster, on top of skin graft, with surgical staples (Ethicon Sutures Ltc.).

Fig. 6-10. *(A)* Untidy wound with ragged abraded wound margins and traumatic tattooing. *(B)* Eight days after conversion to a tidy wound closing with subcuticular sutures.



ABRADED WOUNDS

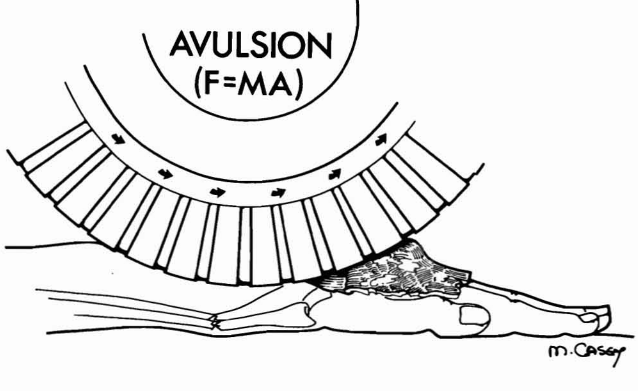
The most common soft-tissue injuries seen by the orthopaedic surgeon, requiring special care, have an element of crush–avulsion to them (Fig. 6-11). The wound results from a combination of shearing, compression–burning, and even bursting forces. The pattern of injury is influenced by acceleration; thus, the formula F = MA is directly involved in the classification of these injuries. For example, in the escalator-crush of a foot, the mass is great but acceleration is minimal, and compression is the major factor. If the mass is less and the acceleration slightly greater, as in a wringer injury, the resultant effect is primarily a burning–tearing of the skin. If both mass and acceleration are extreme (a moving car tire or a missile), the soft tissues and deeper structures may be torn away. All types of injury in the following pages involve this crushing avulsion phenomenon.

Simple Brush Burn

Brush or friction burning is a common result of shearing forces, and like all burns it can involve any or all layers of the skin. It is often patchy in distribution and linear in orientation with streaks of perdermis injury and a more diffuse surrounding second-degree burn.

Any area with this clinical picture should be treated topically, as if it were a burn. Use fluid to debride the wound. Then apply fine mesh tulle gauze and change it after a minimum of 7 days. The fine mesh prevents late stippling or tattooing of the

Fig. 6-11. Schematic drawing demonstrating forces producing tire (crush-avulsion) injury.



wound area with a salting of hyperpigmentation. Waiting 7 days permits a degree of central reepithelialization from hair follicles, sweat glands, and sebaceous glands.

Traumatic Tattooing

Frequently the injuring agent, such as a road surface, provides ample opportunity for nonabsorbable foreign bodies to become deeply embedded in the dermis, producing a traumatic tattoo (Fig. 6-12). If you suspect this to be the case, bring out the "scrub brush" and abrade the wound until it bleeds and until there is no evidence that foreign bodies remain.

Traumatic tattooing can cause more esthetic discomfort to the patient and personal dissatisfaction to the surgeon than any other minor associated injury that you are likely to encounter. Certainly a common medicolegal complaint is, "the fractured femur has united perfectly, the contour is normal, gait normal, and no detectable leg-length discrepancy, but the ugly black scarring is distasteful to the patient." The specific treatment is certainly less assured at this point than the results you could have achieved had the problem been recognized and corrected initially. Dermabrasion, excision, and even skin grafting may be necessary at a later date. Its a great price for the patient to pay because the surgeon did not spend a few initial seconds with the scrub brush. Don't spare the brush!

Brush Burn With Tissue Loss

Most traumatic injuries of this type demonstrate a pattern similar to a bull's-eye, with a central zone of maximum destruction and a peripheral zone of less severity (Fig. 6-13). They may be classified as simple injuries, because deep structures are not involved. Faced with an injury of this type we have to accept the fact that there is a soft-tissue defect that will always result in a relatively undesirable scar. Therefore, excise all margins that are suspiciously third-degree. This increases the primary defect area but not necessarily the degree of scarring. This concept is often a difficult one to put in practice, but it is important. Primary healing is the ultimate aim. If marginal necrotic tissue remains due to an inadequate excision, then primary healing is impossible. Wound closure can be obtained using a free split-thickness skin graft.

Fig. 6-12. *(A)* Facial abrasion with small periorbital lacerations from a road injury. *(B)* If adequate fluid and mechanical debridement *had* been done initially, tattoos on the lower lid and infraorbital margin could have been precluded.

Fig. 6-13. *(A)* Zone of skin loss on dorsum of foot with marginal second- and third-degree skin burn, similar to a "bullseye." *(B)* Primary "wide" excision and free split-thickness skin graft coverage.

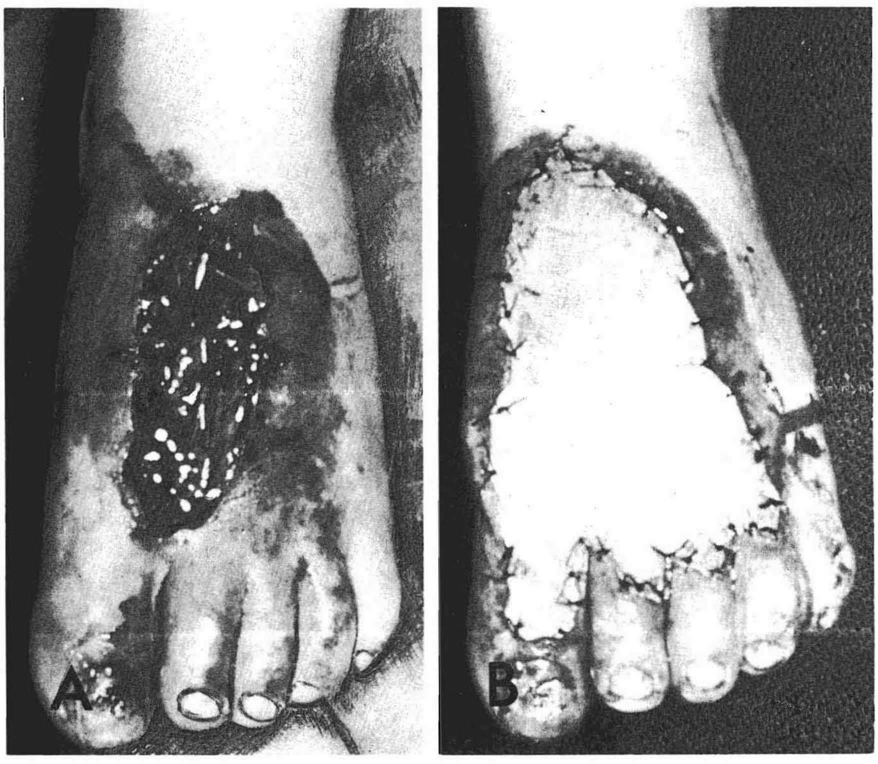
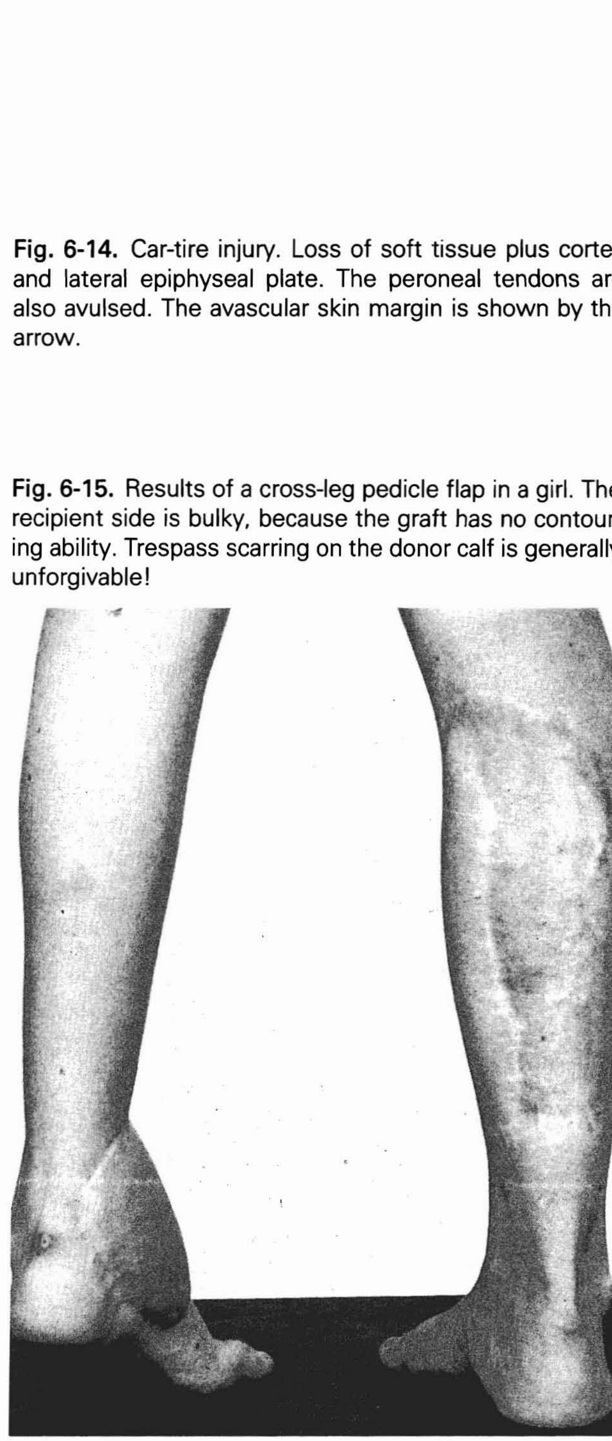


Fig. 6-14. Car-tire injury. Loss of soft tissue plus cortex and lateral epiphyseal plate. The peroneal tendons are also avulsed. The avascular skin margin is shown by the arrow.

Injuries produced by a heavy, fast-moving object (such as an automobile tire) that exerts friction to soft tissue overlying bone may grind away the skin and fascia along with the outer cortex of bone. The ankle area is a common site when the foot is caught between the curb and the tire (Fig. 6-14). There are two common complications that can be anticipated:

1. Disruption of the epiphysis with subsequent growth arrest may occur. This may cause a functional and esthetic problem in the very young patient. It certainly is an important point to keep in mind from a medicolegal point of view.
2. Rupture of the peroneus longus and brevis tendons due to a burning–fraying force is also common. The surprising feature here is the fact that adequate soft-tissue replacement and immobilization permits reconstitution of these tendons, even when no specific attempt is made to repair them. However, the tendons may be irreparable owing to extensive loss of substance and unavailability of soft-tissue coverage. These patients can be managed best with primary skin-graft closure at the time of debridement. If possible, local *fascial-fat* flaps can be rotated to cover denuded cortex or open joints. This creates a receptive bed for a free split-thickness skin graft. The use of local *skin* flaps, even in children, should be considered with great caution and only by experts. Similarly, the dramatic cross-leg pedicle should remain with the classic literature, except in very rare situations (Fig. 6-15). It is much better to use a cross-thigh

Fig. 6-15. Results of a cross-leg pedicle flap in a girl. The recipient side is bulky, because the graft has no contouring ability. Trespass scarring on the donor calf is generally unforgivable!



pedicle if this type of coverage is a must! If you are going to proceed with a flap, be sure the base-to-length ratio of the flap is adequate. It is better to increase the size of the recipient area than to risk death of a long, narrow flap.

It is very important to remember that primary wound healing without sepsis is your basic responsibility. A skin graft is usually the answer. Even when deep reconstruction will be necessary at a much later date (for example, tendon transfers and nerve repair), the graft can be replaced later with local or distant pedicle tissue on an elective basis.

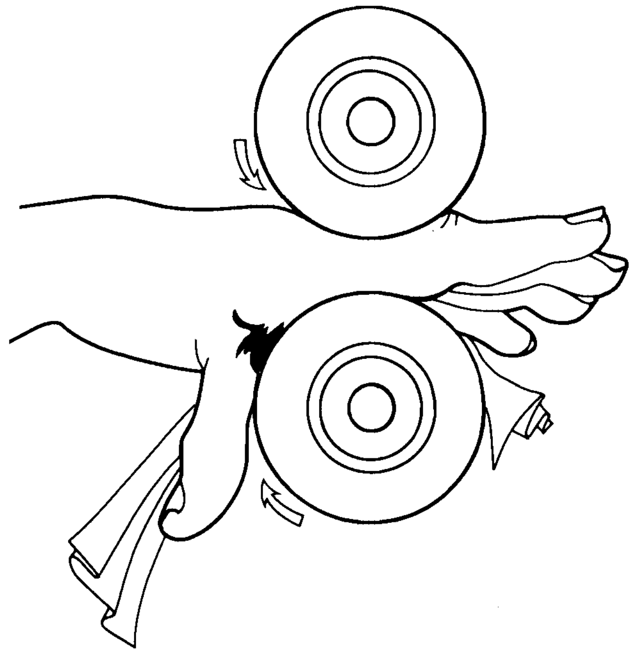


Fig. 6-16. This drawing demonstrates wringer injury that causes first interosseous tear and fracture dislocation at the metacarpophalangeal joint.

WRINGER INJURIES

A child injured by a washing-machine wringer always has some degree of soft-tissue damage. Fractures occur in only 2% of these patients. This percentage increases dramatically with greater forces, such as those produced by a roller press. When fractures do occur, they are in the distal radius and ulna and are usually greenstick in nature. Easily overlooked is a self-reduction fracture dislocation at the first metacarpophalangeal joint (Fig. 6-16). This is suspected when the first interosseous web space is torn, with or without nerve, tendon, or vascular injury.

In general, the soft-tissue damage associated with the wringer injury demonstrates various degrees of superficial burning coupled with an element of deep shearing. A black eschar can often be seen surrounded by white avascular dermis. Peripheral to this is an erythematous superficial second-degree burn (Fig. 6-17). The initial superficial and deep damage is not always so obvious, and therefore it is difficult to establish the best treatment program. When in doubt, dress the wound as an abrasion, and review in 24 hours, as with a fracture. If an extensive fluctuant hematoma associated with deep induration is present, be prepared to do a subfascial decompression of the hematoma through two proximal and two distal fascial incisions. It is necessary to insert drainage tubes. A fasciotomy is rarely necessary.

Injury localized to a small area with a well demarcated black eschar is treated satisfactorily by primary excision of the eschar under tourniquet and replacement with a split-thickness skin graft. This method of treatment does reduce morbidity, but it requires additional clinical judgment. If you lack this judgment, you can wait for spontaneous separation of the eschar in 3 to 4 weeks and graft the receptive granulations that result (Fig. 6-17B).

Occasionally the slow, relentless, burning pressure causes deep soft-tissue damage and can destroy fascia, tendon, nerve, and vessel (Fig. 6-18A). This creates a complex type of wringer injury. There is less doubt concerning the treatment of this injury. The involved area is excised, and a direct jump flap from the other arm or the abdomen is used to close the defect and thereby protect the deep vital structures (Fig. 6-18B). Indeed, there is strong argument that the blood supply provided by the pedicle flap has the ability to salvage and prevent further necrosis of vital structures in the depths of the wound.

When the mass is large but the acceleration is minimal, such as a steamroller or escalator, there may be a minor brush burn with minimal avulsion but severe compression. When the child is seen within an hour, the tissues are thinned in the zone of compression and

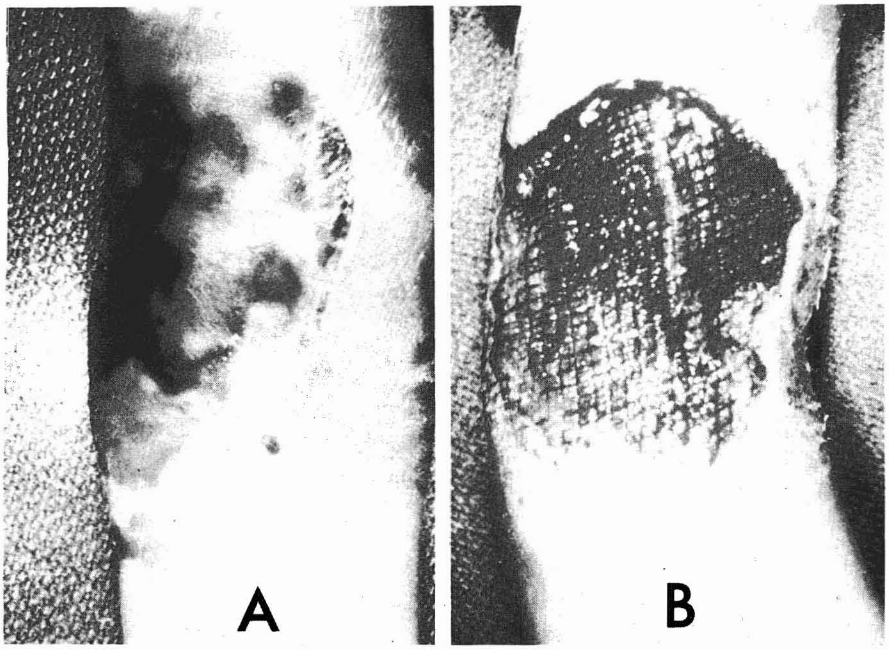


Fig. 6-17. *(A)* Central black eschar with surrounding avascular dermis. *(B)* After 3 weeks there is spontaneous separation of eschar, demonstrating receptive granulation tissue.

Fig. 6-18. *(A)* Well demarcated acute wringer injury of the forearm with deep structures involved. *(B)* Primary eschar excision uncovering infarcted median nerve *(arrow)*. This area was covered immediately with a jump flap from the abdomen.

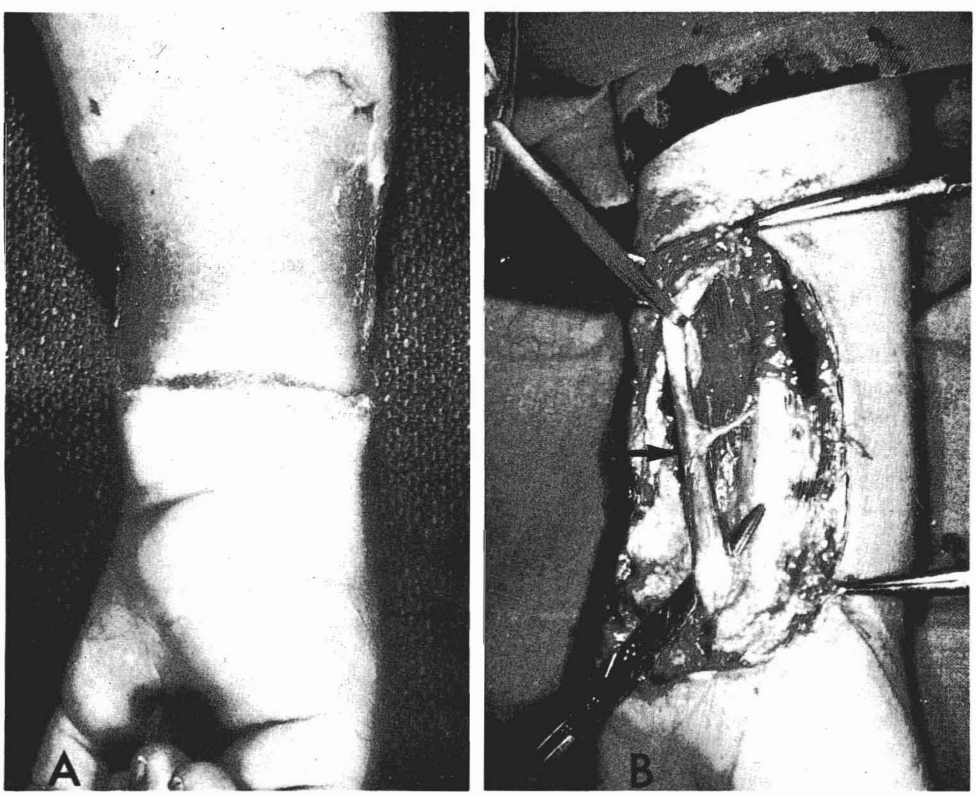
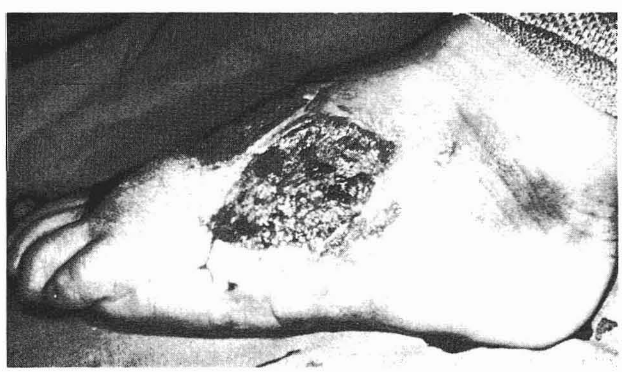


Fig. 6-19. *(A)* Acute crush injury. Note thinning of the avascular forefoot with scattered areas of infarct. *(B)* Radiographic appearance of the forefoot.

appear white and avascular (Fig. 6-19A). Bones may be fractured by the crushing force (Fig. 6-19B). *These extremities should be surgically decompressed as soon as possible* (Fig. 6-20). Local escharectomy–fasciotomy will cause the clinical appearance to change with resultant edema, venous congestion, and possible additional infarction. The use of sympathetic blocking agents, anticoagulants, coupled with antisludging parenteral therapy, local hyperoxygenation, and even hyperbaric chamber dives are all controversial—singly or in combination. All too often the injured limb is salvaged, only to leave the patient with a hypoesthetic extremity, which may require late amputation.

Fig. 6-20. The immediate vascular response after escharectomy and fasciotomy. (Note increased swelling compared with Fig. 6-19.)



AVULSED FLAPS

Simple Avulsion

Sharp avulsion of a soft-tissue flap (whether produced by a bale hook and associated with fracture of both bones of the forearm is not complicated by crushing, friction-burning, or additional shearing force on the skin flap. It is important to realize that, in general, this flap is a viable structure. The variables determining survival of the skin flap are: vascular supply of the general region; whether the flap is based proximally or distally; proportions of the avulsed flap (length-to-base ratio); depth of the plane (such as dermis–fat, fat–fascia, fascia–muscle); and scything and ragged skin edges.

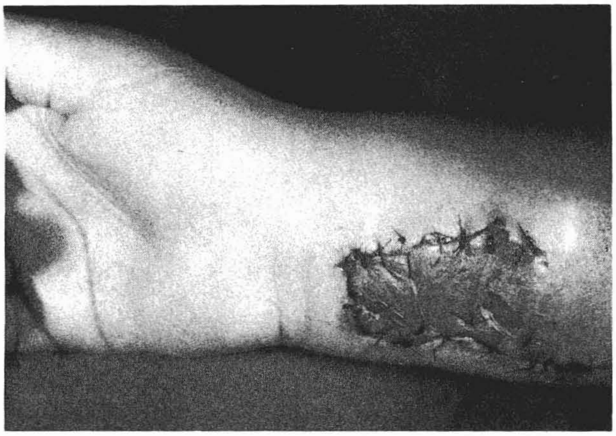


Fig. 6-21. Sharp, avulsed flap demonstrating cyanosis, blistering, and early evidence of total infarction, even though proximally based.

If there is no doubt concerning the survival of the flap, it can be replaced and atraumatically sutured. A three-sided flap has a tendency to bulge after suture when the wound contracts, pulling the flap up in a "pout." This can be corrected at a later date by simply breaking up the scar line with a few carefully placed **Z**-plasties.

On occasion there is no doubt in your mind concerning the survival of the flap, but it is replaced only to become edematous, blue, and blistered in 3 to 5 days owing to infarction (Fig. 6-21). It should be excised across the base, and a free split-thickness skin graft should be used to cover the defect.

If, in your opinion, the flap has a 50–50 chance of survival, it is sutured. Both the patient and the relatives should know the reason for your decision, and you should be prepared to look at the flap within 5 to 7 days. If it is infarcted, it should be excised and replaced with a free split-thickness skin graft (Fig. 6-22).

If some or all of the criteria for viability have been violated and the flap is assured of subsequent infarction, primary wound closure should be obtained. This can be done by total excision of the flap at its base, removing a split-thickness skin graft from it, discarding the remnants, and resurfacing the defect. However, if it is so severely compromised, it is probably better to throw the whole flap away and obtain a free skin graft from an elective donor site, such as the high lateral thigh or buttock region. Remember, free split-thickness skin grafts have a great propensity to survive on almost all living tissue, including periosteum.

Complex Avulsion With Exposure of Vital Structures

A sharp, penetrating object, such as a fence spike, may tear up a nonviable flap and expose deep vital structures. Amputation of the avulsed flap is completed, and immediate local or distal pedicle flap coverage is applied over the repaired deep structures. The local use of myocutaneous or myodermal flaps is a safe and excellent method of filling a defect covering vital structures (Fig. 6-23). This will encourage primary skin healing as well as providing adequate protection for the repaired deep structures.

DEGLOVING INJURIES

Partial Degloving

This type of injury may appear to be a broad-based flap or even a simple-looking laceration. The wound is often disarming at first sight, but on sterile examination the operator's whole hand and forearm can be passed up and around the cleavage plane. There is shearing at the fibro-fatty fascial interface with tearing of communicating veins. The decision to save or replace the skin is important to the fate of the underlying tissue; primary wound healing must be achieved (Fig. 6-24).

If evidence of crush and contusion is judged to be minimal considering the mechanism of injury, the lack of abrasion, ecchymosis, and avascular white zones, then the degloved tissue is replaced after fluid and mechanical debridement; suction drainage is used for 36 hours.

Fig. 6-22. *(A)* Large, broad-based flap undermined by injury at deep fascial level and thought to be viable. Obviously this opinion (the author's) was incorrect. *(B)* Ten days later, after wide excision and free split-thickness skin graft.

Fig. 6-23. *(A)* Sharp, avulsion of distally based, infarcted flap with transsection and repair of brachial artery and median nerve. *(B)* The flap was excised and the wound was closed with a primary thoracic tube pedicle flap.

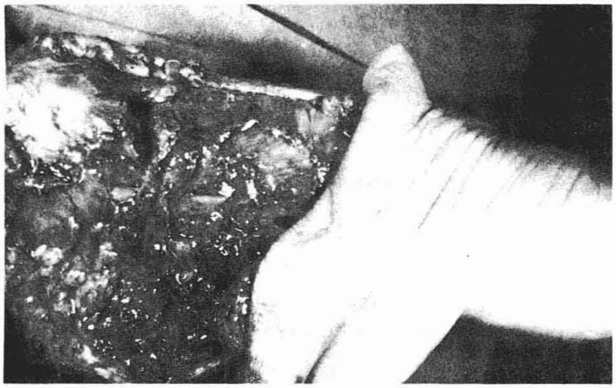
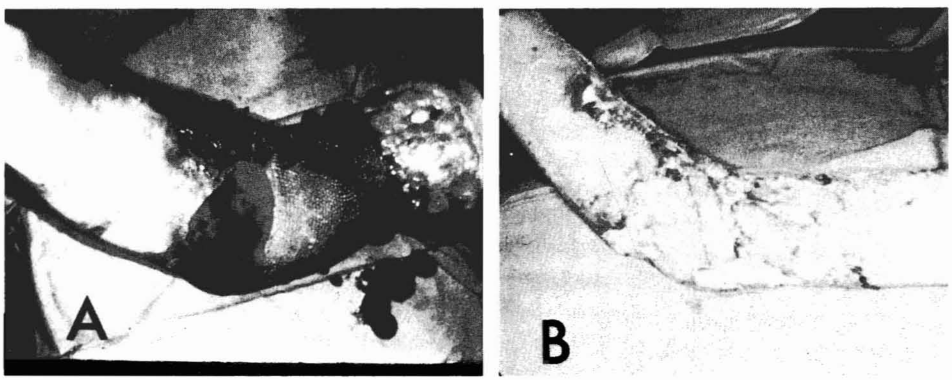


Fig. 6-24. Degloving of foot with exposure of ankle joint.

Fig. 6-25. *(A)* Extensive degloving of the upper arm and elbow with obvious infarction and associated supracondylar fracture. *(B)* Ten days after internal fixation of fracture and primary free split-thickness skin graft.



If the wound shows minimal crush and contusion but is abraded or "friction burned," as can occur in a rope-tow or water-ski injury, then the abraded superficial wound requires attention as well as the deep injury. This takes the form of deliberate brushing to remove all foreign material and to prevent traumatic tatooing. It is necessary to use some form of tulle gauze or antibiotic ointment to prevent a purulent coagulum from forming. This dressing should remain intact for 7 to 10 days, the required time for reepithelialization.

A truck tire may produce severe injury. Not only is a large flap raised, but severe ecchymosis and abrasions are in evidence, plus some scattered white areas as well as a general duskiness to the flap. Removal of the flap is imperative. When removal is necessary, it must be complete. If you are going to have a defect, then a big one is no worse than a small one. If the wound bed can be made suitable with muscle–fascial rotation flaps over any fracture fragments, a skin graft is an ideal cover (Fig. 6-25). Formal plaster or K wire immobilization above and below the wound is important. A window is made immediately in the plaster to provide access to the skin graft area for both observation and dressings.

Some degloving injuries are very complex. If a small or large area of specialized soft tissue has been degloved or torn away and a specialized covering is required, a free split-thickness skin graft may not be the ideal coverage for primary wound closure. In these cases, consideration must be given to the use of local, regional, or distant skin-flap coverage. Local muscle rotation may be helpful (*e.g.*, gastrocnemius or soleus). Delayed free flaps with microvascular anastomosis may be required. This type of tissue can ultimately supply a good milieu for nerve regenera-

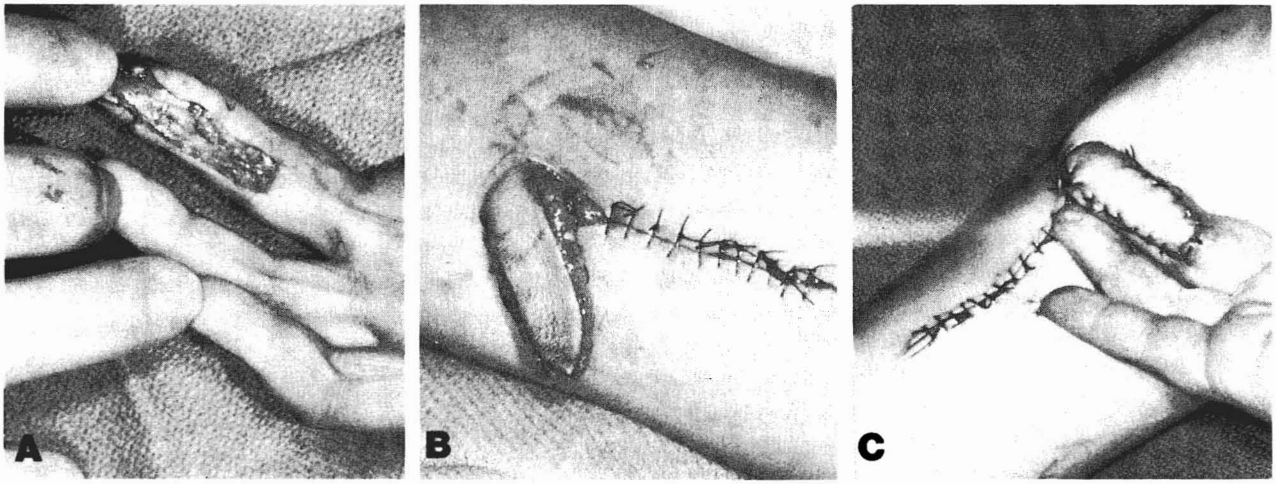


Fig. 6-26. *(A)* Partial degloving of specialized surface. *(B)* Cross-inner arm pedicle flap, *(C)* After primary direct closure of donor site and insertion of flap.

tion and tactileognosis. It also provides flexibility to the tissues, and there is less tendency to contract or hyperpigment. It does bring an independent blood supply, permitting joints to move freely, bone to regenerate, and reconstructive surgery to be done later (Fig. 6-26).

Total Degloving

Total degloving may be (1) simple—in which no vital subcutaneous structures are exposed, (2) complex—in which important structures are bared and cannot be covered with split-thickness skin grafts, or (3) unsalvageable.

Simple Total Degloving. The patient who presents with total degloving of an unspecialized area that does not expose vital structures has a simple problem. Careful wound toilet under operating-room conditions, and wound closure are required. The degloved skin is rarely brought into the hospital. Because a large circumferential area may be involved, free split-thickness skin grafts alone are adequate to provide closure (Fig. 6-27).

The high thigh or buttock of the contra or ipsilateral sides (as governed by associated injuries) should be the donor sites. The grafts can be obtained rapidly with a power dermatome. The grafts should be gently spiralled around the circumferential defect. This lessens the intrinsic contraction of the graft and the effect of the shortening of the scar at the skin-graft junction. It is important to realize that there are many methods of achieving primary wound closure, but the simplest is often the best. The use of split-thickness skin grafts supports this concept. Remember that skin grafts can always be excised at a later date and be replaced by a more ideal type of skin coverage.

A fingertip amputation is another common example of this type of injury: the tip can be replaced as a composite graft in the form of a free full-thickness skin graft. This injury is usually the exception to the previous rule, because the tip is usually brought into the Emergency Department. As with all other avulsed and degloved skin, the operator's management must be influenced by the degree of intrinsic skin injury and the expired time. If this is minimal and the wound tidy, it is worthwhile replacing the defatted free composite graft (Fig. 6-28). All the principles of skin grafting must be applied, even more than with a split-thickness graft. A free composite graft must obtain a good vascular supply within 48 hours, as it will not survive on a plasma clot. This means the graft must be treated with even greater respect, and the recipient site must be better than with the free split-thickness graft. The role of microsurgery for avulsed tissues is reaching a more practical clinical level. The use of vein grafts along with arterial pedicle transfer make this a new vista.

Complex Total Degloving. An extensive area of degloving which exposes tendon, joint, cartilage,

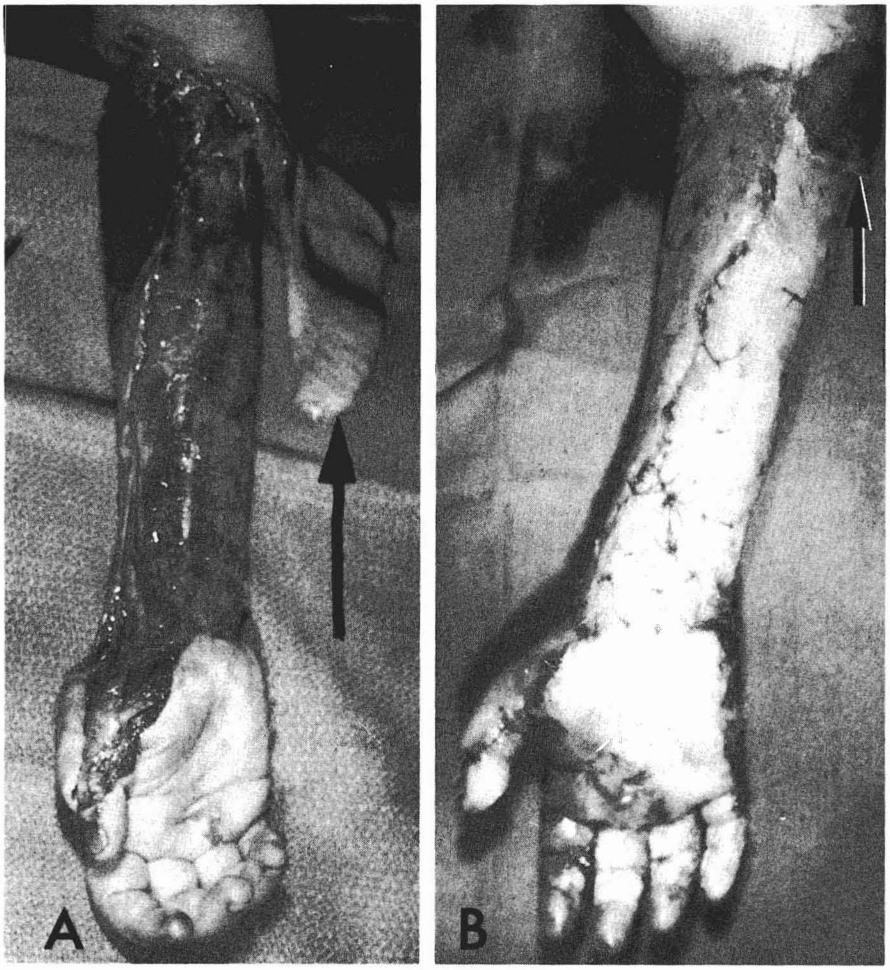
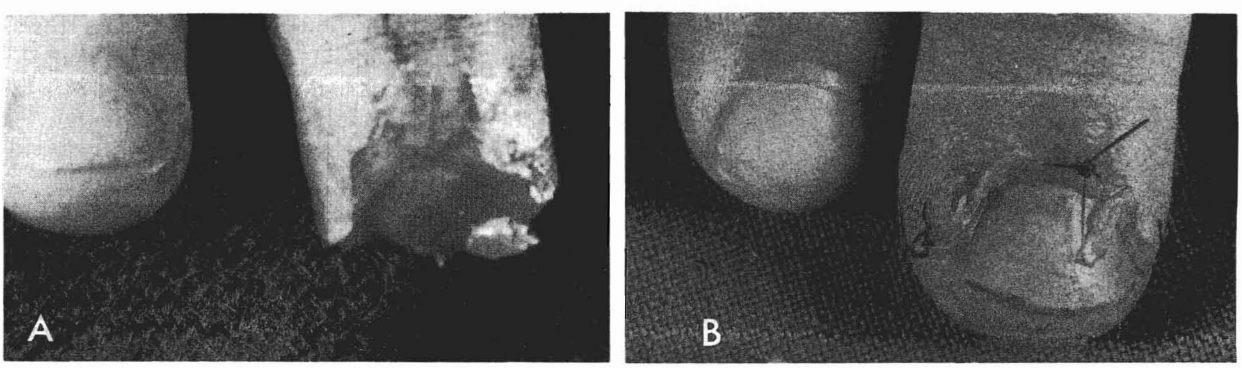


Fig. 6-27. *(A)* Total circumferential degloving of the forearm with a residual attached skin flap. *(B)* Ten days after primary free split-thickness skin graft. (Arrow shows that even residuum of replaced flap is infarcted.)

Fig. 6-28. *(A)* Total avulsion of fingertip showing phalangeal tuft. *(B)* After defatting and replacement as a free full-thickness graft (nail left attached as a splint).



and bone may not be amenable to a simple skin graft. This limits the available methods for primary wound closure. It may be possible to close the defect with a large pedicle flap from the contralateral extremity. This could include an entire leg and thigh. Occasionally, another fracture site in the same injured leg can be used as a false joint to permit soft-tissue coverage for a more important injury on the same extremity. There is no doubt that if the articular cartilage, joint, bone, and tendon can be covered with vital skin, there is more assurance of their survival. Sufficient flap tissue may not be available because of the size of the wound area or the mechanical difficulty of moving the flap to the wound. If this is the case, then the important dogma of primary wound closure must be abandoned. In its place must be substituted a delayed primary skin graft. The wound is fastidiously debrided, and as much local fat-fascial tissue or even muscle is mobilized to cover the tendon, joint, cartilage, and bone. A tulle gauze dressing is applied, with or without topical antibiotic. The initial dressing should be changed 3 days after the wound debridement, and daily thereafter for a total of 7 to 10 days, depending on how rapidly granulation tissue forms. When the granulations appear receptive, a split-thickness skin graft is applied. A few minor modifications in skin-graft technique must be considered with this type of procedure. Granulation tissue bleeds readily and may cause a hematoma that will elevate the graft and cause its demise. Therefore, fixation sutures cannot be inserted into the wound margins; rather they are inserted into the skin surface wide of this zone. For the same reason, no deep fixation quilting sutures can be used. All other rules must be followed stringently.

The avulsed skin can be replaced only occasionally as a free full-thickness skin graft, because the skin itself is usually so severely injured. On rare occasions the totally degloved area is small, and specialized circumferential coverage is needed, (for example in the finger; Fig. 6-29). Coverage can be achieved in these injuries with a cross-arm tube pedicle from the medial aspect of the upper arm. This tissue is ideal, as it is thin and soft and the donor site scar is relatively hidden. The donor site can be closed directly edge-to-edge or with a skin graft, depending on the required width of the pedicle flap. The flap is separated, and the wounds are closed in 3 weeks.

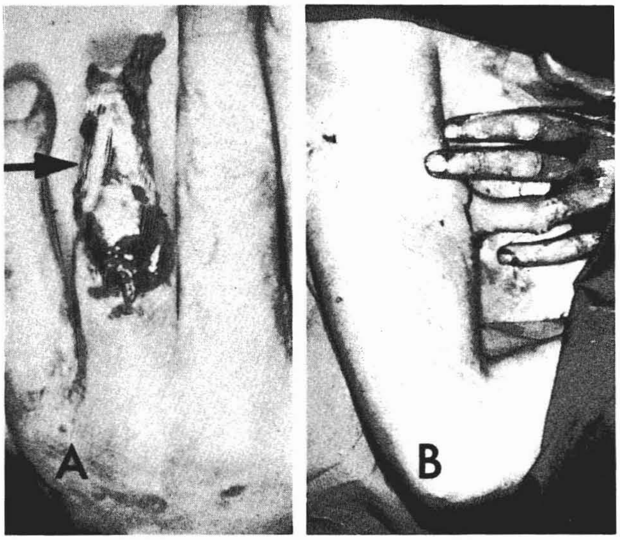
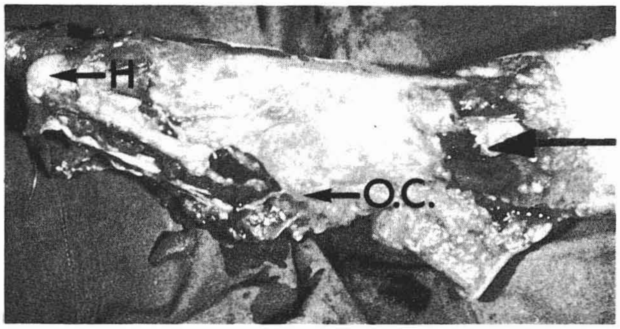


Fig. 6-29. *(A)* Total degloving of the phalanx and exposure of tendon and joint *(arrow)*. *(B)* Three weeks after cross-arm tube pedicle insert.

Fig. 6-30. Unsalvageable right foot. Note fractures and partial amputation of hallux *(H)* and os calcis *(O.C.)*.

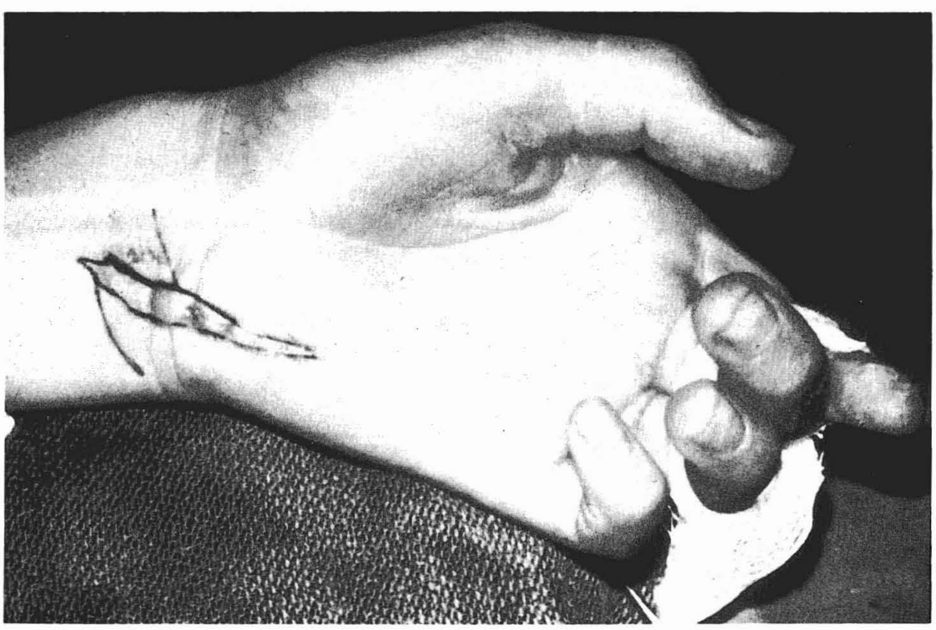


The Unsalvageable Degloved Extremity

This type of limb injury is usually associated with a degloving of both skin and soft tissues, including nerve, vessel, tendon, and muscle, as well as multiple fractures and open joints (Fig. 6-30). This is probably the most difficult injury to deal with, particularly for the novice. It provides a tremendous hurdle because amputation is required. If you are torn with indecision, then it is imperative to obtain a colleague's opinion in the Operating Room and have this second opinion documented. Even if you are not racked

Fig. 6-31. *(A)* B/K stump salvaged with a cross-thigh pedicle flap with excellent prosthetic durability. *(B)* B/K stump salvaged with primary free split-thickness skin graft coverage, again with an excellent prosthetic durability.

Fig. 6-32. Hypertrophic scar at right angles to wrist flexion crease. Elliptical excision and a single Z-plasty is proposed as a solution to the problem. Had it been done initially, it would have prevented this problem.



with indecision, consultation is a good idea. It is important for you, for the patient, and for medicolegal purposes. When the decision to amputate is delayed, it becomes psychologically more difficult for the patient and relatives to accept and leads to many useless salvage operations and heartbreak. On the other hand, and much in your patient's favor, is the ease with which children can adapt to a prosthesis (Fig. 6-31).

COMMON COMPLICATIONS

Hypertrophic Scars

The hypertrophic scar is red and raised, with linear shortening along its length. It always remains within the confines of the original wound. It is frequently confused with the rare keloid. The main significance to your patient is the fact that the hypertrophic scar will improve with time and certainly will improve if properly revised. This is not true with the keloid. An incision or wound crossing at right angles to a flexion crease will always develop a hypertrophic scar unless initially revised. This is not always technically possible. You will find that the **Z**-plasty is your closest ally for early or late revision of this problem (Fig. 6-32). It entails an elliptical excision of the scar and the elevation of the two **Z**-plasty flaps which are interposed. Remember: in order to lengthen the scar on an extremity, you are gathering soft tissue *in a circumferential direction*. Therefore, beware of the flaps being too large and the angles greater than 60 degrees. It is better to make two or more **Z**-plasties in tandem gathering a little circumferentially with each rather than one very large **Z**-plasty. Make sure they are *in* tandem and not *out!*

Linear Tightness

In time, the juncture point between wound margin and a skin graft will cause linear tightness. It may form a hypertrophic scar, but the treatment is the same. If 12 months have elapsed since the skin graft was inserted, the graft itself can be used in the formation of the **Z**-plasty in the revision (Fig. 6-33).

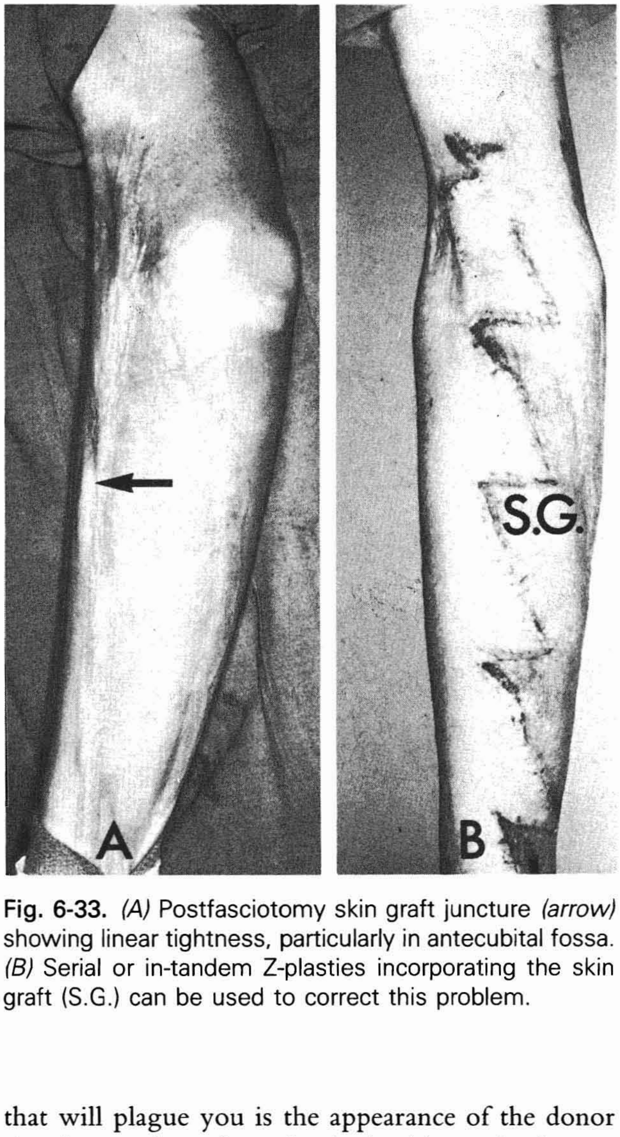


Fig. 6-33. *(A)* Postfasciotomy skin graft juncture *(arrow)* showing linear tightness, particularly in antecubital fossa. *(B)* Serial or in-tandem Z-plasties incorporating the skin graft (S.G.) can be used to correct this problem.

Donor-Site Scarring

Until you become experienced in handling the dermatome equipment, the most common complication that will plague you is the appearance of the donor site. It may be ugly and raised with patchy hypertrophic scars because the skin graft was too thick or because the donor site became infected secondarily. To avoid these problems, the site of the donor area should be the high thigh or buttock region. If the area of skin graft is extensive, use the other side as well, or, if you need still more skin, advance down to the mid-thighs or "miniskirt level." *Using the anterior thigh or abdomen as a donor site is inexcusable* (Fig. 6-34). When you begin to obtain your skin graft, *take a small sample of skin and stop*. Feel the graft and look at the bed. If the graft feels thin and the edges are not curling, you are doing fine. If the donor bed is finely stippled with bleeding you can proceed, but if the

Fig. 6-34. Hypopigmented and slightly raised donor site scar on anterior thigh. The graft was elective and could have been taken anywhere!

Fig. 6-35. Zones of skip donor on buttock and back, as well as anterior chest, giving a zebra effect, demonstrates donor-site ravages.

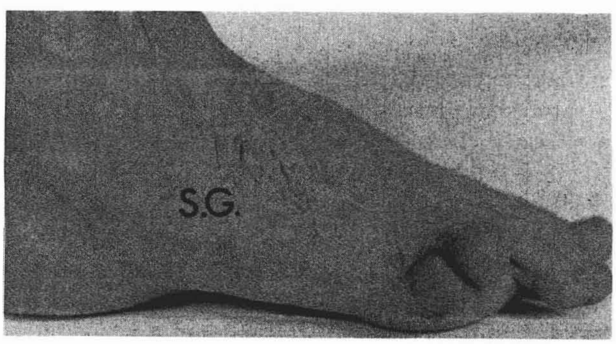


Fig. 6-36. Skin graft (S.G.) contracture causing dislocation of metatarsophalangeal joints.

Fig. 6-37. Late hyperpigmentation of free split-thickness graft used to close a skin defect on the little finger.

graft is thick and curling and if the donor bed bleeds from a few large, widely separated points, you are too deep (Fig. 6-35). Stop! When a thin graft has been removed, a nonshearing, antiseptic tulle gauze dressing should be applied to the donor site to lessen potential destruction of the new epithelium by friction and infection.

Skin-Graft Contraction

One of the inevitable features of skin grafting is the intrinsic contraction that accompanies maturation. The thinner the graft, the more significant the contraction. The skin graft will have an accordion-pleated tight appearance which should lessen with time. An involved joint can be progressively subluxated or even dislocated by this phenomenon (Fig. 6-36). Revisionary correction must be carried out long before this point is reached, and it can be done with another skin-graft insert or an interposed local pedicle flap. The use of orthoses can be helpful!

Skin-Graft Hyperpigmentation

Hyperpigmentation is esthetically displeasing (Fig. 6-37). The thinner the skin graft, the more pigmentation can be anticipated. If this condition requires treatment, the skin graft is excised and replaced with a full-thickness skin graft or local flap. However, there will still be an element of hyperpigmentation with the replacements.

SUMMARY

In this Chapter I have outlined the important principles which should be applied to the treatment of common problems that you will encounter. This style of presentation was chosen to provide a quick reference, but it is not detailed enough to provide all the problems and solutions that will confront you. Remember, this is the age of specialization and fellowship. When in doubt, take comfort by consulting with one of your professional associates.

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7/ Chest and Gastrointestinal Tract

Sigmund H. Ein

Statistics

Accidental injury is the most common single cause of death in children over 1 month old. Among Canadian children, accidents outnumber all other causes of death combined, leaving many permanently handicapped.

Orthopaedic surgeons, who care for children with fractures, should be able to recognize the common injuries that may accompany pediatric bone trauma, to institute initial resuscitation, and to know when and who to call for help.

Causes. At the Hospital for Sick Children in Toronto in the 1970s, the number of injuries from all causes ranged between 16,000 and 18,000 annually for a population of 2 million. The most common causes were falls, bumps/blows, sports, and transport (Table 7-1). In 1979, of 17,000 such injuries, 1,400 were admitted to the hospital and 19 died.

1. **Falls and Bumps.** Falls down stairs were most common, and more than half the children were less than 3 years old. Slides proved to be the most dangerous playground equipment. Bumps and blows were caused mostly from furniture, stationary equipment, household structures, and person-to-person injuries.
2. **Sports and Games.** These caused 14% of all injuries, with ice hockey, football, baseball, gym, and ice skating being the top five. Penetrating injuries are much less common than blunt trauma.
3. **Transportation.** Transport accidents accounted for 7% of the total injuries; 23% were admitted, and much less than 1% died. These accidents are frequently associated with injuries to several body systems (central nervous system, musculoskeletal system, and trunk). Children were injured in cars, on bicycles, and as pedestrians. One fifth of the total deaths could be attributed to accidents involving transport; more than half the children injured while riding in cars were under 5 years old, and many had been thrown against the dashboard in sudden stops. Seat belts or proper infant seats would have prevented these injuries.
4. **Child Abuse.** A fraction of 1% of infants and children had been physically abused by their parents or other adults.

Our experience has taught us that accidents are most common in June, July, and August, and least common in February and December. Most accident victims come for emergency treatment between 4:00 P.M. and 8:00 P.M. Sixty percent of the accidents occur at home, and 10% at school. One quarter of the children are between 2 and 3 years old, and al-

Table 7-1. Top Four Injuries at the Hospital for Sick Children, Toronto—1979

CAUSE	NUMBER	ADMITTED	DIED
1. Falls	5000 (29%)	400	0
2. Bumps and blows	2600 (15%)	100	0
3. Sports	2400 (14%)	150	0
4. Transport	1300 (7%)	300	4
Total	17,000	1400	19

most half are not yet attending school. Boys are invariably found to be hospitalized for accidents more frequently than girls.

This unhappy picture has an optimistic side: children involved in trauma tolerate major reparative surgery surprisingly well, heal quickly, and in general have vigorous powers of recuperation. They rarely suffer from pulmonary, thromboembolic, or cardiovascular complications, so that convalescence is rapid, except when there has been irreparable tissue loss or neurologic damage.

Newborn Injuries

Most injuries result from perinatal trauma to the head and limbs. The death rate per 1000 live births is less than 1%.

Pharynx and Esophagus. Vigorous attempts at birth resuscitation may lead to perforations. These injuries will be recognized by respiratory distress, by sepsis, and by abnormal radiologic findings of the mediastium, pleural cavities, and esophagus. Treatment may include drainage, nasogastric tube feedings, and antibiotics.

Chest Injuries. Chylous pleural effusion, usually on the right side, seems to be the most common chest injury. Chest-tube drainage plus feedings of a medium chain triglyceride formula (Portagen) usually cures this problem. Thoracotomy to tie off the torn duct is rarely needed.

Abdomen. The most common traumatic birth injuries are subcapsular hematomas to the liver and spleen. They present as in the older child, and the investigations and treatments are the same. Bowel perforations owing to birth trauma are quite unusual, but every so often a thermometer will inadvertently perforate the rectosigmoid area, causing lower abdominal wall cellulitis, free intra-abdominal air, and rectal bleeding. The treatment is a temporary colostomy.

Battered Child

The statistics regarding intentional child trauma are alarming; everyone should develop a sixth sense for child abuse. In the Province of Ontario even a suspected case of child abuse must be reported by law. The Hospital has its own Child Abuse Team. Child abuse usually injures the preschool child and involves the soft tissues and musculoskeletal areas. Blunt trauma to the trunk involving the chest, abdomen, and brain is a close second. Principles of care are the same whether the child has been battered or hit by a car.

INITIAL CARE OF SEVERE INJURIES

Hospitals should have a special room equipped for resuscitation, to which a severely injured child can be taken directly from the ambulance. Put the child on a radiolucent stretcher so that he need not be moved for radiography. Look over the child quickly and deal with any respiratory difficulty until the anesthetist arrives. Control external hemorrhage with a pressure pad. Cut off clothes and make a quick inventory of the injuries. Put out a call for all the speciality services likely to be needed.

Wait until the situation is under control before taking a detailed history of the accident. Assume that all victims of major accidents have multiple injuries; expect children injured in road-traffic accidents to have a head injury, some degree of blunt trauma to the trunk, and a limb fracture (usually of the femur; see Waddell's triad, p. 271).

On the immediate examination look for:

1. Respiratory difficulty
2. Major hemorrhage
3. Depression of the state of consciousness
4. Shock
5. Internal injuries
6. Fractures
7. Superficial soft-tissue injuries

Obviously the child should not die while you are carrying out your examination: be quick; you can be thorough later. Relieve respiratory difficulties, control hemorrhage, and start an infusion at once. The specialty service responsible for the care of the most pressing injury should take charge. Confusion can be prevented only by having one person, not a committee, in charge of the patient; very often this is the general surgeon.

There is often a conflict between making a complete evaluation and starting treatment. Patients rarely need to be rushed to the operating room. Rush only when a pupil dilates quickly or when the abdomen becomes distended with blood before the surgeon's eyes.

Airway

Transport unconscious patients on their side to reduce the chance of aspiration. A clear airway is vital. An anesthetist will maintain the airway expertly, but do *not* wait for the anesthetist before providing aid. Remove vomitus and debris by pharyngeal suction, and pass a large nasogastric tube to empty the stomach. Apiration pneumonia will add insult to injury. If these measures are ineffective, pass an endotracheal tube (an oral airway is useless, and an immediate tracheostomy is rarely indicated). If respiratory difficulties persist after a good airway has been established, look for signs of a tension pneumothorax.

Shock

Although neurogenic mechanisms may initiate and potentiate post-traumatic shock, always assume that clinical shock is due to blood loss. Fractures and lacerations seldom deplete the blood volume sufficiently to produce shock, so shock should always be attributed to intrathoracic or intra-abdominal hemorrhage. Abrasions and bruises on the trunk are external signs of an internal injury.

When shock is suspected, take blood for emergency crossmatch, and order an amount equal to the patient's blood volume (approximately 10% of the body weight in grams). Determine hemoglobin and hematocrit (the only other blood test that may be initially useful is serum amylase; elevation usually indicates pancreatic injury). Serum electrolytes are unnecessary at this time.

Rapid transfusion may be needed; use a large-bore catheter or cutdown as the intravenous route. The site must be carefully chosen. Infused blood should reach the heart before escaping from the circulation, so when intra-abdominal injury is suspected, use an arm vein. The transfusion should not be set up on a fractured limb. While awaiting blood, use lactated Ringer's solution, normal saline, or concentrated human albumin as a volume expander. Dextran may interfere with future crossmatching or cause capillary bleeding and, sometimes, renal tubular necrosis.

The time needed for the most rapid blood-typing, blood-grouping, and crossmatching, should not exceed 30 minutes. Immediate transfusion of O-negative blood is seldom warranted and can cause transfusion reactions. Hemoglobin less than 10 g or hematocrit less than 30 g indicate blood loss and require transfusion. The old standbys of pulse, blood pressure, skin perfusion, and urine output are recorded, but remember that a child will lose 20% of blood volume before these signs change.

The urgency of surgery for internal hemorrhage is determined by the rate and volume of the bleeding. Very few children bleed so suddenly and massively that surgery is mandatory upon arrival at the hospital; however, some children are brought to the emergency department in shock, and after urgent resuscitation, the abdomen becomes distended with blood. Children who require less than 40 cc/kg of blood are usually treated nonoperatively, whereas those who require more than 80 cc/kg (*i.e.*, one blood volume) almost always require surgery within 18 hours of admission.

When blood is transfused in quantities approaching the child's blood volume, certain precautions should be taken. Incorporate a small micropore (40 μ) filter in the transfusion set to remove debris that may produce "post-transfusion lung." Warm the blood as it passes through the tubing. Give 5 ml of 8.4% sodium bicarbonate and 1 ml of 10% calcium gluconate for every 100 ml of blood transfused. Check the serum electrolytes. Depletion of coagulation factors and platelets can cause continued bleeding, so a hematology consultation is warranted.

No analgesics, in any amount, should be given, because they may confuse the clinical picture, produce respiratory depression, and mask concealed injuries, thereby postponing assessment and treatment for several hours.

Gastric Dilatation

(See Fig. 7-1.)

The hallmark of abdominal trauma in children is gastric dilatation owing to neurogenic shock, ileus, or air swallowing. Only a small percentage of children with multiple trauma suffer significant intra-abdominal injuries, which may be hard to diagnose immediately. Trauma may cause injury to the abdominal surface, preventing complete examination and assessment. Pass a nasogastric tube if the child's abdomen is not completely soft and scaphoid. This will relieve the very common gastric dilatation and allow the child to be more comfortable, improve breathing, reduce the chance of vomiting and aspirating, and make abdominal examination much easier. Decompression reduces increased intra-abdominal pressure that may push the diaphragm upward and compromise a possibly damaged thoracic cage. Connect the tube to intermittent suction, and periodically irrigate for continued patency and function. It is gratifying to see how quickly a functioning nasogastric tube will reduce a distended, tense, tender abdomen to a flat, soft one.

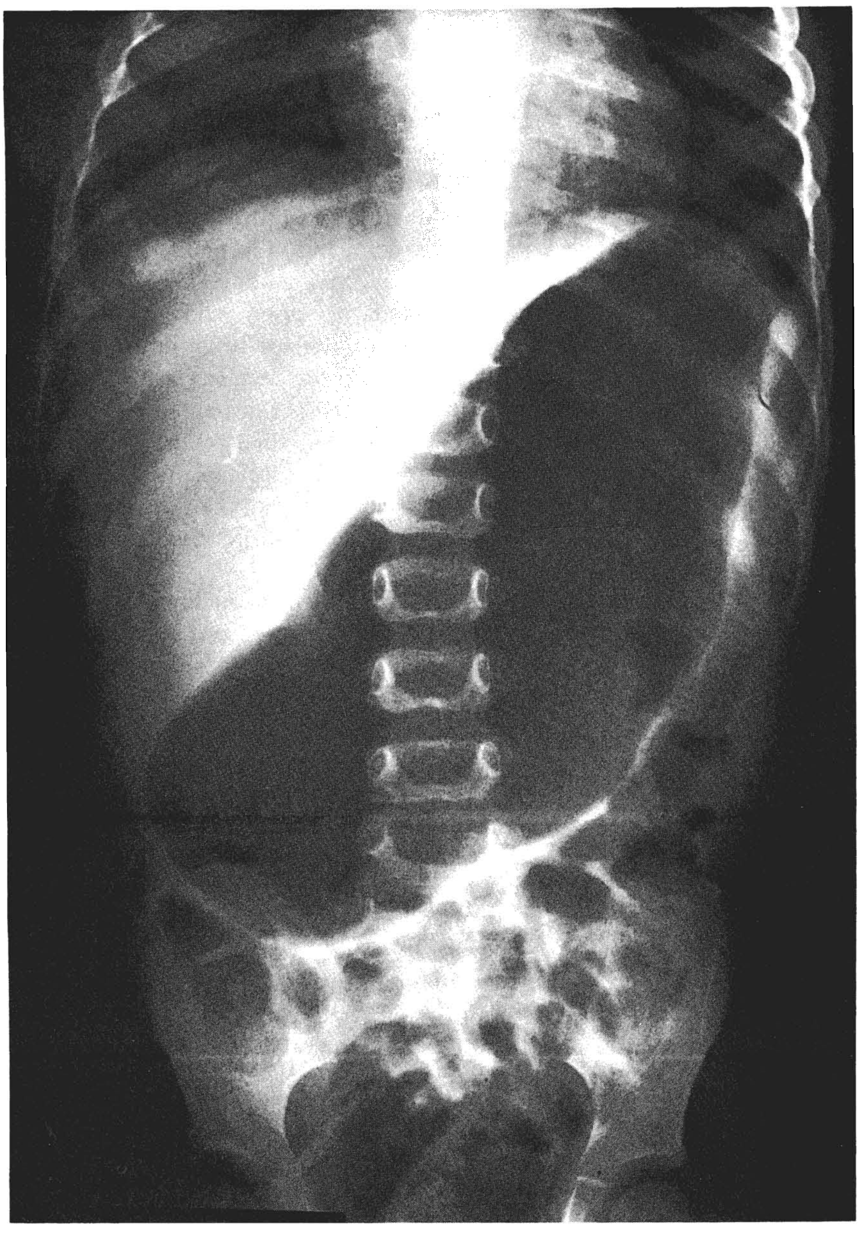


Fig. 7-1. Gastric dilatation is the hallmark of abdominal trauma in children. (Courtesy of Dr. William Holland)

Head Injury

Head injuries frequently accompany injuries of the trunk and extremities. The apparent seriousness of the head injury should not distract attention from other injuries. A combination of head and abdominal injuries is four times as likely to cause death as a head injury alone. Coexisting chest injuries and major fractures do not affect the mortality rate from head injuries.

Head injury alone does *not* produce shock; another cause must be found. However, shock may depress the level of consciousness.

Head injury does *not* cause a rigid abdomen (unless rigidity is generalized throughout the body) and does not cause ileus. The signs of an abdominal injury in an unconscious patient may include hypotension, abdominal rigidity, ileus, and restlessness on palpation. The unconscious child with abdominal injuries should be catheterized and the catheter left in.

Radiography

For most patients there is time to make a fairly detailed clinical assessment and to obtain appropriate and necessary radiographs *after* resuscitation. The patient with multiple injuries must not be left in the semidarkness of the radiology examining room with an inadequate airway, a malfunctioning intravenous, and no crossmatch.

Most patients require radiographs of the skull, chest, abdomen, and one or two limbs. The lateral film of the skull should include a lateral view of the cervical spine. The abdominal radiographs should include the pelvis. Ideally, the chest and abdominal radiographs should be taken with the patient upright to show free air or fluid levels, but when the child is unconscious or too sick, lateral decubitus views will suffice. More specific radiologic investigations (ultrasonography, CT scans, nuclear medicine scans, angiography) may be needed.

Urologic Investigation

The kidneys are frequently injured in abdominal trauma; this will be discussed in Chapter 8. Suspicion of injury is much more common than injury requiring treatment. Bruises or abrasions on the trunk, hematuria, blood from the meatus, and a fracture of the pelvis should suggest a urologic injury requiring investigation.

Antibiotics

The use of antibiotics for trauma, in general, is probably unnecessary, but if and when they are used (usually for specific major injuries) they should, if possible, be given intravenously as soon as possible, especially if surgery is contemplated. At the present time, ampicillin (200 mg/kg per day, q6h) and gentamicin (5 mg/kg per day, q8h) give the best overall protection, with the addition of clindamycin (50 mg/kg per day, q6h) if there are any bowel injuries, and cloxacillin (200 mg/kg per day, q6h) for open bone injuries. Tetanus prophylaxis should not be overlooked, especially if the injury is a dirty one.

After Resuscitation

When the vital signs are stable and the injuries are identified, the patient can be moved to the Operating Room or to the Intensive Care Unit (ICU). In the ICU, the neurologic, respiratory, abdominal, and limb status is systematically determined. Frequent examinations are needed, because signs and symptoms of other injuries may develop insidiously.

Some children go straight to the Operating Room for craniotomy or for reduction of an open fracture. If the blood pressure becomes difficult to maintain and the abdomen becomes distended while the child is under anesthesia, suspect massive intraperitoneal bleeding. Confirm the diagnosis by finding blood (which does not clot) on aspiration of the lower quadrants. Immediate laparotomy is necessary.

Injury Severity Score

Each injury is scored according to a formula, and the total is tallied. The higher the score, the more severe the injury and the greater the chance of death. The injury severity score (ISS) is useful in prognosis because it is a method for numerically describing the overall severity of injury. Death rates increase in the presence of injuries in a second or third body area, even when such additional injuries may individually not be life-threatening. Patients with scores below 10 rarely die, while those with scores of 50 and over may die if their treatment is not prompt, correct, and given by adequately trained specialists with the necessary experience and resources.

The ISS may also tell the story about the local emergency care system in evaluating the results of the patients who score between 10 and 50. It is in this gray area where some injured may be adversely affected by poor care, and others not that severely injured may die, even with optimal care. At the Hospital for Sick Children, Toronto, we have not as yet used this ISS on a formal basis.

CHEST INJURIES*

Chest trauma in children is not as common nor as serious as abdominal injury. More boys suffer chest injuries than girls; most result from closed blunt trauma caused by motor vehicles in the summer months. Penetrating injuries are quite unusual. Morbidity and mortality are directly related to the severity of the chest injury and the number of injuries to other systems; 25% have thoracoabdominal injuries.

The child's chest wall is more flexible than that of an adult, so the chest contents can be injured even though the ribs are not fractured. Indeed, the mortality of closed-chest injuries is higher in children without fractures than in those with fractures. Simple rib fractures, so common in adults, are uncommon in children.

Few chest injuries are fatal; most are so minimal that they are missed. Severe respiratory difficulty demands examination for signs of tension pneumothorax, in which the simple insertion of a needle or chest tube into the pleural cavity may be lifesaving.

Closed-chest injury may produce few outward signs and may be overshadowed by other injuries. The surgeon may be unaware of serious lung damage until there is gross impairment of respiratory function, by which time there may be uncertainty whether the cause is anesthesia, fat emboli, fluid overload, aspiration, or the trauma itself.

The significance of fat emboli producing significant pulmonary injury in children is unclear. There is no specific therapy, and the principles of respiratory support remain the same irrespective of the underlying cause.

In every patient with multiple injuries a search for chest injuries should be made by looking for signs of rib fractures and subcutaneous emphysema. The chest must be auscultated, and radiographs must be obtained in an upright position because pleural fluid cannot be seen on supine films. Blood gases should be measured when there is clinical evidence of pulmonary injury. Tachypnea, cyanosis, grunting respiration, flaring of alae nasi, tachycardia, and restlessness with apprehension indicate significant hypoxemia. Initial treatment should be oxygen via a face mask or head box, and careful observation and monitoring. Radiologic and clinical deterioration with documentation of a widening alveolar–arterial oxygen gradient are indications for intubation and positive pressure ventilation irrespective of the cause. In addition, loss of lung volume associated with contusion, aspiration, or pain from rib fractures will contribute further to respiratory distress and are also indications for early intubation and continuous positive pressure ventilation. Low pulmonary compliance will increase the work of ventilation resulting eventually in fatigue and hypercapnia. Sputum retention from pain or an unstable chest wall will contribute further to hypoxemia and increase respiratory work.

* The preparation of this section was assisted by Geoffrey A. Barker, M.B.B.S., F.F.A.R.C.S.

Lung Contusion (Fig. 7-2)

Lung contusion, the most common major chest injury in children, usually develops insidiously. Initially, a child with lung contusion and no rib fractures may be completely asymptomatic and unsuspected until (1) a routine chest radiograph shows the fluffy infiltrates of perivascular and peribronchial parenchymal hemorrhage and (2) bloody sputum or frank hemoptysis. A few children progress to develop "traumatic wet-lung" ("shock lung") syndrome with increasing tachypnea, dyspnea, mild cyanosis, wheezes, and rales at both bases. The child becomes apprehensive, as mucus, serum, and blood fill the bronchial tree.

The *diagnosis* should be reached before this stage by clinical observation, serial radiography, and repeated blood-gas determinations.

Treatment. *Oxygen Therapy.* Oxygen therapy and prevention of edema by fluid restriction aided by diuretics (furesomide 1 mg/kg per intravenous dose) may be all that is necessary, but if unsuccessful, intubation and ventilation is indicated.

Ventilatory Support.

1. Intubation and constant positive airway pressure (CPAP) require scrupulous attention to proper fluid balance. Cardiac output may decrease, and monitoring of central venous pressure (CVP) or pulmonary wedge pressure via a Swan–Ganz catheter will be necessary.

2. Spontaneous ventilation with CPAP may be adequate for minimal pulmonary contusion.
3. Continuous (or constant) positive pressure ventilation (CPPV = IPPV + PEEP) during the initial 48 hours will significantly increase lung volumes, re-expand collapsed alveoli, control alveolar edema (allowing surfactant to regenerate), decrease respiratory work, and contribute to the removal of secretions.*
4. Intermittent mandatory ventilation (IMV) may be sufficient provided that there is adequate pain relief. During weaning from the ventilator, IMV allows the patients to gradually increase their respiratory work, and assessment of its effects can be evaluated prior to extubation.

Adequate Pain Relief. This is necessary for fractured ribs, or upper abdominal injuries after evaluation of all injuries is complete. A continuous infusion of a narcotic (such as morphine, 10 μg/kg/hr–20 μg/kg/hr) is often effective.

If there is a coexisting head injury producing significant cerebral edema, consider the use of intracranial pressure monitoring, muscle paralysis and hyperventilation, Mannitol, high-dose barbiturate therapy, or hypothermia may further compromise pulmonary function, especially if these measures are prolonged. Under these circumstances, priorities of therapy should be frequently reevaluated and treatment modified to avoid further compromise of pulmonary function, which will contribute further to hypoxemia.

Chest Physiotherapy. Incentive spirometry in the cooperative patient, and forced vital capacity will contribute to sputum removal and to maintenance of lung volume.

Cultures of the airways should be obtained and antibiotics (ampicillin, gentamicin) started. Inhalations may loosen secretions, and bronchoscopy is occasionally helpful. Most lung contusions resolve within a week or two, leaving no sequelae.

*IPPV = Intermittent Positive Pressure Ventilation; PEEP = Positive End Expiratory Pressure.

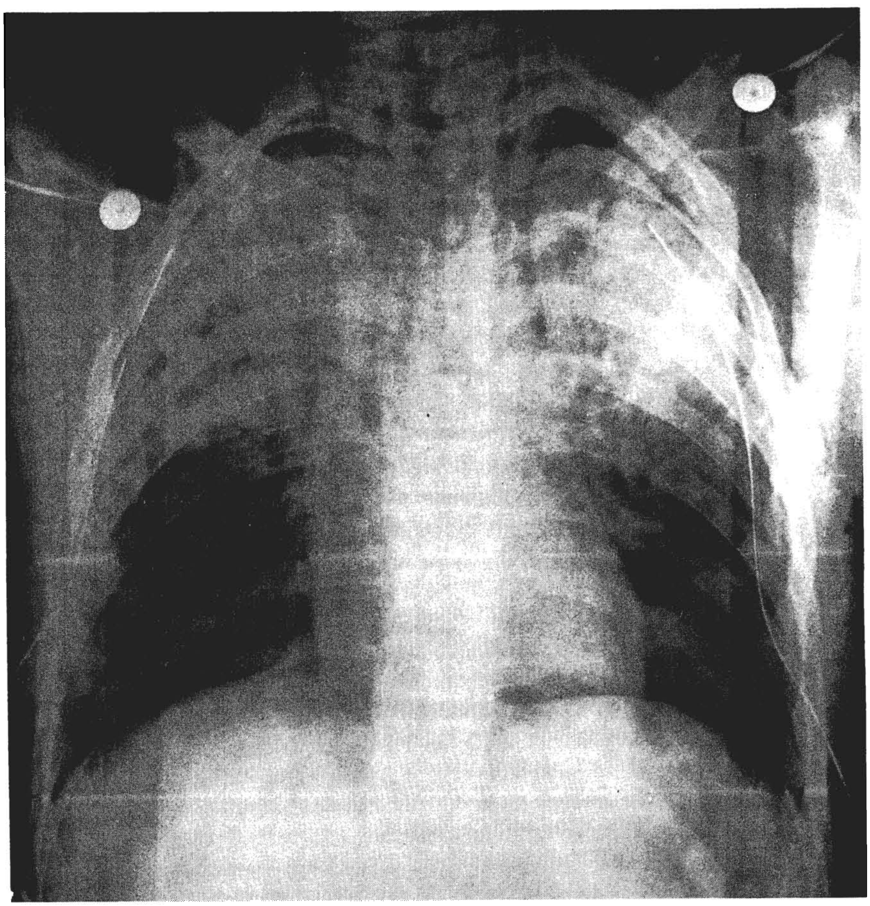


Fig. 7-2. Lung contusion. Note the fluffy infiltrates, which are perivascular and peribronchial parenchymal hemorrhages. (Courtesy of Dr. William Holland)

Pneumothorax

(See Fig. 7-3.)

Pneumothorax, with or without hemothorax, may result from any lung contusion. In a simple pneumothorax, air enters the pleural cavity slowly through a laceration of the surface of the lung. In a tension pneumothorax, air is pumped into the pleural cavity because the laceration behaves like a valve. Intrapleural pressure increases, and the mediastinum shifts. A tension pneumothorax is very dangerous and may not allow time for the desired chest x-ray film. The emergency treatment is insertion of a needle into the pleural cavity followed by a chest tube. Remove accumulated air and blood with a large intercostal tube connected to an underwater seal and suction. When the blood does not clot, there is a hemothorax: the blood has already clotted once and has lysed in the pleural cavity.

The most common cause of subcutaneous emphysema is a pneumothorax owing to a fractured rib. The subcutaneous air may track from head to scrotum, producing an alarming appearance, but, because the air can spread, no vital structures are compressed. Once the air leak is treated, the emphysema gradually disappears.

Technique. In children, the chest tube is best inserted at the anterior axillary line in the fifth or sixth intercostal space so both air and fluid can be removed without damage to the major vessels, which are very

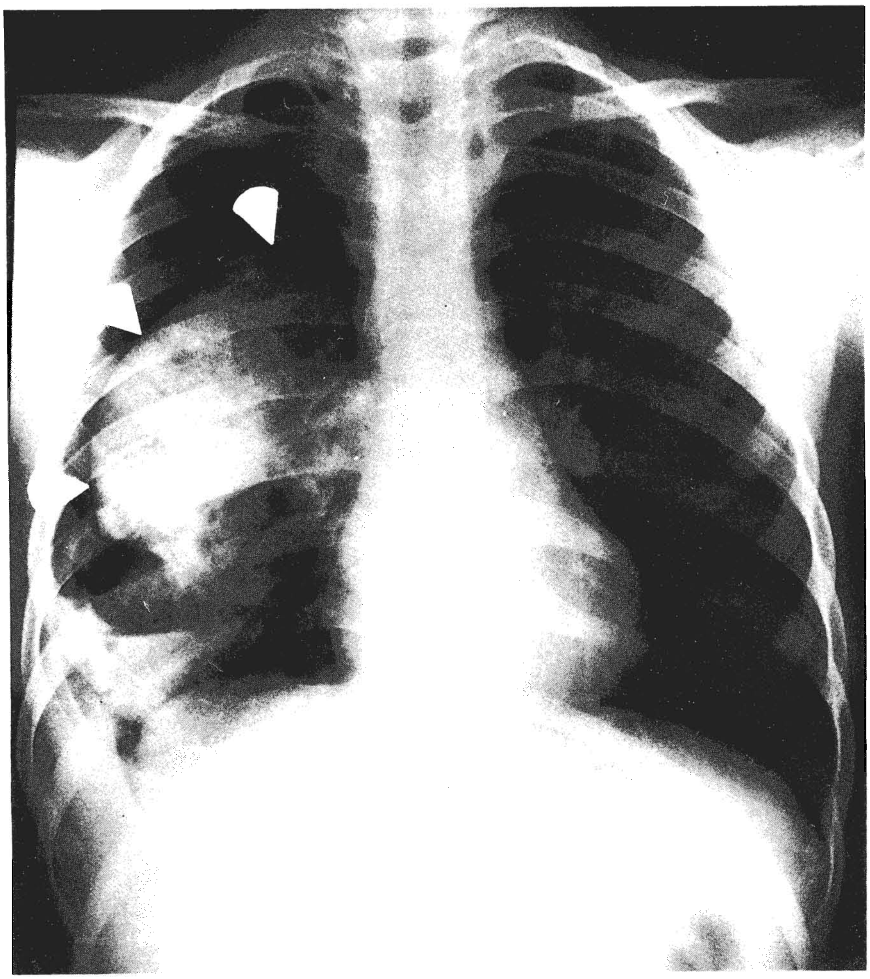


Fig. 7-3. Penumothorax. (Courtesy of Dr. William Holland)

close to the infraclavicular area. A Heimlich flutter valve attached to the distal end of the chest tube works immediately and allows time for setting up the underwater suction apparatus (either bottles or Pleurivac). If the flutter valve is to be used for several days, it must be kept clear of blood clot and serum by replacing it when necessary.

The efficiency of the chest tube can be assessed by repeat radiographs taken in the upright or in the lateral decubitus position to allow fluid to layer out. The chest tube can be removed after a few days, when the air leak has sealed and the lung has expanded. However, when ventilation is maintained with a respirator, the air leak may persist due to high transpleural pressures. Therefore, the chest tube should remain in position until mechanical ventilation is discontinued.

Experience from the Vietnam war has shown that a chest tube and blood transfusion (equal to the losses from the injuries) makes thoracotomy unnecessary. Thoracotomy is only needed when bleeding continues unabated from the chest tube accompanied by unstable vital signs. At operation the lung laceration, which is the usual cause, is easily closed with large sutures.

Traumatic Asphyxia

The cause is a temporary obstruction of the superior vena cava and a concomitant increase in intratracheal and intrapulmonary pressure. The child takes a deep breath, holds it, closes the glottis, and braces for the blow to the chest.

This injury is infrequent but easy to recognize; it results from a child being run over by a vehicle. When there are head and abdominal injuries, the diagnosis of traumatic asphyxia may be quite tricky.

The child is severely cyanosed, with engorgement and ecchymoses of the upper half of the body, and with subconjunctival hemorrhage. These children are initially agitated and disorientated, but any loss of consciousness is usually due to concomitant cerebral contusion or to secondary brain injury. The cerebral irritability probably results from minor intracranial ecchymoses and edema. However, all these signs and symptoms recede within a few days, and neurologic sequelae are rare.

Management. Children with traumatic asphyxia must be observed in the ICU with appropriate oxygen therapy; this will provide good oxygenation and will assist in the absorption of any residual air trapped in the mediastinum and pleural cavities. The presence of pneumothorax, pneumomediastinum, pulmonary edema, and major pulmonary and mediastinal hemorrhage make the traumatic asphyxia more serious and may well require chest tubes, diuretics, and mechanical ventilation. However, most children with this injury, bad as it looks, need only oxygen and close observation, and will make a complete recovery. Those who die immediately probably do so at the scene of the accident and from more serious associated injuries.

Flail Chest

This is an uncommon childhood injury, because the pediatric chest cage is "elastic." Although ribs may fracture when a child is run over, they spring back into place and may *not* be seen on chest x-ray film. Even when multiple rib fractures occur, paradoxical movement is seldom sufficient to hinder respiration. As with other serious chest injuries, one must be on the constant lookout for associated underlying lung contusions and accumulation of tracheobronchial secretions, which further embarrass respiratory exchange.

Treatment. Adequate pain relief is essential. Mechanical ventilation by means of an endotracheal (or rarely, a tracheostomy) tube may be required to stabilize the chest wall on rare occasions.

Tracheobronchial Injuries

Any neck injury may damage the trachea. Complete rupture of the trachea is very rare and results in a quick death at the accident scene. Subcutaneous emphysema, respiratory distress, and hemoptysis quickly develop. Lateral x-ray film may show discontinuity of the trachea. Operative repair must be undertaken once a clear airway has been established in the operating room. Tracheostomy may be essential in the postoperative management.

There must be an even greater number of partial tracheal tears that heal spontaneously and make their presence felt many weeks later when the child develops a stricture, which will require either dilatation or resection.

Bronchial tears are not quite as rare as tracheal injury (we have seen five in the last 6 years). They occur after major chest trauma (fall from a great height, shearing force between stationary and moving objects, compression with high energy impact). Such injuries produce cyanosis and respiratory distress, and they usually take either of two routes: acute becoming worse or acute becoming chronic.

Acute Becoming Worse. Initially, bronchial tears within the mediastinum give rise to mediastinal and subcutaneous emphysema of the head and neck—a puffball appearance—and possibly a pneumothorax that may expand with chest-tube treatment. A tear beyond the reflection of the pleura is suggested by a pneumothorax that does not expand with chest-tube section (Fig. 7-4). This is the more common picture, and immediate repair is necessary. Although the tear may be located by bronchoscopy or bronchography, there is seldom enough time. The repair may require a lobectomy (if the tear is near the junction of a lobe bronchus).

Acute Becoming Chronic. At the other end of the spectrum (Fig. 7-5) the subcutaneous emphysema and pneumothorax will disappear with passage of a chest tube, but the child may develop wheezing or atelectasis (usually) weeks later. In time, this persistent or intermittent atelectasis will be shown to be due to a post-traumatic bronchial stenosis, which can be either dilated or resected. Resection may still necessitate the removal of a lobe in the elective repair.

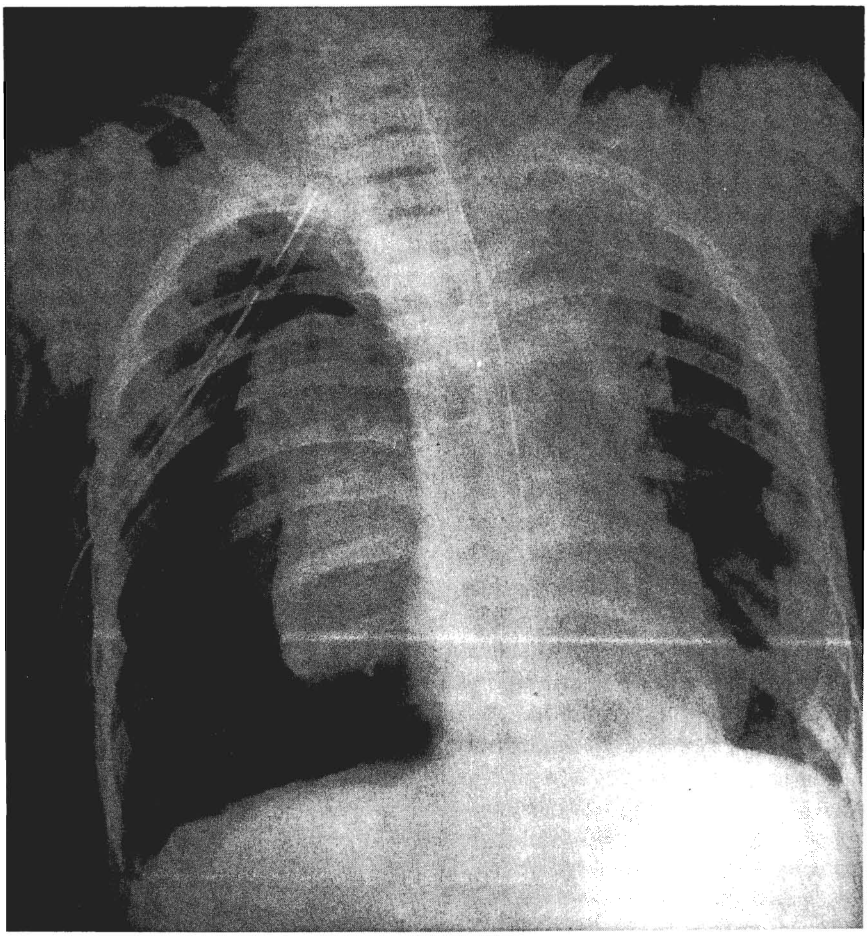


Fig. 7-4. Bronchial tear beyond the pleural reflection unrelieved by chest tube to suction. This requires immediate repair. (Courtesy of Dr. William Holland)

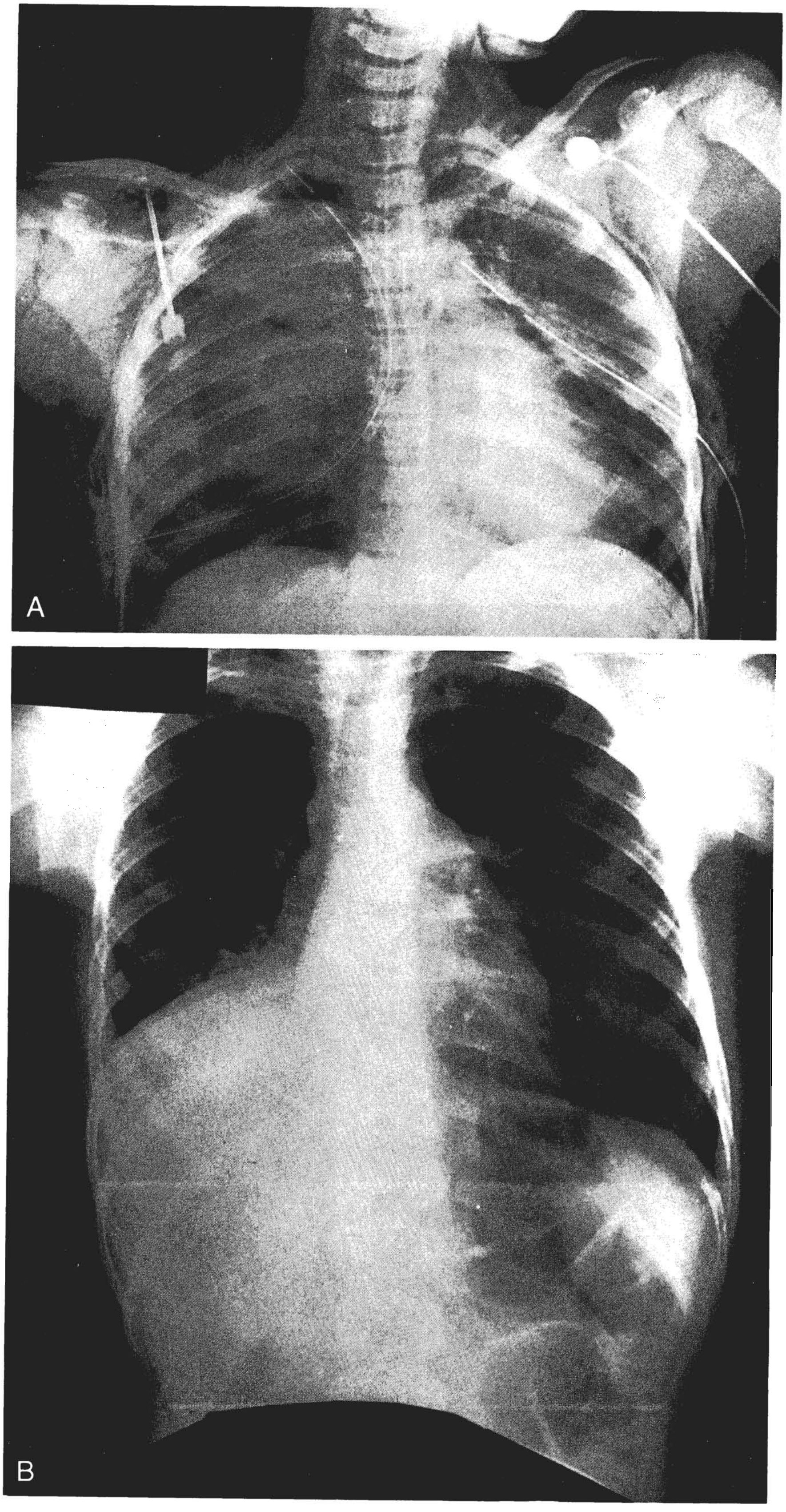


Fig. 7-5. Bronchial tear beyond the pleural reflection relieved by chest tube to suction. This may require later repair. *(A)* Early stage. Right pneumothorax has disappeared with placement of chest tube, and subcutaneous emphysema is slowly being resorbed. (Courtesy of Dr. William Holland) Bronchial tear. *(B)* Late stage. Persistent right lower lobe atelectasis.

Heart and Great Vessels

Damage is rare but must not be forgotten. After resuscitation of the polytraumatized child, clinical and radiologic evaluation of the heart and great vessels is wise. Electrocardiogram and echocardiogram will define the myocardial injury, while the key to great vessel injury will be a widened mediastinum (Fig. 7-6). It is rare for patients with massive damage to these structures to survive transport to a hospital; if a widened mediastinum is discovered, the next step is urgent angiography with subsequent cardiovascular repair.

Rupture of the Diaphragm

A ruptured diaphragm, while not common, will often produce immediate symptoms. The rupture is usually on the left, and a chest radiograph shows bowel in the pleural cavity (Fig. 7-7A). Immediate laparotomy is required to repair the tear in the diaphragm, to prevent strangulation of the herniated bowel, and to treat any associated intra-abdominal injury, such as a damaged spleen. Occasionally a child will return weeks or months later with the sudden onset of mild to moderate respiratory complaints. Retrospective review of his original radiographs may reveal an uneven diaphragm (Fig. 7-7B), and one may speculate that the hemidiaphragm was torn at the time of the injury, but the hernia was delayed. Late repair may be difficult technically because of adhesions from the injury in the operative area; however, the child's condition is a lot more stable.

When a child's trunk is crushed, always think of rupture of the diaphragm.

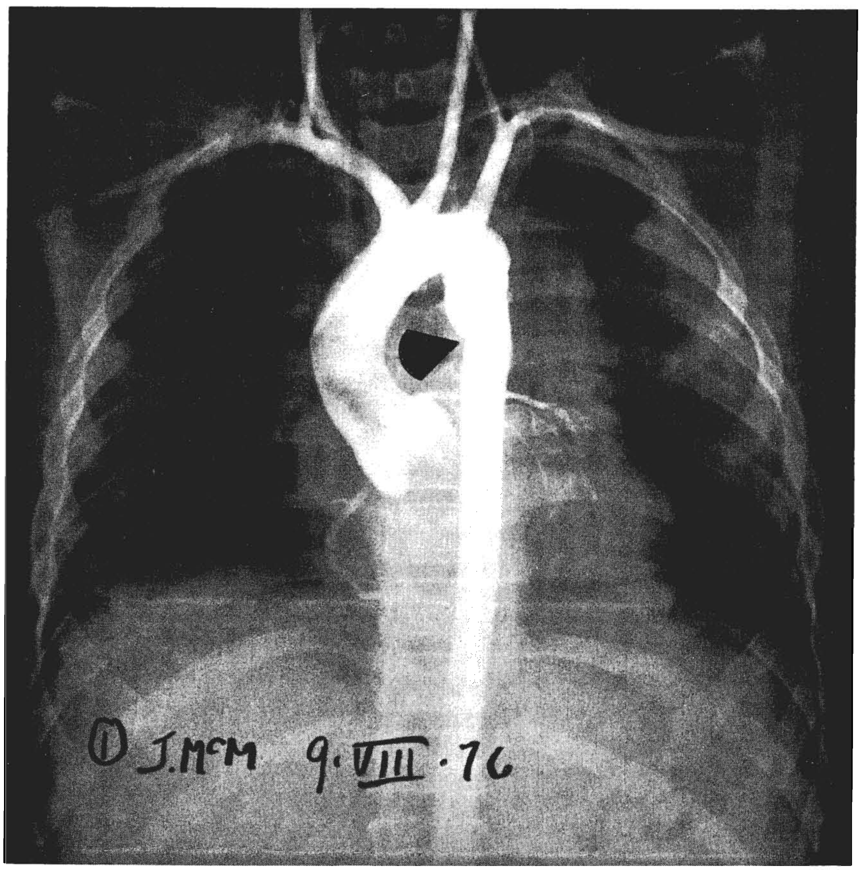


Fig. 7-6. Widened mediastinum is the key to great vessel injury in chest trauma. This finding requires arteriography, which herein shows tear in wall of thoracic aorta. (Courtesy of Dr. William Holland)

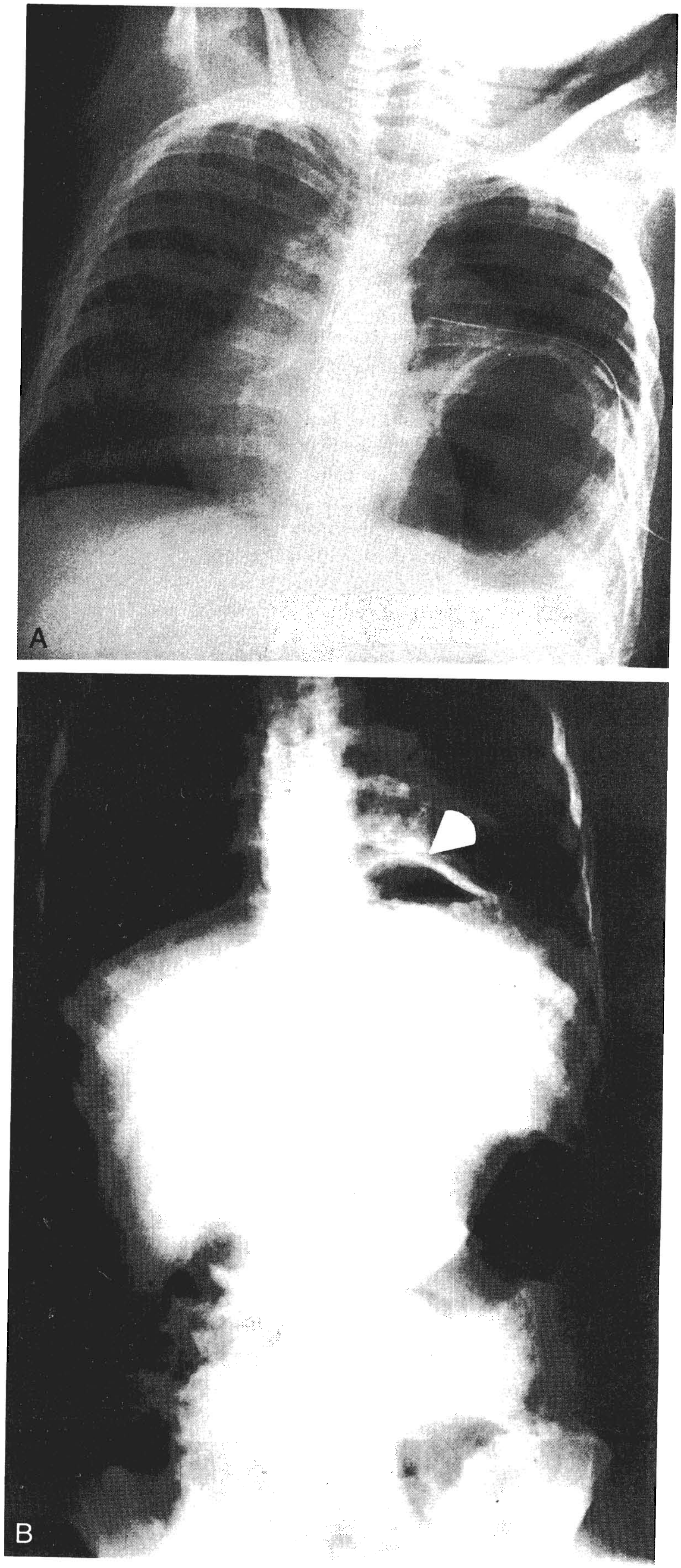


Fig. 7-7. Traumatic diaphragmatic hernia. *(A)* Obvious. Usually on left and shows bowel in pleural cavity. (Courtesy of Dr. William Holland) *(B)* Hidden. Uneven left hemidiaphragm torn at time of injury, but intra-abdominal contents have not yet gone up through the defect into left pleural cavity.

Penetrating Chest Injury

Penetrating chest injury is so dramatic that signs of damage to thoracic viscera will be seen immediately. Wounds usually cause a pneumothorax and damage to the lung, either hematoma, laceration, or both. As an emergency measure, relieve the pneumothorax by inserting a chest drain through the wound, and pack off any air that may be leaking around the tube. Most patients who reach a hospital can be adequately treated with debridement, closed-tube thoracostomy, and blood replacement. Surgical intervention (as for President Reagan) should only be considered when there is a brisk, continuous flow of blood from the chest tube and when the volume of blood transfused exceeds the child's estimated blood volume. Lung laceration, the most common cause of hemorrhage, can easily be controlled with large catgut sutures at thoracotomy. Resection is rarely necessary.

Penetration of the heart, great vessels, esophagus, and abdomen is possible. Cardiac tamponade threatens life and demands paracentesis as first aid, followed by radiologic and ultrasonographic confirmation (if time allows), and then by immediate exploration. Repair of a major vessel is preferable to ligation. Direct pressure is the best method of immediate control until the hole in the vessel is isolated with vascular clamps or tapes.

ABDOMINAL TRAUMA

A review of 200 cases of blunt abdominal trauma seen and operated on at The Hospital for Sick Children, Toronto, has produced several interesting facts. Seventy-five percent of the injured were boys. Most of the injuries occurred during the summer and early fall. Car accidents, direct blows (including athletics), and falls caused 70% of injuries. The kidney, spleen, or liver had been ruptured in 75% of patients. In addition to the abdominal injury, 45% of the children had one or more other injuries: fractures (25%), craniocerebral injuries (20%), and thoracic injuries (15%). More than one important abdominal structure was damaged in 10%. The mortality rate was 12%.

Although only a small percentage of children with multiple trauma suffer intrathoracic or intra-abdominal injuries requiring exploration, many have minor injuries that present worrisome and difficult diagnostic problems. Initially, a diagnosis can only be reached in the most obvious cases. For the remainder, careful initial examination, constant close observation, and frequent reexamination is required.

Initial Management

A brief review of the highlights of initial management of abdominal trauma bears repeating. The key thing here is to stabilize the patient while initiating and planning definitive treatment and investigations for diagnosis. Stabilization means nasogastric tube, intravenous, and crossmatch.

It is essential to pass a nasogastric tube in any child whose abdomen is not completely soft and scaphoid to relieve gastric dilatation, which is commonly present. This, in itself, will often make the child more comfortable, reduce the chance of vomiting and aspiration, and make abdominal examination much easier. The tube should be connected to intermittent suction and should be irrigated periodically to ensure its patency. Gastric dilatation (Fig. 7-1), the hallmark of abdominal trauma in children, may be due to neurogenic shock, ileus, or crying. A large-bore, intravenous catheter should be inserted into a vein in the arm (not the leg), and an intravenous started with lactated Ringer's solution. Blood should be sent off for hemoglobin, hematocrit, crossmatch, and amylase.

Much has been written about the unreliability of physical signs in abdominal injuries. The most useful signs are shock, tenderness, guarding, rigidity, and increasing girth. The site of tenderness is a guide to the site of injury. Penetrating wounds may be overlooked unless every square inch of a child's abdomen and back is examined. Blood at the urethral meatus and hematuria should be looked for. Rectal examination should be carried out in all such children.

In addition to radiographs, isotope scans may assist in the diagnosis of ruptures of the spleen and liver. Ultrasonography is easy, fast, reliable, noninvasive, and can be done at the patient's bedside. With increasing finesse, the ultrasound pictures are looking more and more like CT scans and are providing valuable information about previously inaccessible areas of the abdomen (*e.g.*, pancreas and retroperitoneum).

The value of peritoneal tap or lavage is still controversial because some believe that a small amount of blood in the abdomen of an otherwise stable child is not necessarily a reason to operate; moreover, we have observed false-positive and false-negative results from these tests.

Definitive Care

Nonoperative Care. Children with trauma to the trunk should be admitted to the hospital and observed closely; the most worrisome go to the intensive care unit. The majority improve with time, nasogastric tube, and intravenous fluid. When gastrointestinal function returns after a few days, the tubes are removed. As soon as a child has progressed from clear fluids to a regular diet and is eating and stooling normally, he can be transferred to the appropriate service for treatment of the residual injuries (usually orthopaedic). If there are none, he or she can be discharged from the hospital, with an appointment to return in a few weeks.

Operative Care. The indications for operation are:

1. Shock occurring *after* resuscitation, particularly when associated with increasing abdominal girth
2. The presence of free intra-abdominal gas
3. Gradually increasing abdominal pain, tenderness, and rigidity

Intraperitoneal Hemorrhage

Solid viscera are more commonly ruptured than hollow organs because solid viscera are relatively fixed in the abdomen and are subject to shearing forces; the ribs, normally protective, can become agents of injury. Intraperitoneal hemorrhage, the result of a ruptured viscus, is manifest by shock, abdominal distension, tenderness, and a falling hemoglobin.

The American College of Surgeons' manual on *The Early Care of the Injured Patient* states, "The presence of abdominal tamponade especially in a patient responding poorly to intravenous fluids is a grave prognostic sign. When the peritoneal cavity is opened and the tamponade is released, sudden collapse from fresh hemorrhage is a common event."[1] To prevent this problem, one should take care to decompress the abdomen slowly while maintaining the patient's vital signs with autologous bank blood. The use of the Bentley Autotransfusion System* may be of definite aid for massive bleeding, but it takes time and staff to set it up. At our hospital, the cardiac pump technicians operate this apparatus. The blood removed through the initial, small, abdominal incision is collected in the reservoir, and if not contaminated from a perforated viscus, it can be delivered back to the patient at rates of up to 300 cc/min, as requested by the anesthetist. Systemic heparinization is unnecessary. The patient's coagulation status is checked frequently, and fresh frozen plasma, platelets, and protamine sulphate are given when necessary.

*Autotransfusion System, Bentley Laboratories, Irvine, California

Injured Spleen

By far, the most common cause of intraperitoneal hemorrhage is damage to the spleen. About one third of children with blunt abdominal trauma at our hospital will have injured their spleen, and about one third of spleen injuries will have associated left renal injuries. Only 10% of injured spleens in children involve overlying rib fractures. The speed and volume of bleeding determines the clinical picture and the treatment. If damage to the spleen is suspected, a radioisotope spleen scan is obtained. A positive scan shows a filling defect correspnding to a splenic laceration or hematoma (Fig. 7-8).

Needle aspiration of the abdomen has given us both false-positive and false-negative results. Even when blood is aspirated, surgery is not necessarily indicated. Therefore, paracentesis for diagnosis is restricted in our hospital to the anesthetized or the unconscious patient. The aspirated blood will *not* clot if it was floating free within the peritoneal cavity, because the original clot has been lysed. We have had no experience with saline lavage of the peritoneal cavity, nor have we found the necessity or the advantage of angiography on a routine basis. Untrasonography and the CT scan offer good alternatives to the nuclear medicine scan.

The condition of most children improves within 24 to 48 hours, and the abdomen is less tender with the return of some bowel sounds. At this point, the child can be safely moved out of the ICU to a surgical floor. The intravenous and nasogastric tube are not removed until gastrointestinal function has returned to normal and until the abdomen is soft and nontender. This usually takes several days. Needless to say, such a child must be observed in the hospital for several weeks and when discharged should be on restricted activities for at least another month or so. By 2 months after the spleen injury, most spleen

Fig. 7-8. Spleen scan. Radioisotope study showing filling defect corresponding to splenic laceration or hematoma. (Courtesy of Dr. Judy Ash)

scans have either returned to normal, or the scarring that will remain forever has reached its final stages. At this point, we feel the child can safely return to normal activities. Only one fifth of all our patients with damaged spleens diagnosed by radioisotope scan and treated nonoperatively heal completely (usually within 3 months) by follow-up spleen scan. The remaining injured spleens heal with a residual defect (assumed to be scar), which is stationary by scan in 2 to 3 months.

Children with abdominal trauma are suspected of having a damaged spleen because they show signs of mild shock, complain of left-shoulder tip pain, and have signs of left upper-quadrant peritoneal irritation. They are treated nonoperatively in the ICU if the hemoglobin is above 10 g and if the vital signs are stable after initial treatment is instituted. Blood is kept available. If the hemoglobin falls below 10 g (even if the vital signs are stable), transfusion is given. When the vital signs are unstable, a blood transfusion usually corrects the situation. If, however, the blood pressure and hemoglobin remain unstable and if there are continuing signs and symptoms of intra-abdominal bleeding, the child will need immediate operation, and this will usually be decided within the first 18 hours of admission.

The two cardinal abdominal signs of intraperitoneal bleeding are distention and tenderness hence, the need for repeated abdominal examinations and girth measurements.

A problem that frequently crops up in nonoperative management of blunt abdominal trauma is the child who has some degree of shock (neurogenic or hypovolemic) and responds to nonoperative management with or without transfusion. If damage to the spleen is revealed by more aggressive investigation (such as abdominal needle aspiration, peritoneal saline lavage, spleen scan, and arteriogram), a debate ensues as to what should be done: laparotomy with the possibility of splenectomy or further observation. Although these investigations are useful, they should be considered as guides to treatment; the decision remains with the surgeon and his clinical evaluation of the patient. If continuing doubt exists and if the child's general condition is unstable, laparotomy is indicated.

Very few children bleed so suddenly and massively that immediate surgery is mandatory upon arrival at the hospital; these are usually the children who are brought to the emergency department in shock and, after urgent resuscitation, the abdomen becomes distended with blood. A few injured children will develop unexpected hypotension, hypovolemia, and abdominal distention under anesthesia while being operated on for other injuries, and these bellies will also have to be opened.

We believe that the need for surgery in splenic trauma is determined primarily by the rate and volume of the bleeding. Children who require less than 40cc/kg of blood seldom need surgery, whereas those who require more than 80cc/kg (*i.e.*, one blood volume) almost always need operation within 18 hours of admission. With this approach to isolated splenic injuries, we have preserved 75% of damaged spleens and have avoided laparotomy in almost 70% of children with proven splenic injuries.

The chance of delayed rupture of a subcapsular hematoma is rare in children, but when it occurs, there is unanimous opinion that laparotomy is mandatory.

At laparotomy for splenic bleeding, some of the spleen should be preserved because total splenectomy is harmful. The methods of preservation include: suturing, topical hemostasis, splenic artery ligation, partial resection, and autografting. Whatever method used, the remaining splenic tissue must have a normal blood supply.

There has been increasing pressure on surgeons to avoid the removal of any spleen (whether diseased, damaged, or normal) because of the strong possibility of overwhelming postsplenectomy infection, which has a 50% fatality rate. The organism most frequently isolated from such septic children is *Diplococcus pneumoniae*. Therefore, if splenectomy is carried out, specific immunization with associated long-term prophylactic antibiotic coverage might reduce the increased susceptibility to serious and fatal infection. Our hematology colleagues use Pneumovax vaccination and ampicillin or trimethaprim for children under 10 years of age, and penicillin for older children.

Not only has overwhelming postsplenectomy infection been noted in all clinical conditions whenever the spleen is absent, it has been noted in all ages, and it is not restricted to infancy or childhood. The suggestion has been made that the incidence of such sepsis in posttraumatic splenectomy is 50 times greater than occurs in the general population. Therefore, preservation of the damaged spleen should not be in formalin, but instead in the peritoneal cavity!

Liver Injury

Traumatic damage to the liver is the next most common cause of intraperitoneal hemorrhage. While the features are similar to those of splenic rupture, the risk of morbidity and mortality is greater. The spectrum of liver injury is wide. At the one end are the minor lacerations, which are of no clinical significance and which go unnoticed in a similar fashion to those of the spleen. Some children who come to laparotomy for other reasons are found to have minor liver lacerations often requiring no repair or, at best, simple suture closure.

At the other end of the spectrum is the less common massive liver injury in a case of multiple trauma that causes death at the scene of the accident. The lucky child makes it to the emergency department in shock. The liver (usually the right lobe) may be lacerated or pulped, and there is often tearing of the hepatic veins and inferior vena cava. There is usually not much doubt about such intra-abdominal bleeding. As with splenic trauma, overlying rib fractures seldom occur. The initial resuscitation, treatment, and investigation of such liver injuries is similar to that of spleen injuries, especially if time permits (Fig. 7-9). As with splenic damage, most liver injuries do *not* require operative repair.

In recent years, thanks to experience gained in the Vietnam war, a more knowledgeable and aggressive approach to liver trauma has improved the results of treatment. However, this has been tempered by the realization that a less radical surgical approach produces less morbidity and mortality than extensive liver resection.

The indications for laparotomy are the same as those for rupture of the spleen. When bleeding is rapid, establish several large-bore intravenous routes with pumps in the arms. Order blood equal to twice the patient's blood volume. Take the child to the

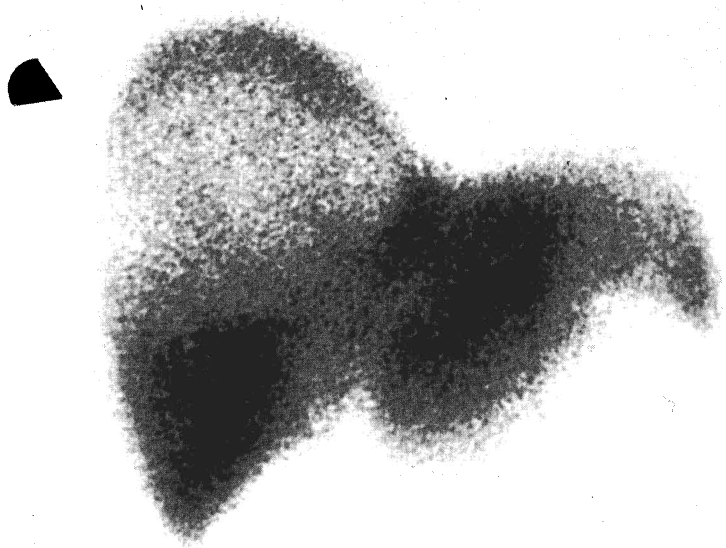


Fig. 7-9. Liver scan. Radioisotope study showing large defect in right liver lobe, which at laparotomy for continued bleeding was ruptured subcapsular hematoma. (Courtesy of Dr. Judy Ash)

Operating Room. There will seldom be time for any investigations. When the abdomen is opened, the blood pressure may plummet to zero as the tamponading effect of the intraperitoneal blood is lost. In such hectic and potentially disastrous situations, autotransfusion (and even bypass) can be lifesaving. The pressure remains very low until hemorrhage is controlled. Many children are lost at this stage because of bleeding from hepatic veins that have been torn from the inferior vena cava. Repair or ligature these severed vessels, if possible; it is usually easier said than done. Remove transsected devascularized liver; plug lacerations and liver defects with pedicled omental grafts, and close with large catgut sutures. Leave smaller liver lacerations, especially if not bleeding.

The postoperative course may be long and stormy compared with a severe splenic injury. The child may be jaundiced for a week or two, and chemical indices of liver function may take several weeks to return to normal. Meanwhile, the patient will require extra sugar, proteins, fresh frozen plasma, and vitamin K_1. Infection and bleeding from the operative site are matters of concern. Infection is most often due to associated bowel injuries, which give rise to subphrenic and subhepatic abscesses. On the optimistic side, the liver will regenerate a new lobe in 3 to 6 months; regeneration can be followed by liver scans.

Traumatic hemobilia is due to a fistula between the biliary and vascular systems of the liver, the result of a central contusion that had not required exploration. Bleeding occurs 4 to 6 weeks after injury. The child is often home and appears to have recovered from the abdominal injury when suddenly he has biliary colic accompanied by severe upper gastrointestinal hemorrhage. Hepatic angiography (Fig. 7-10) will show the lesion, which is best treated by selective hepatic artery embolization, by ligation, or, failing this, by lobectomy.

Retroperitoneal Hemorrhage

In many cases of blunt abdominal trauma there is some degree of retroperitoneal hemorrhage, but this is usually of no clinical significance. It is helpful if retroperitoneal hemorrhage can be distinguished from intraperitoneal hemorrhage, because the former tends to tamponade to a halt luckily, and because it does not lend itself so readily to operative correction. Retroperitoneal hemorrhage owing to renal, spinal, and pelvic injuries can often be recognized on abdominal radiographs, intravenous pyelography (IVP), ultrasonography (Fig. 7-11), and CT scan (Fig. 7-12). The problem of retroperitoneal bleeding with renal trauma is at times perplexing. Suspect trauma to the left kidney when the spleen is damaged (and vice versa) and suspect trauma to the right kid-

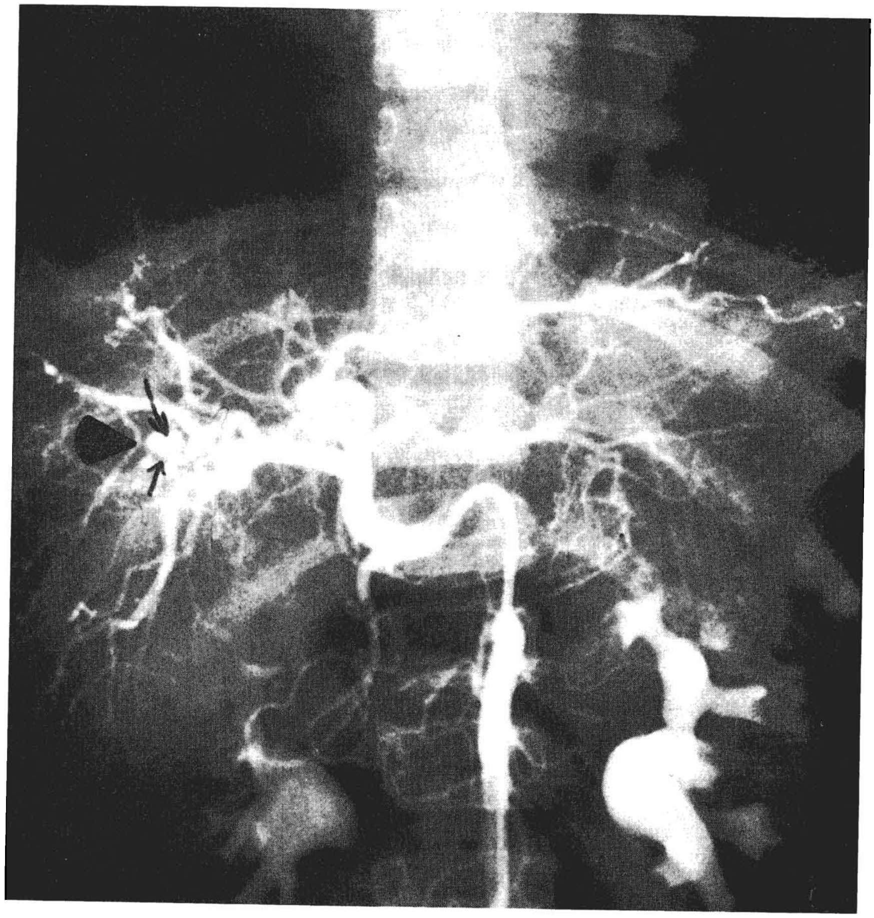


Fig. 7-10. Traumatic hemobilia lesion seen on hepatic angiogram.

Fig. 7-11. Retroperitoneal hematoma seen by longitudinal ultrasonography. (Courtesy of Dr. David Martin)

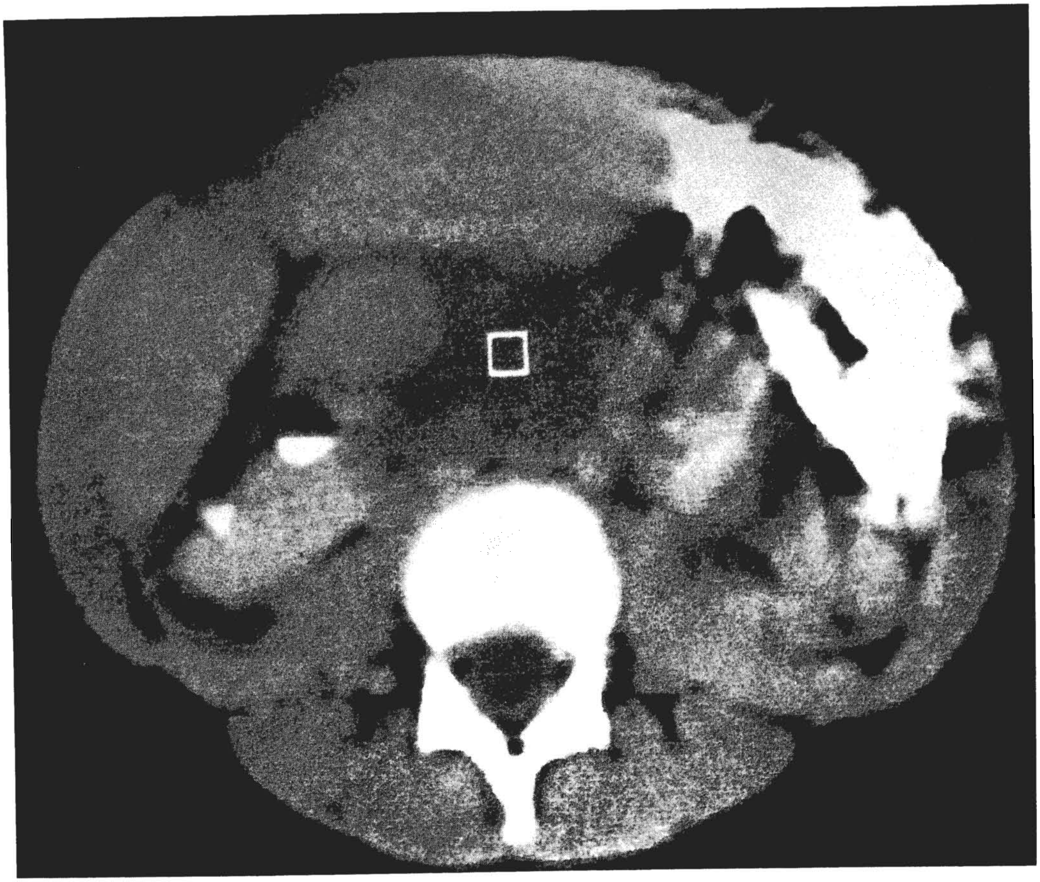


Fig. 7-12. Retroperitoneal hematoma seen by transverse CT scan. (Courtesy of Dr. Alan Daneman)

ney when the liver is damaged. Even when IVP shows one kidney functioning and the other without function, there is still no necessity to explore the kidney unless angiography shows vascular damage (Fig. 7-13). Apart from vascular injury, salvage of the otherwise damaged kidney is seldom possible; function may be temporarily suppressed, only to return again when the hematoma resorbs.

Minor degrees of retroperitoneal hemorrhage produce ileus, and are best managed by nasogastric suction and intravenous fluids for a few days until bowel function returns. The problems arise when hemorrhage is continuing or massive. Left alone, tamponade arrests bleeding by allowing small vessels and plexuses within muscle and bone to clot. This may take several days and several transfusions. The hematoma produces a grossly distended abdomen, prolonged ileus and duodenal obstruction. Time, nasogastric suction, and hyperalimentation will see this situation successfully resolved. Transient prehepatic jaundice may accompany resorption of the large hematoma. The duodenal and renal obstructions usually subside.

Avoid operation. Occasionally continuing retroperitoneal bleeding may masquerade as an intraperitoneal injury and force the surgeon to operate. Only then is the retroperitoneal hematoma discovered. It may be massive and may extend throughout the entire retroperitoneal area. The bleeding is usually from inaccessible torn lumbar and pelvic vessels, and for this reason most surgeons prefer *not* to disturb this enclosed space. To open such a massive hematoma leads to a very difficult situation, because brisk bleeding (usually venous) comes from multiple sites that

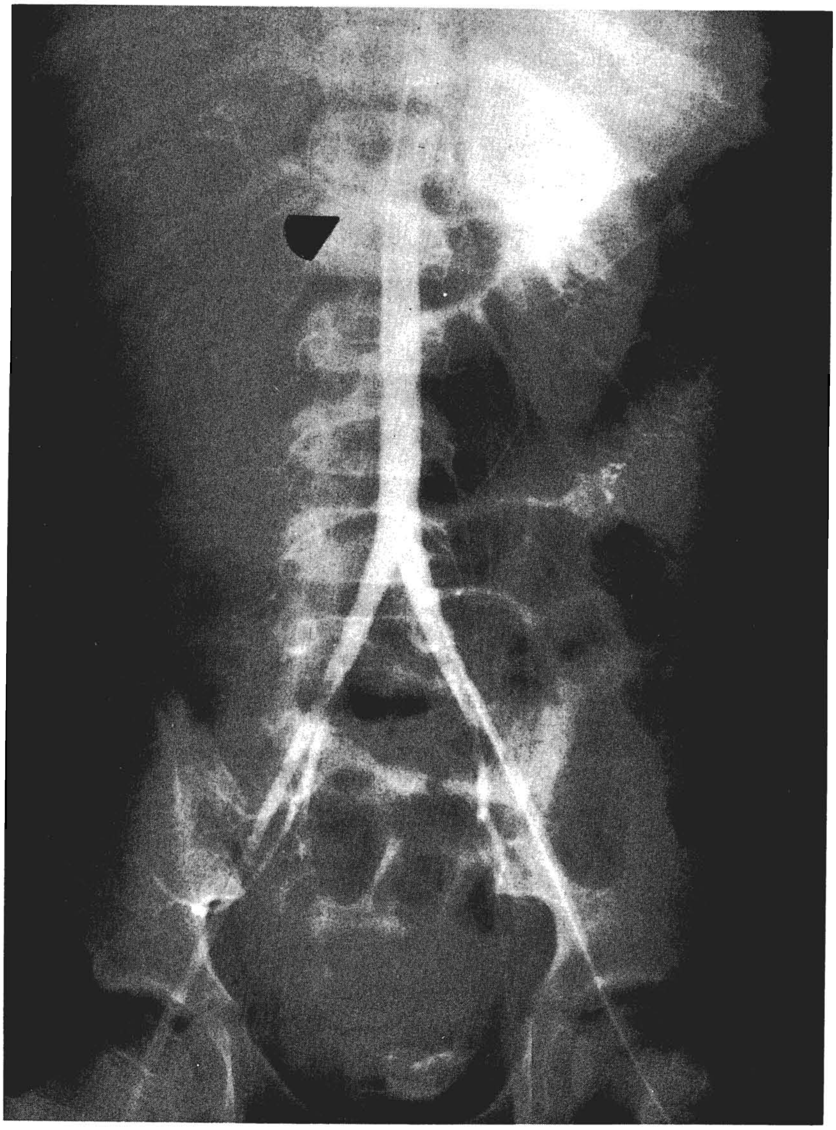


Fig. 7-13. Right renal artery injury seen by angiography after IVP showed nonfunctioning kidney after trauma. (Courtesy of Dr. William Holland)

cannot be identified and cannot be controlled. The only solution is to pack the area and hope that this will stem the tide. Therefore, the exploration should be considered only when there is the suspicion of a large laceration of the inferior vena cava causing the abdomen to fill before the surgeon's eyes. Venography may help to confirm this. When the peritoneum and retroperitoneum are opened, massive hemorrhage and shock will follow, so one must have plenty of blood available. Unfortunately, whatever is done is often fruitless.

Fractured Pelvis

While this injury may be an orthopaedic problem, it falls within the realm of the general surgeon too; it may be best for the patient if both specialties collaborate for treatment. There is frequently retroperitoneal hematoma and urologic injury, because the force to fracture a child's pelvis is of some magnitude (usually a motor vehicle accident). The pelvis in the pediatric patient is less rigid than the adult's pelvic ring and provides less protection to the enclosed viscera.

We see a similar situation in the upper abdomen, where the flexible rib cage can bend and damage the underlying spleen, liver, and kidneys; similarly, the young pelvis can undergo distortion without fracture, allowing visceral damage.

Minor undisplaced pelvic fracture without associated injury is common. Urologic injury to the bladder and urethra should be sought. Retroperitoneal hemorrhage owing to this type of pelvic fracture is usually minimal, often showing up as a hematoma compressing the sides of the bladder—"the teardrop" bladder (Fig. 7-14). Blood coming from the meatus indicates a torn urethra, until otherwise proven, and requires urologic consultation and a carefully done cystourethrogram. The treatment is bed rest for 10 to 14 days and gradual return to full activity.

Severe pelvic damage will occasionally produce the most taxing of problems: contaminated, comminuted bony injuries and massive, degloving, soft-tissue injuries to the buttocks, perineum, and thighs. Rectal injuries must not be overlooked in such situations, and the perineum should be explored under general anesthesia if necessary. If rectal injuries are found, the area should be widely drained from below and defunctioned from above by a colostomy. Wide-spectrum antibiotic coverage in such situations is a must. Other intrapelvic and intra-abdom-

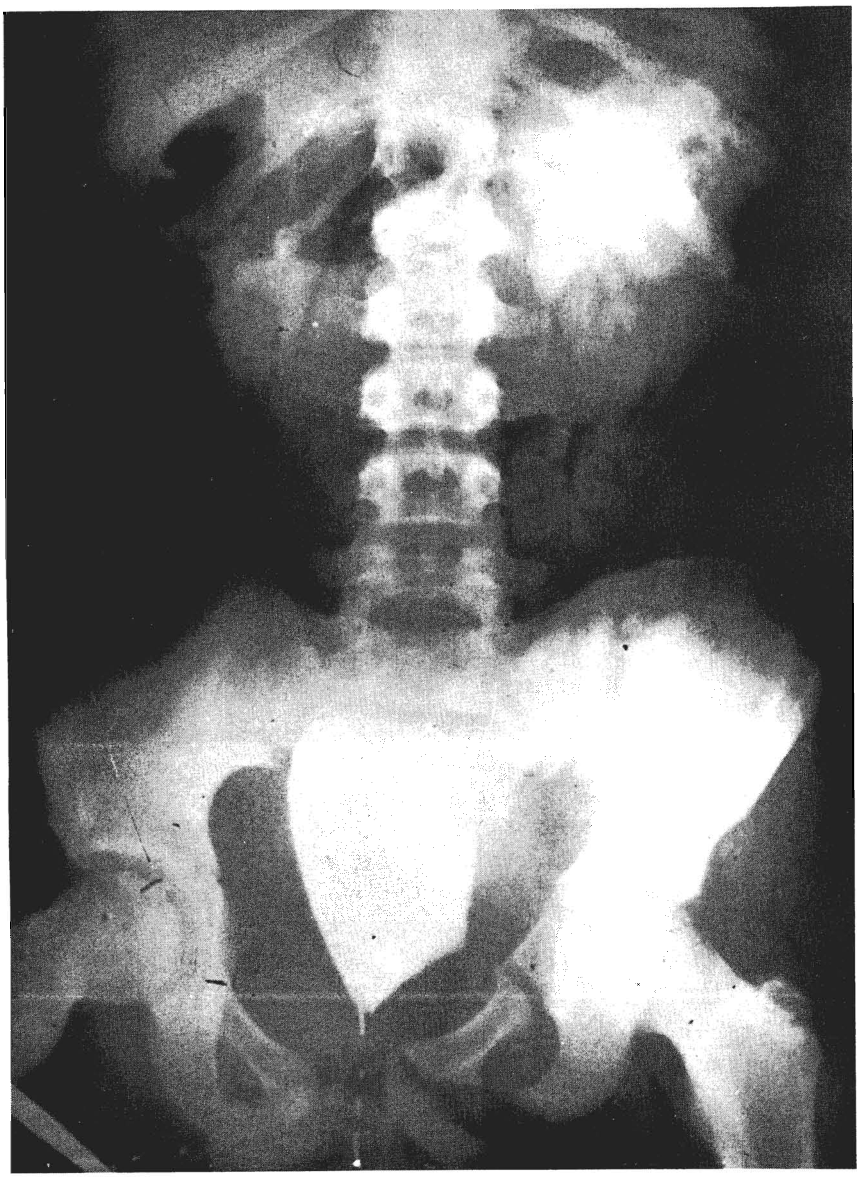


Fig. 7-14. Fractured pelvis with retroperitoneal hematoma compressing both sides of bladder (so-called teardrop bladder).

inal damage often accompanies the above injuries. The shock that accompanies such severe pelvic injuries is predominantly hemorrhagic rather than neurogenic, and immediate transfusion to overcome hypovolemia is essential. Septic shock from contamination is not unusual. Exploration for hemorrhage associated with pelvic fractures only arises in rare and desperate circumstances and only after the child has been transfused by an amount equal to the blood volume. Such children usually have extensive surface and soft-tissue wounds, and severe disruption of at least one sacroiliac joint with frequent loss of femoral pulse and possibly sciatic nerve function. These latter findings demonstrate the vulnerability of such major vessels and nerves as they pass over the sacroiliac joint. Plastic, orthopedic, and cardiovascular surgeons may have to work together to save such a precarious situation.

Bowel Injuries

The bowel injury that requires attention is a perforation. Small bowel perforations usually occur near fixed attachments (the ligament of Treitz and the ileocecal valve), although a distended stomach or colon may rupture. The abdomen becomes tender and distended with decreased bowel sounds. As time quickly passes, signs of peritonitis will appear. In the unconscious patient there is a special need to look for these signs in order to make an early diagnosis. Fever, leukocytosis, and free intraperitoneal gas on upright or lateral decubitus radiographs are usually present (Fig. 7-15). The immediate treatment is the same as in all serious abdominal injuries: nasogastric tube, intravenous fluids, transfusion, and wide-spectrum antibiotics, especially against the anaerobes. At laparotomy, every inch of the bowel should be examined for injury to it and to the mesentery. Injuries cannot be felt, they must be seen. There may be more than one injury. Damaged small bowel should be treated by resection and anastomosis. Perforated colon should either be exteriorized or repaired, drained, and defunctioned by a temporary proximal colostomy. Tears in the mesentery that require surgical intervention are rare; bleeding is the usual indication.

Although the advent of seat belts has markedly diminished the morbidity and mortality of car accidents, seat belts have produced their own crop of injuries. The American Medical Association and the American Academy of Pediatrics have strongly advocated "only those restraints which incorporate use of the adult seat belts already in the automobile" and "under no circumstances should children use the adult seat belt as their sole protection until their pelvic structures are sufficiently developed, usually at about 4½ or 5 years age."[2]

Despite the general acceptance of the seat belt as presently designed and the recognition of its value in accident prevention, its use has been involved in a characteristic injury pattern known as the "seat-belt syndrome." This group of injuries includes most typically avulsion of the small intestine, laceration of the intestinal mesentery, and bowel perforations. These injuries seem to result from the forcible impact between the abdominal wall and seat belt, which creates the tearing and rupturing of hollow viscera.

Injuries to Duodenum and Pancreas

Blunt abdominal trauma, especially bicycle-handlebar injuries to the mid and upper abdomen, are notorious for many intra-abdominal injuries, but one area that is often overlooked is the area in which the duodenum and pancreas are located. Injuries to this area are easily missed when laparotomy is undertaken for some more obvious injury. The lesser sac must always be opened and inspected. Both the duodenum and pancreas may be injured simultaneously. Upper abdominal bruising, pain, and guarding should raise the suspicion of injury. Regardless of which (or both) is injured, the immediate treatment is use of a nasogastric tube and an intravenous.

The duodenum may be ruptured or it may contain a subserosal hematoma. Order an upright radiograph of the abdomen for free intraperitoneal air or the "double bubble" appearance of duodenal obstruction. Next, introduce barium through the nasogastric tube to differentiate hematoma from rupture (Fig. 7-16). Extravasation indicates rupture, which requires immediate laparotomy and repair. A subserosal hematoma shows up as an intact but narrow duodenal "C" loop. A hemotoma can be surgically evacuated, or it can be treated nonoperatively with nasogastric suction. Nutrition is maintained by hyperalimentation or by a radiologically passed nasojejunal tube (Fig. 7-17) while the hematoma resorbs spontaneously during the course of a few weeks.

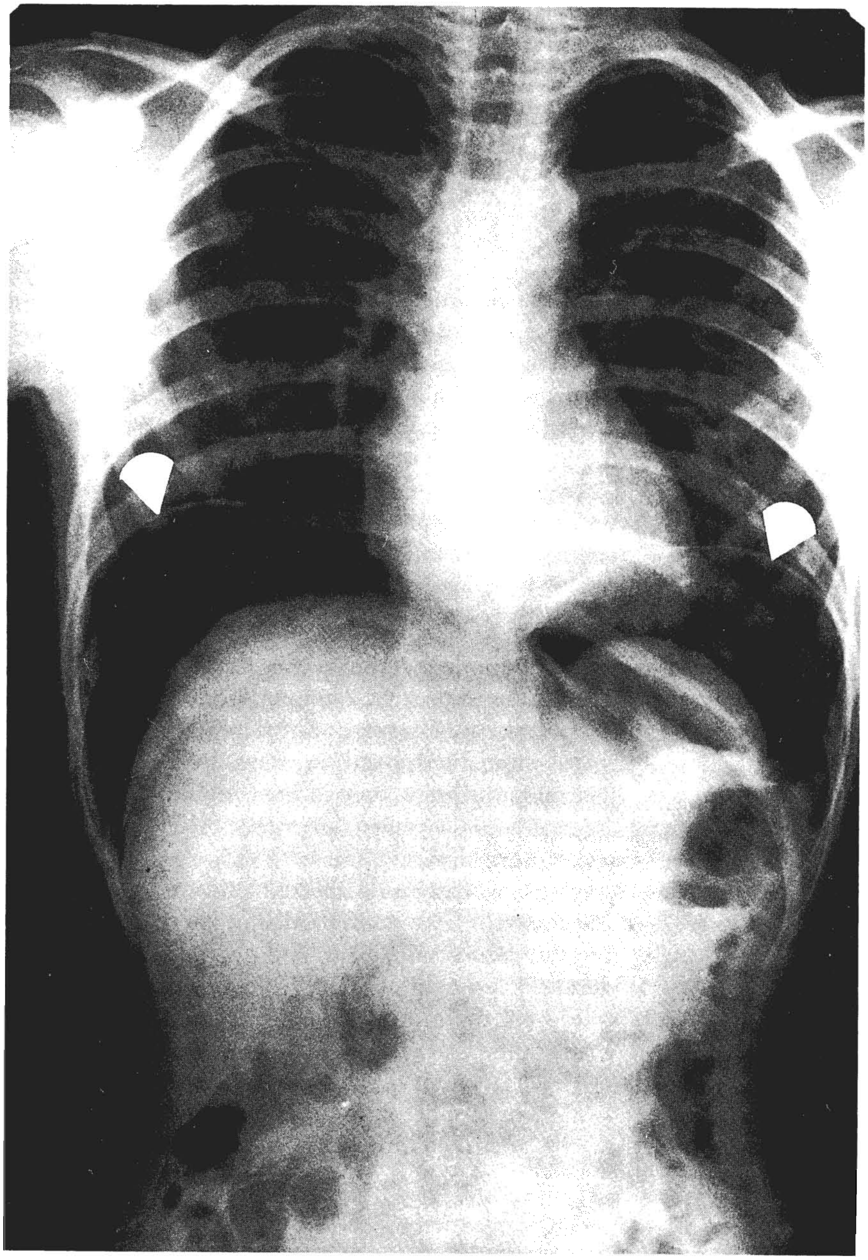


Fig. 7-15. Free air. Free intraperitoneal gas on upright radiograph of child with traumatic bowel perforation. (Courtesy of Dr. William Holland)

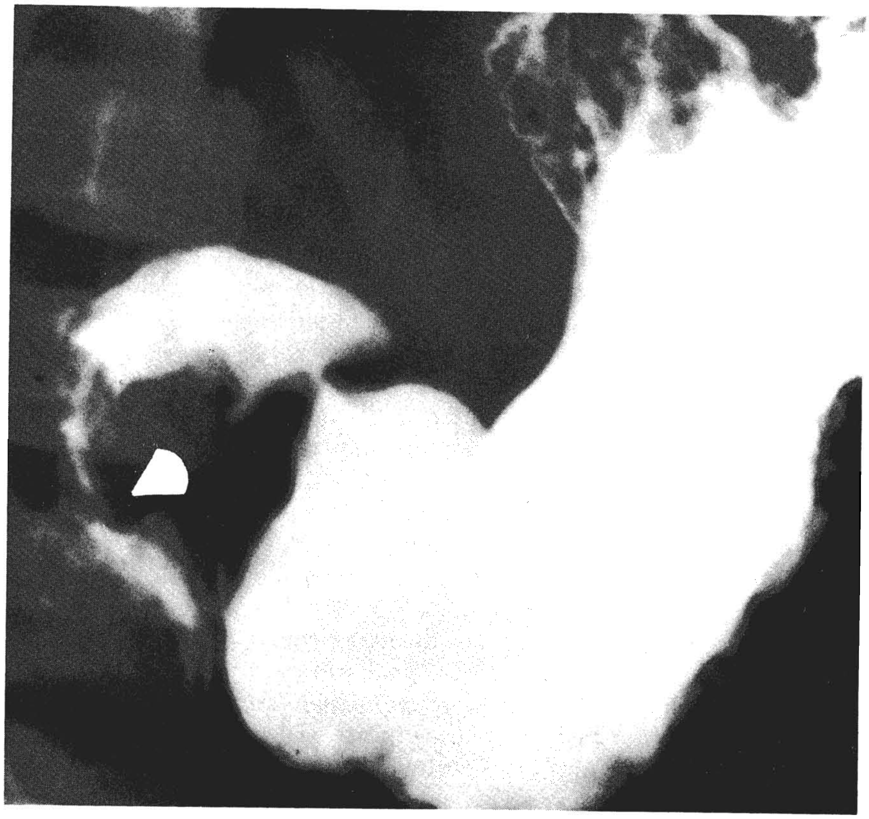
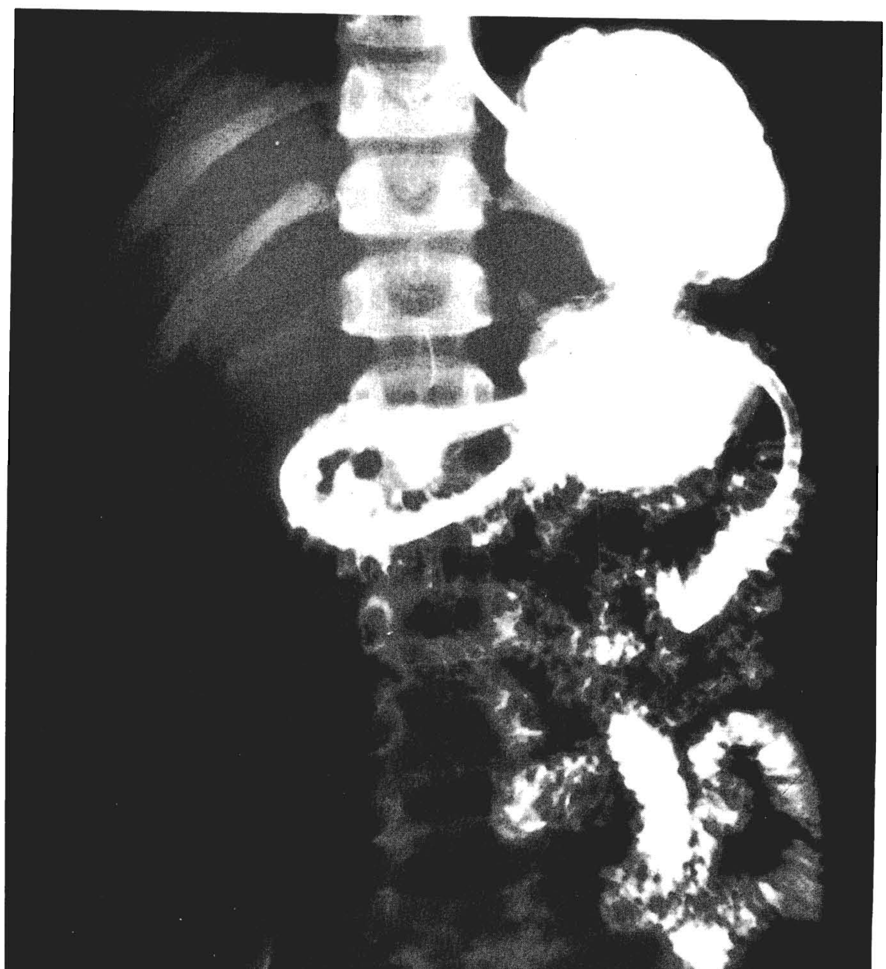


Fig. 7-16. Duodenal hematoma and rupture seen on emergency barium study. Extravasation indicates rupture, and subserosal hematoma shows up as narrow duodenal loop.

Fig. 7-17. Nasojejunal feeding tube passed radiologically and left in place until damaged duodenum or pancreas heals.



If pancreatic injury is suspected, order immediate and follow-up amylase determinations. Pancreatic injury will produce peritoneal signs (similar to those of duodenal rupture), which increase as enzymes leak out. It is very important to know whether the pancreas has been bruised or torn. When torn, the damaged distal half of the pancreas is best resected and the proximal pancreas, with its open duct, closed with nonabsorbable sutures, and the area drained. Ultrasonography and CT scan may differentiate the two. The management of mild injury is nonoperative with nasogastric suction and Cimetidine to decrease pancreatic stimulation. The management of major pancreatic injury is controversial if definite transection cannot be proven. A severely bruised pancreas is not the ideal area to explore, looking for a torn duct. The treatment is exactly the same as for the nonoperative treatment of a duodenal hematoma. All treatment should be continued until amylase determinations are normal. Some surgeons feel that an initial trial of nonoperative management is worthwhile. Healing sufficient to allow oral feeds may take several weeks. Those surgeons who favor immediate laparotomy feel that the morbidity is much less, but this is by no means a decided issue. However, remember that pancreatic exploration may not be easily done more than once. Regardless of the method of therapy, there is a real possibility of a pancreatic pseudocyst developing within a few weeks after the injury. A pseudocyst can be diagnosed and followed by barium studies, ultrasonography, (Fig. 7-18), and CT scan. The cystic mass may be enormous, causing marked abdominal distention with some symptoms of respiratory distress and intestinal obstruction. Internal drainage via cystogastrostomy or external drainage are the usual surgical procedures for this complication.

Penetrating Injury

Penetrating wounds (including stabbing and gunshot wounds) are quite uncommon in the pediatric age range, but the same general principles apply at any stage. The usual emergency resuscitative measures outlined above should be immediately instituted. There is no place for probing abdominal wounds in

Fig. 7-18. Pancreatic pseudocyst seen by transverse ultrasonography. (Courtesy of Dr. David Martin)

the emergency department, however innocent they may appear. If there are obvious signs of intraperitoneal hemorrhage or free air, laparotomy is mandatory, but opinions vary on the value of laparatomy when there is no sign that the peritoneum has been entered. Some surgeons inject a mixture of blue dye and contrast material through a rubber catheter inserted as far as possible into the stab wound and held in place with a purse-string suture; a lateral abdominal radiograph will show if the contrast material enters the peritoneum. This has been useful as a method of distinguishing patients requiring laparotomy from those requiring nothing more than debridement. It seems a reasonable alternative in stab wounds, but less so in gunshot injuries. Penetrating wounds are treated in most pediatric trauma centers by laparotomy and not by a wait-and-see policy.

At surgical exploration remember that bullets tend to ricochet. Examine every inch. Remember the possibility of abdominothoracic injuries. Every entry point must have a lodged bullet or exit site. Try to determine the course of the bullet as precisely as possible, using the appropriate radiographs and noting the entrance and exit points.

All penetrating trauma (especially gunshot wounds) carry in a gross amount of contamination; take great care to irrigate all areas. Start triple antibiotic therapy (ampicillin, clindamycin, and gentamicin) preoperatively. Give tetanus toxoid (1 ml) if the child has not received it within 5 years prior to injury. If gross contamination is present, use the same dose. If no such immunization had been carried out or if there is doubt, give the child 250 units (1 ml) of human immune globulin (Hyper-tet) intramuscularly.

Gastrointestinal Stress Bleeding and Perforation

Trauma of any kind to an infant or child is stressful. Stress ulcer is not unusual. Bleeding is much more common than perforation. Stress bleeding is common in children who have a severe head injury. In addition to the cerebral trauma causing a vagal disorder, these children are often on steroids to decrease cerebral edema, and aspirin for fever. It is felt that these three factors, as well as others (sympathetic stimulation and release of histamine), act upon gastrointestinal mucosa already somewhat ischemic from the hypovolemic shock suffered in the trauma. The subsequent focal necrosis of gastric or duodenal mucosa can result in bleeding (when normal blood volume is reestablished) or in perforation (if the intestinal wall necrosis is deep enough).

Upper gastrointestinal bleeding is manifest by tarry stools, nasogastric aspiration of blood, and falling hemoglobin. Most episodes of bleeding tend to be self-limiting with only local therapy and without operative treatment. Irrigate the stomach using a nasogastric tube with the antifibrinolytic agent. Aminocaproic acid (Amicar), 500 mg in 500 cc saline, is an excellent topical means of stopping the bleeding. Remove as much clot as possible through a large nasogastric tube, if possible. Stop steroids and aspirin. A histamine hydrogen ion antagonist (Cimetidine) is helpful, but it may have cerebral effects, so be cautious if a head injury is present. After the hourly nasogastric tube irrigations leave 30 cc of antacid in the stomach. Antacids are excellent and safe but must be given at least every 2 hours to be effective. Transfusions must maintain a hemoglobin level of 10 g. When the bleeding (which is from the duodenum or stomach, and from one or many superficial ulcerations) persists or increases, and when transfusions surpass the entire blood volume, consider surgical intervention to stop the bleeding. Gastroscopy may help with the diagnosis, but in the pediatric age range, a general anesthetic will be necessary. However, when gastroscopy shows a diffuse gastritis, further nonoperative therapy may be worthwhile. Prior to operation in an already ill child a trial of controlled hypotension with sedation may stop the bleeding. If surgery is required, the simplest operation to stop the bleeding is probably the best. Needless to say, all these modes of therapy require constant medical observation in the ICU. After the bleeding has stopped for 24 hours, remove the nasogastric tube or use it for feeding.

Perforation is less common than bleeding and usually occurs in the posterior wall of the proximal duodenum. It is often preceded by bleeding. Because these infants and children are already so sick, the only sign will be sudden abdominal distention. Plain abdominal radiographs will reveal free air. Operative closure of the perforation must also be simple and expedient.

Cimetidine and antacids can be used prophylactically and continued until the stress has passed. Monitor treatment by checking the gastric pH; keep it above 4 or 5.

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8 / Genitourinary Trauma in the Pediatric Orthopaedic Patient

Martin Barkin and J. F. Schillinger

Trauma is the most common cause of death in the pediatric age group (17/100,000). Major genitourinary trauma, however, is relatively rare. When it does occur, it is usually associated with multiple severe injuries or with a preexisting urinary tract abnormality. Death is more commonly due to nongenitourinary injury rather than to genitourinary injury *per se*.[8]

There are certain features of the child's urinary tract that distinguish it from its adult counterpart and result in somewhat different manifestations of injury.

1. The bladder tends to be intra-abdominal rather than intrapelvic, and therefore *intra*peritoneal extravasation of urine is slightly less rare in children than in adults.
2. The retroperitoneum is extremely thin, and severe injuries of the kidney may produce intraperitoneal extravasation of blood or urine that can make the diagnostic abdominal tap deceptive.
3. The vessels in the pediatric age group are more elastic, and vascular injury is more likely to produce intimal tear and thrombosis rather than pedicle avulsion.[5]
4. The elasticity of bone increases the incidence of greenstick fracture and decreases the incidence of sharp spicules producing secondary penetrating injuries.
5. Since congenital anomalies may be present, relatively minor trauma may be associated with signs, symptoms, and injury of an inordinantly severe nature. Fifteen percent of children presenting to an emergency department with signs of severe renal injury come after minor trauma associated with a preexisting congenital abnormality such as hydronephrosis or cystic disease.[7] Figure 8-1 demonstrates a copious blood clot collecting in the renal pelvis of a hydronephrotic kidney that ruptured after a fall from a tricycle.

INITIAL MANAGEMENT OF THE TRAUMATIZED CHILD

The first obligation of the casualty officer is the immediate assessment and correction of conditions that are immediately life-threatening, such as obstructed airway, massive hemorrhage, expanding hematoma of the central nervous system, sucking wounds of the chest, and tension pneumothorax. An adequate infusion should be placed into the circulatory system, and volume replacement should take place immediately, with guidance by central venous pressure monitoring.[3]

The subsequent discussion is confined to the genitourinary aspects of the patient's injuries.

PRESENTATION AND DIAGNOSIS OF GENITOURINARY INJURIES

Children with multiple injuries and those with fractures to the lower ribs or pelvis should be examined for genitourinary injuries, whether or not any of the other signs and symptoms listed below are present.

Hematuria

The presence of hematuria confirms the diagnosis of urinary tract injury, but neither the site nor the severity of the injury is proportional to the degree and intensity of hematuria. Note that intimal disruption with vascular occlusion may produce no hematuria, gross or microscopic.

Urethral Bleeding

Urethral bleeding is diagnostic of an injury below the vesical neck. The patient should not be asked to void, and a urethrogram should be made prior to attempts at catheterization.

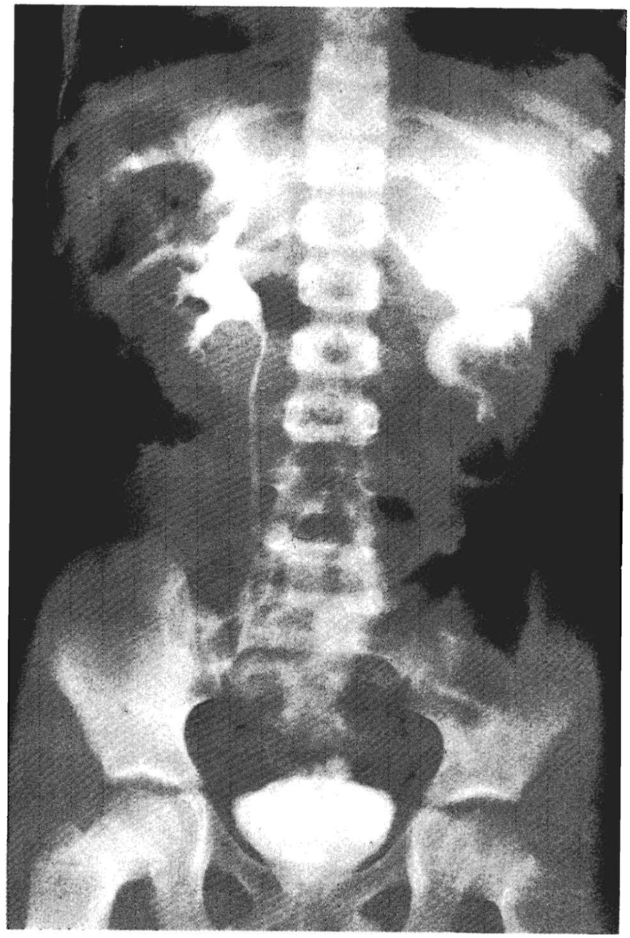
Extravasation in the Perineum

Either blood or urine may extravasate within the perineum, along the lines of attachment of Buck's or Colles' fascia. This is an indication of disruption of urinary tract continuity below the urogenital diaphragm and is similarly an indication for an early retrograde urethrogram.

Rectal Examination

A rectal examination may reveal the prostate to be displaced from its usual location or replaced by a soft pelvic hematoma. Either finding is clinical evidence of transection of the urethra above the perineal diaphragm. This also is an indication for retrograde urethrogram.

Fig. 8-1. Intravenous urogram of 8-year-old girl who fell from a tricycle. The left kidney is hydronephrotic owing to ureteropelvic junction obstruction. The filling defect in the lower pole is a blood clot secondary to renal injury.



Evidence of Severe Occult Bleeding

Injuries of the kidney and the renal vascular pedicle are suggested by increasingly refractory shock, increasing abdominal girth, and ecchymosis in the flank.

Pain

Pain, abdominal guarding, and splinting are unreliable signs of urinary tract injury and more often reflect the severity of trauma to overlying bones or muscles.

SPECIAL TECHNIQUES FOR UROLOGIC EVALUATION

In almost all cases of injury there is ample time for careful and complete evaluation of the urinary system.[4] An intravenous urogram is indicated in all cases where genitourinary injury is suspect, not only to help delineate the injury, but also to determine the structure and function of the contralateral renal unit. Prompt function and normal configuration on an intravenous urogram are sufficient criteria to indicate that a particular renal unit is capable of sustaining life. Bilateral nonfunction usually is due to poor renal perfusion secondary to hypovolemia. (Rarely it may be due to unilateral injury with contralateral absence or to bilateral severe injury.) The urogram should be done when the patient's circulatory status has stabilized. The high-dose infusion urogram will accurately delineate the severity of injury in 80% of cases.[6] The immediate "flush phase" may also indicate injury to solid viscera, such as liver and spleen.

While you await the delayed films, cystourethrograms should be done. If there is blood at the meatus, rectal or perineal hematoma, or extravasation, or if a catheter cannot be passed, a retrograde urethrogram is mandatory. Retrograde urethrogram is performed by placing a #8 Fr Foley catheter into the meatus. Gentle inflation of the ballon fixes the catheter in the fossa navicularis. Traction on the catheter while the patient is slightly oblique permits radiographs to be taken while injecting the medium. Dynamic retrograde urethrograms permit visualization of the entire posterior and anterior urethra.[2] Figure 8-2 is a retrograde urethrogram of a 9-year-old boy who sustained an anterior compression injury to his pelvis. Blood was present at his urethral meatus, and rectal examination revealed a dislodged prostate. Retrograde urethrogram demonstrates extravasation at the supramembranous urethra and indicates disruption at this level. Special studies, such as angiography and retrograde pyelography, may be indicated.

SPECIFIC INJURIES OF THE UPPER TRACT

The classification and radiologic signs of injury to the upper tract are summarized in Figure 8-3 and in Table 8-1. Most patients will respond to conservative management with bed rest. Monitor the physical signs, urinalyses, and urographic changes carefully and frequently.

Fig. 8-2. A retrograde urethrogram showing extravasation from the supramembranous urethra. Note also fractures of the pelvis.

Indications for Surgical Management

1. Massive unrelenting hematuria
2. Continuous hematuria
3. Increasing extravasation of urine (Fig. 8-4)
4. Fever
5. Expanding abdominal mass
6. Severe intra-abdominal hemorrhage
7. Retroperitoneal hemorrhage
8. Absent nephrogram with vascular occlusion confirmed by angiogram

Whenever surgery is carried out for renal injury the status of the contralateral kidney must be known, if necessary by intraoperative urography. If during the course of laparotomy a retroperitoneal hematoma is found, it should be left undisturbed, provided it is stable and not enlarging. Surgical treatment may consist of nephrectomy or renal salvaging procedures, such as suture and drainage, partial nephrectomy, or renovascular reconstruction. The late complications of renal injury are hypertension, hematuria, loss of renal function, chyluria, urinoma, obstruction, cyst formation, and calcification.

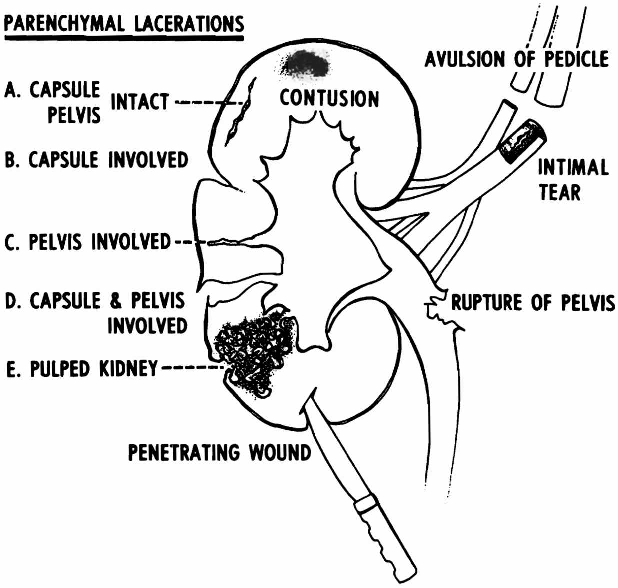


Fig. 8-3. Schematic representation of types of renal trauma.

Table 8-1. Classification of Renal Injuries Correlated with Clinical and Radiographic Findings

INJURY	CLINICAL FINDINGS	RADIOGRAPHIC FINDINGS
Contusion	Hematuria, gross or microscopic	Normal Slight delayed function
Laceration		
Subcapsular	Hematuria	Distention of renal outline Delayed function
Through capsule	Hematuria, flank tenderness, ± mass, signs of intraperitoneal hemorrhage	Loss of renal outline and psoas shadow Retroperitoneal mass, minimal dye extravasation, nephrogram phase present
Intrapelvic	May be all of above	As above plus more marked dye extravasation
Shattered kidney (total or polar)	All of above Shock	As above Nephrogram phase may be absent
Avulsion of Ureter	Hematuria, often expanding flank mass	Massive extravasation, prompt function
Pedicle Injuries		
Transection	Rapid death, severe shock Late post-traumatic collapse	No nephrogram (if live)
Intimal tears	Flank pain Asymptomatic loss of kidney	No nephrogram

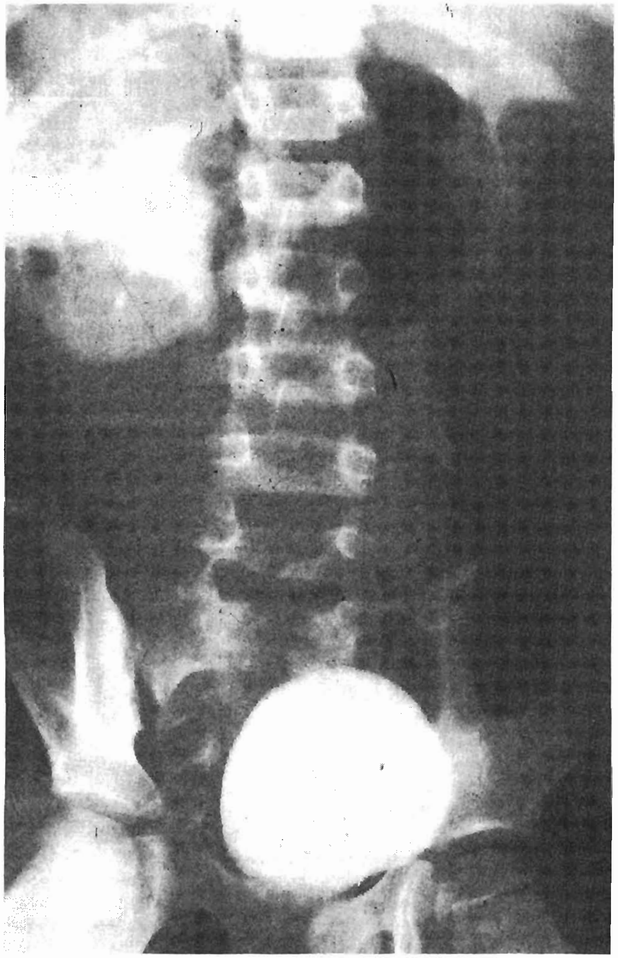


Fig. 8-4. Intravenous urogram of 8-year-old boy after blunt injury to right flank. Note extensive extravasation obscuring right renal outline.

URETERAL INJURIES

Injury to the ureter almost never occurs as a result of blunt trauma. Penetrating injuries and surgical procedures are the usual causes. Urinary extravasation confirmed by retrograde pyelography confirms the presence of this injury. Treatment is surgical reconstruction with adequate local and urinary drainage.

VESICAL AND URETHRAL INJURIES

Injury to the urethra and bladder are the most common urologic sequelae to blunt abdominal trauma. Vesical contusion is common and is of academic significance only. When a child sustains an injury severe enough to fracture his pelvis, there is a high probability of a surgically significant vesical injury.[8]

The cystogram will reveal the nature of the injury. Two thirds of vesical disruptions are retroperitoneal; only one third are intraperitoneal.

All injuries of the bladder accompanied by radiologically proven extravasation must be managed surgically. The peritoneal cavity is opened and explored. If the rupture has been *intraperitoneal,* the rent in the bladder should be repaired using two layers of absorbable sutures. If extraperitoneal, the laceration need be repaired only if easily accessible. In either instance the bladder should be drained suprapubically, and an adequate drain should be placed in the space of Retzius.

Disruption of the supramembranous urethra is the most serious urinary injury in this group. The high incidence of stricture (50%) and impotence (40%) have made its management controversial. At one extreme, some surgeons advocate complete mobilization and visualization of the affected area transpubically or perineally with direct suture repair and suprapubic urinary diversion. At the other extreme is an ultraconservative approach that avoids any surgery of the injured site and provides suprapubic drainage only.[1,6] This latter group of patients will for the most part later require two surgical procedures to treat their strictures. We recommend that urethral alignment be secured as atraumatically as possible, with a Foley urethral catheter under slight traction. Adequate suprapubic drainage should be provided to the bladder and space of Retzius.

The diagnosis and treatment of lower urethral injuries follows the same principles. Surgical intervention is always necessary when there is radiologic confirmation of extravasation.

Suprapubic diversion, direct suture repair, and adequate local drainage remain the mainstays of treatment. Late sequelae of lower-tract injury include stricture, infection, impotence, vesical dysfunction, incontinence, stone formation, abscess, and diverticula.

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9 / Craniocerebral Injury

E. Bruce Hendrick

The early diagnosis and possible complications of craniocerebral injury have been surrounded for many years with an aura of mysticism which, unfortunately, has led to unnecessary and irrational anxiety on the part of many physicians faced with the treatment of this injury. Because many children with limb fractures have head injuries, orthopaedic surgeons should know something about craniocerebral injuries, in particular; first aid; assessment; the indications for referral to a neurosurgical center; and the influence of a head injury on the treatment of a fractured limb.

EXAMINATION

The approach to a craniocerebral injury should be systematic and careful. Begin with a history, then go to a general assessment and examination of the cranium and the central nervous system.

History

A careful history obtained from relatives or witnesses to the accident will do much to determine the type of injury, when it occurred, how it occurred, and what the patient's immediate level of consciousness following the injury was. Find out if the level of consciousness decreased and whether or not there was a lucid interval.

General State

In the initial examination, the general state of the patient is much more important than any evidence of local intracranial damage. The use of the Abbreviated Injury Scale, developed by the American Association for Automotive Medicine in 1976, will quickly point out the injuries requiring immediate attention (Fig. 9-1).

The six "B" priorities—breathing, bleeding, brain, bowel, bladder, and bone—indicate the order in which attention must be paid to multisystem injuries. Airway patency and normal intergaseous exchange in the pulmonary system have a profound affect on cerebral blood flow, metabolism, and intracranial pressure. An obstructed airway not only carries with it the secondary pulmonary complications of atelectasis and infection, but it produces a gross abnormality in gaseous exchange so that the cerebral vascular system is perfused by arterial blood of high carbon dioxide content. This, in turn, increases cerebral blood flow, and causes cerebral edema and intracranial hypertension. In addition, the struggle against an obstructed airway raises intrathoracic pressure and, eventually, intracranial venous pressure.

The patient should be examined carefully for signs of tension pneumothorax, hemothorax, and aspiration. If bronchial toilet is required, bronchoscopy and endotracheal intubation should be carried out immediately in the emergency department.

Positioning of the patient can make the difference between life and death (Fig. 9-2). For transportation from the site of injury to the hospital and from the emergency department to the x-ray film department, and on the ward, the child should be in a semiprone position so that nasopharyngeal secretions may drain out rather than be aspirated.

If there can be one statement that should be repeated over and over again to a physician in charge of an emergency room or to people concerned with first

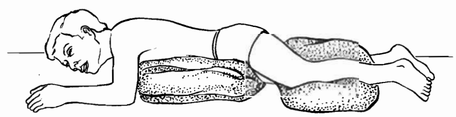
DESCRIPTION OF BODY REGIONS	
General:	Any body region, external or surface
Head:	Head, face, eye, ear
Neck:	Cervical spine, throat
Chest:	Thoracic organs, thoracic spine
Abdomen:	Abdominal/pelvic organs, lumbar spine
Pelvis:	Bony structures only
Extremities:	Upper and lower
SCALE CODE	
0	No injury
1	Minor
2	Moderate
3	Severe (not life-threatening)
4	Serious (life-threatening)
5	Critical (survival uncertain)
6	Maximum (currently untreatable)
7	Unknown

Fig. 9-1. Abbreviated injury scale.

Fig. 9-2. Brain injuries—emergency measures. All emergency rooms should have a chart such as this.

1 BREATHING
- ESTABLISH AIRWAY
- SUCTION
- ASSIST VENTILATION
- TREAT ASPIRATION

TRANSPORT SEMIPRONE



2 BLEEDING
- CONTROL VISIBLE HEMORRHAGE
- SECURE INTRAVENOUS ROUTE
- REPLACE BLOOD/FLUIDS

NOTE: DO NOT ATTRIBUTE SHOCK TO BRAIN INJURY

3 BRAIN

OBSERVE FOR
- DECREASING LEVEL OF CONSCIOUSNESS
- PUPILLARY INEQUALITY
- LIMB PARALYSIS
- COMPOUND BRAIN WOUND
- CHANGING VITAL SIGNS
  - PULSE ↓
  - BLOOD PRESSURE ↑
  - RESPIRATIONS IRREGULAR

OBTAIN EXPERT ADVICE WHEN THESE SIGNS ARE PRESENT

aid, it should be this simple statement: Hypotensive shock is never due to a head injury alone. The presence of shock indicates injury elsewhere; therefore, be scrupulous in examining the abdomen, chest, and extremities. Only in the head-injuried patient with failing vital centers, or in the patient with extensive scalp lacerations are the classic signs of shock detected. Occult hemorrhage within the chest, abdomen, or pelvis may cause profound hypovolemic shock, which is more lethal than a head injury and which certainly exacerbates the effects of the head injury.

Replacement of lost fluid by the intravenous route is mandatory. Because whole blood is more effective, it should be used if it is available and if it can be obtained in the necessary time. There is no truth in the rumor that fluid replacement is contraindicated in craniocerebral injury.

Cranial Examination

Only after the general examination has been carried out and first aid is instituted to improve the airway, restore blood pressure, and stop hemorrhage should detailed examination of the head be undertaken. Obvious fractures of the skull with laceration of the brain and extrusion of brain content on the surface need no comment. In patients with large masses of scalp hair, lacerations and depressions may go unnoticed unless careful palpation and examination of the whole head is carried out. Blood or spinal-fluid draining from the nose or the external auditory canal should be noted and taken as presumptive evidence of a fracture of the base of the skull in the anterior or middle fossa. To prevent the possibility of contamination of the intracranial content by bacteria from outside, a broad-spectrum antibiotic should be administered, in the same dosage used for meningitis, immediately upon admission to the hospital.

Examination of the Central Nervous System

The importance of the first examination of the central nervous system cannot be overemphasized because this examination assists in diagnosis and forms a base for judging subsequent progress. Much of the anxiety that often attends the treatment of a head injury in the acute stage stems from the fact that at the outset no accurate assessment was made of the patient's level of consciousness, and the presence of neurologic abnormalities was not noted. There are usually two reasons for this: the patient may be quite uncooperative and may not allow an ordinary neurologic examination, or the presence of other injuries may make examination difficult. Yet there are few cases in which it is not possible to record accurately the level of the patient's consciousness, the size and reaction of the pupils, the tone and power of the limbs on command or stimulation, the presence or absence of reflexes, and the state of the plantar responses.

A "mini-neurologic" examination will form the basis for decisions made later by a team of doctors and nurses who were not present in the emergency room. Therefore, technical language should be avoided in describing the conscious level of the patient and his reactions to the examination. A simple sentence on the patient's record stating that he is responding verbally to his name or simple commands, or indeed, that he responds briskly to pinprick in all four extremities by withdrawing, is of inestimable value to all who will subsequently participate in treatment. Such phrases as comatose, semicomatose, or semiconscious should be used only by poets. This cannot be overemphasized: The most important single factor to be observed on repeated examination and noted accurately on the chart is the patient's level of consciousness.

The use of a consistent measurement of the coma or the altered state of consciousness, which can be readily assessed and consistently charted as the care of the patient passes from one individual to another, is mandatory. Not only does this allow for changes in therapy and investigation, but also provides a mechanism for early and long-time prognosis. Experience with the "Glasgow Coma Scale" has proven it to be a most satisfactory measuring device that can be utilized by medical and paramedical personnel (Fig. 9-3).

Progression of the patient to a higher scale number is a sign of recovery. However, failure to improve or a shifting of the score to a lower number is a grave prognostic sign calling for immediate action. Because it is difficult to estimate the progress of a patient who has been unconscious throughout, the careful recording of other vital signs is invaluable. The patient's temperature, blood pressure, respiratory rate, and pupillary reactions should be charted at regular intervals together with coma scale numbering. Slowing and irregularity of the pulse, elevation of the blood pressure, changes in pupillary reactions to light, change in pupillary size, and loss of corneal reflexes may be the only signs of deterioration in the comatose individual.

Deterioration of the patient's condition immediately suggests that the intracranial problem is becoming more serious. On the other hand, one should not overlook the possibility of chest complications causing cerebral hypoxia, cerebral fat embolism, metabolic disorders, and shock from other injuries. The restless agitated state seen in many patients with head trauma is often related to a full bladder, a tight encircling bandage or cast, or cerebral hypoxia. Unless these factors are taken into account, the cause of deterioration may be erroneously interpreted as intercerebral, and fruitless intracranial procedures may be instituted.

BEST MOTOR RESPONSE		
	Obeys	6
	Localizes	5
	Withdraws	4
	Abnormal flexion	3
	Abnormal extension	2
	Nil	1
BEST VERBAL RESPONSE		
	Oriented	5
	Confused conversation	4
	Inappropriate words	3
	Incomprehensible sounds	2
	Nil	1
EYE OPENING		
	Spontaneous	4
	To speech	3
	To pain	2
	Nil	1

Fig. 9-3. Glasgow coma scale. (Jennett B, Bond M: Assessment of outcome after severe brain damage—a practical scale. Lancet 1:480–484, 1975)

Investigations

Usually the first thought of those called to see the head injury is that a radiographic examination of the skull must be carried out. This procedure has been greatly abused and, indeed, if the patient is showing signs of rapidly increased intracranial pressure or intracranial localization, radiographs will be of little value, will delay treatment, and will adversely influence the outcome to a significant degree. Depressed fractures of the skull do require radiography to allow the surgeon to determine the extent of the fracture and the depth to which the fractured fragments have penetrated. However, in subdural or extradural hematoma, or in acute cerebral edema, radiographs should be delayed until the primary problems have been resolved.

The development of the CT scan (computerized axial tomography) has revolutionized the ability to accurately diagnose intracranial mass lesions, such as hematomas, and to differentiate them from focal or diffuse traumatic cerebral edema. However, the equipment is beyond the budget of many institutions. It requires skilled operators and may not always be "on line" at the time required. It is a diagnostic aid and should not be substituted for clinical judgment in the treatment of the deteriorating head-injured patient.

Cerebral arteriography will help distinguish between surface and intracerebral hematomas and will aid localization. It does require time, and time may be a luxury that the patient's condition cannot afford.

The decision to procede with surgery is based on the clinical data and on the rate of deterioration of the patient, not on diagnostic aids! The simplest diagnostic procedure that comes to the mind of many doctors is a lumbar puncture. Lumbar puncture should never be carried out in the presence of an acute head injury. The rapid removal of fluid from the lumbar sac may produce a change in intracranial pressure relationships and subsequent coning or herniation of the cerebellar tonsils or the cerebral peduncles; either may be fatal. Lumbar punctures should be considered only when the patient develops an unexplained fever after a period of 2 or 3 days; that is, when meningitis is a possibility. The presence of blood in the spinal fluid is of no significance except as an indication that there has been bleeding into the subarachnoid or ventricular areas.

DIAGNOSIS

A few more words might be said at this point about the differentiation of extradural hemorrhage, subdural hemorrhage, and cerebral edema. In a review of several thousand head injuries it was my intention to differentiate these three. At the end of the review, it was found they could not be differentiated by the presenting features or by signs or symptoms.

The classic form of the extradural hemorrhage is consistent with a space-occupying lesion in the middle cranial fossa. The picture of an initial period of consciousness following injury with a subsequent time interval and then increasing stupor and coma is known. The triad of an ipsilateral dilated pupil, contralateral hemiparesis, and a linear fracture in the temporal parietal area would alert most physicians to impending disaster. Review of a large series of extradural hematomas showed that the classic picture occupied less than 10%. The most common features were deepening unconsciousness and a dilated pupil, necessarily on the side of the hematoma. In the series, a skull fracture was present in less than 15% of patients. The use of x-ray films, therefore, is clearly contraindicated in the deteriorating patient.

Posterior fossa extradural or subdural hematomas are rare. They present with changes in blood pressure, respiratory rate, or pulse rate. They do not tend to show lateralizing neurologic deficits. They do not progress as quickly as supratentorial clots. Radiography usually reveals a fracture crossing the transverse site and extending down to the foramen magnum.

Spinal Injuries

A word of warning about spinal injuries associated with head injuries. They are not common, but they occur. One should be alert to meningismus and to tenderness in the neck or spine. Flaccid paralysis of the lower extremities in a patient with a head injury should suggest a spinal-cord injury. Urinary retention may be a primary indication of injury to the spinal cord itself. These problems are easily missed because neurologic deficits are attributed to brain injury, but one should be always alert to a second neurologic problem. Sensory deficit to pinprick or absence of sweating beside the level of a spinal-cord lesion may be of some help in diagnosis.

TREATMENT

Treatment is determined by the urgency of the problem and by the facilities available. For example, a patient with obvious extradural hemorrhage cannot be transported. Minutes count. If a neurosurgeon is not immediately available, the surgeon on call should make burr holes. Children with severe head injuries who show no signs of deterioration can be transported to the regional neurosurgical unit. Be sure that they are transported semiprone with a good airway and are not suffering hypovolemic shock owing to visceral injury. If the patient is to be transferred, it should be done quickly and without delay.

If there is no evidence of increased intracranial pressure, an open depressed fracture, or progressive deterioration requiring urgent operative treatment, the patient should be admitted to the hospital and placed under close observation. Head-injury patients should be nursed in the semiprone position. While unconscious, they should be turned from side to side at 2-hour intervals. They should not be placed head down in traction for a lower-limb injury. Some other method of treatment should be used for the lower limb. Rectal temperatures should be recorded regularly, and pyrexia should be controlled by simple measures, such as alcohol sponging and, if necessary, hypothermic blankets. Sedatives are given only if there is evidence of epileptic activity.

In head injuries, cerebral edema is the problem of greatest concern. The use of hyperosmolar 20% mannitol simply buys time. It is not recommended, unless prior neurosurgical consultation has been obtained. If necessary, mannitol may be administered intravenously in doses of 1.5 g/kg to 2 g/kg over a period of 30 to 45 minutes. Be sure that cardiopulmonary function is adequate and that kidney function is intact. The use of mannitol commits the surgeon to another course of action, whether it is in the transfer of the patient from a primary care facility to a specialized unit or the preparation of the patient for immediate surgery.

Intravenous dexamethasone (14 mg initially and 4 mg every 6 hours intravenously or intramuscularly) is said to have some effect on cerebral edema, but the results are not dramatic.

After intracerebral hematoma has been excluded by scan or surgery, cerebral edema may continue to be the only cause of continuing deterioration. Newer techniques utilizing controlled ventilation, barbiturate coma, and hypothermia are of value but require a specially trained team plus the use of constant intracranial pressure monitoring. The risks in these techniques are many and the application should take place in an intensive care unit with major neurosurgical and laboratory facilities at hand.

Operative Treatment

There are only two indications for immediate surgical intervention in head injuries: (1) an open penetrating wound and (2) burr-hole exploration for extradural or subdural clot in patients who have clearly displayed severe and rapid deterioration or neurologic function. This deterioration is usually manifest by a decreasing level of consciousness, a dilating pupil (usually on the side of the suspected clot), and progressive paralysis of limbs on the opposite side. A burr hole will confirm the diagnosis and permit removal of surface hematoma from the extradural and subdural space. The first burr hole is made in the temporal region on the side of the enlarged pupil. The skin incision runs upward to 2 inches from the zygoma, a finger's breadth in front of the ear, and will bring one on to the fleshy belly of the temporalis muscle. The temporal artery itself will be either seen or divided. After temporal artery bleeding is controlled, the temporalis muscle is incised vertically in the same direction as the skin wound, and the muscle fibers are removed from the surface of the skull. With a perforator and burr, a hole is made in the center of the exposure and enlarged by means of rongeurs. If an epidural clot is present, it will be immediately apparent. The skull defect may be enlarged, the clot removed, and the bleeding point identified and coagulated. Do not worry about blood loss; the major concern is death from brain compression. Always make the initial burr hole in the temporal fossa, because the most common source of bleeding in an extradural hematoma is the middle meningeal artery. Although hematomas derived from large venous sinuses have been reported and have been seen by this author, the middle meningeal artery or its branches have been responsible in 80% of cases.

When no extradural hemorrhage is found, the dura should be incised in a cruciate fashion and the subdural space opened to exclude subdural hematoma. If the temporal burr hole reveals no evidence of subdural hematoma, then two more burr holes should be made, one in the posterior frontal area just ½ to 2 inches lateral to the midline and the other 2 inches lateral to the midline in the posterior parietal area. The dura should be opened again to exclude subdural hematoma. Burr holes must be placed bilaterally, because subdural hematomas occur on both sides in more than 50% of head-injury patients. Simple evacuation of the subdural hematoma by suction and irrigation with warm, normal saline solution produces significant improvement.

Treatment of closed depressed fractures of the skull that are not producing a gross neurologic deficit can be safely delayed. An extensive open fracture should be treated by debridement and closure of the scalp wound, followed by transfer of the patient to a neurosurgical facility. Removal of the bone fragments and closure of the scalp is all that is necessary as immediate treatment. Definitive repair of the dura and repair of the skull with cranioplasty can be carried out later.

OTHER PROBLEMS

Unconscious patients require a great deal of care; an experienced team is needed to stay ahead of problems.

Fluid and Electrolyte Problems

Many patients with severe head injury present nutritional and metabolic problems. Use intravenous replacement (in the form of a solution of two thirds dextrose and one third normal saline) for the first 24 to 36 hours after admission to the hospital. Then begin feeding the patient through a nasogastric tube, using a gastric-one diet and an antacid to reduce the real risk of acute gastric hemorrhage. Vitamin supplements are necessary. A fatty diet may cause diarrhea; the problem can usually be relieved by substituting a more dilute solution containing Kaopectate, administered by gastric tube.

Daily determinations of serum proteins, blood glucose, and electrolytes are invaluable in judging what is required to correct the various metabolic disorders as they arise. One of the most common disturbances, water deprivation, usually occurs because of the doctor's reluctance to begin artificial feeding in the unconscious patient. He hopes that the patient will soon regain consciousness and be able to swallow spontaneously. Water deprivation can also be due to increased fluid loss, hyperpyrexia, and unrecognized diabetes insipidus in severe midbrain injury, although this is a very rare phenomenon. Routine dehydration for head injuries, recommended in many early texts, has proven to be an unnecessary and potentially dangerous procedure. It may lead to worsening of the patient's condition and to deterioration of his level of consciousness.

Diabetes insipidus can follow hypothalamic damage. The common time of onset appears to be about the tenth day, because there is usually sufficient antidiuretic hormone to prevent the syndrome from appearing earlier. The condition can be detected from the urinary output and specific gravity. In most individuals, the diabetes is mild and can be treated by increased fluid intake. In the more severe cases, injections of Pitressin* may be necessary. Diabetes mellitus is rarely due to head injury, but patients with head trauma often show transient glycosuria. In recent years, disorders to chloride metabolism have been recognized: (1) inability to secrete chloride results in hyperchloremia and hypochloruria and (2) excessive loss of chloride produces hyperchloruria. A high mortality attends these disorders if the imbalance is not corrected; adequate laboratory investigation and appropriate replacement therapy should eliminate these problems.

Chest Problems

Problems may arise from chest injuries, such as pulmonary fat embolism, atelectasis, and pneumonia.

Pulmonary fat embolism is particularly likely in a patient with associated limb fractures, and accounts for a proportion of cases diagnosed as hypostatic bronchopneumonia following head trauma. Acute pulmonary edema may be produced as the result of brain-stem compression.

Bronchopneumonia in the unconscious patient is always a problem, but it can be treated with endotracheal bronchial toilet and antibiotics. Tracheostomy may be a life-saving procedure, particularly in the patient who has suffered damage to the thoracic cage or who has a respiratory infection. Tracheostomy should be considered for three groups of patients: (1) those in whom it is quickly apparent that unconsciousness is profound and will last for more than 48 hours; (2) patients with other injuries affecting the airway, such as jaw or chest fractures; and (3) patients who cannot lie semiprone because of spinal injuries.

*More recently, DDAVP (Minirin) has been used instead of Pitressin.

Limb Fractures

Patients with cerebral injury should not be placed head down. This will aggravate cerebral edema and bleeding, and should be avoided if at all possible. Fractures of the femur can be left flat in a Thomas splint for a day or two if a rapid recovery can be expected. Alternatively, 90–90 traction should be used. Fractures of the shaft of the humerus frequently require traction. When the child is very restless and seems likely to continue so, internal fixation of fractures of long bones may be advisable.

PROGNOSIS

Orthopaedic surgeons should not give laissez-faire treatment to deeply unconscious children. The prognosis for survival and function is much better in children than in adults. The same standards of fracture care should be observed as in children who have no head injury.

Summary

Treatment of closed head injuries may be summarized under four main headings:

Maintain a clear airway at all times in unconscious patients. Patients who are unconscious should be placed in a semiprone position. In the presence of excessive nasopharyngeal secretions, a nasal airway is necessary with suction available at all times. When prolonged coma, tracheostomy should be considered.

Chart pulse, respirations, and blood pressure at 15- and 30-minute intervals after admission to the emergency room. Intervals for charting the vital signs may be lengthened as soon as the patient remains stable for 6 to 12 hours, providing the depth of consciousness has not deteriorated.

Regularly observe:

1. State of consciousness
2. Size and reactivity of pupils
3. Activity of deep tendon reflexes
4. Character of respirations

Watch for these signs, which carry grave prognostic significance:

1. Temperature over 39.4°C (101°F)
2. Irregular periodic respirations
3. Pupillary abnormalities

4. Paralysis of the extremities
5. Decreasing level of consciousness

At times it is difficult to decide who should be admitted to the hospital and who should not. As a standard rule, all individuals with a history of head trauma who have had an episode of unconsciousness or who are unconscious should be admitted. Individuals who have altered personality or who show neurologic deficit on examination should be admitted for observation.

The treatment of a head injury is similar to that of any other injury or acute illness. Proper examination, observation, and correlation of the changing factors or signs and proper application of treatment in response to the dynamic changes provide the essentials of care. The treatment of the patient with head injury and multiple trauma may call for compromise, but, with the exception of hemorrhage, the head injury should be treated first, because it may be fatal. However, one should not unnecessarily delay treating other injuries on the grounds that the patient has sustained a head trauma. Treatment of the head injury becomes, as time passes, more and more of a team effort involving not only the orthopaedic surgeon and neurosurgeon but the specialist in pulmonary physiology and the intensive care staff.

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10/ Clavicle

Sir Robert Peel, Prime Minister of Britain in 1834, would have been among the first to agree that the clavicle is a badly designed bone. In 1850, he died after falling from his horse on Constitution Hill, having sustained a fracture of the clavicle, which probably penetrated the subclavian vessels. The double curve of the clavicle is a poor mechanical shape, adequate perhaps in arboreal animals and quadrupeds, but definitely a point of weakness in the young male biped. The double curve can produce a very good imitation of a clavicular fracture on some radiographic projections. About half the fractures of the clavicle occur in children under the age of 10 years. In children, the clavicle is the most frequently broken bone. Injuries may occur at three sites.

SHAFT FRACTURES

Fractures of the shaft (usually the midshaft) are most common, being greenstick or complete fractures (Figs. 10-1, 10-2). Fractures unite quickly, though almost invariably with malunion. Remodeling in the course of the year is complete. Despite the proximity of pleura, skin, brachial plexus, and brachial vessels, complications are almost unknown, unless open reduction is attempted. The only complication recorded in children is subclavian vein compression owing to greenstick fracture with an inferior bow. The veins of the arm become congested, and edema forms. Put the child to bed to reduce compression. Alternatively, reduce the fracture, and apply a shoulder spica when this complication is present.

As in most simple injuries, half the treatment consists of programming parents in what to expect and half consists of treating the child. A figure-of-eight bandage works well. Stuff a length of stockinette with a rolled-up length of Gamgee or *ABD* pad. Have the child sit down and hold the arms in the position of surrender (Fig. 10-3). Tie it tightly in this position, and have mother tighten the bandage occasionally over the next few days. Do not have it so tight that axillary sores are produced; there is no sense in striving for anatomic reduction. The bandage is intended to provide comfort and prevent further displacement, not to reduce the fracture. The parents should be instructed not to pull the child's arm and to lift him without yanking the shoulder. To put on an undershirt, the injured arm should be threaded through first, followed by the head and then the good arm. Three weeks' of bandaging, followed by 3 weeks' abstention from contact sports seem to be sufficient treatment. I never take a follow-up radiograph because it just confuses me and does not help

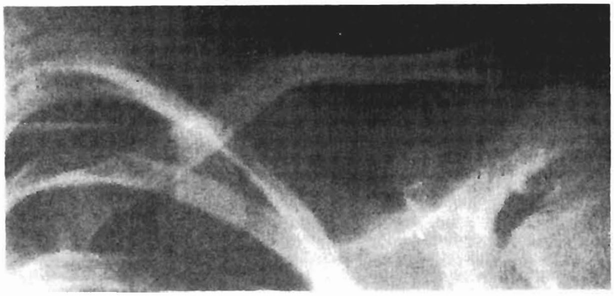


Fig. 10-1. Greenstick fractures are easily missed in infants who present because they do not move the arm. There may be no physical signs to focus the doctor's attention on the clavicle. In this girl, aged 3 years, the diagnosis was missed at first when the displacement was less than it is here.

Fig. 10-2. Incomplete fractures may require two or three views to establish the diagnosis.

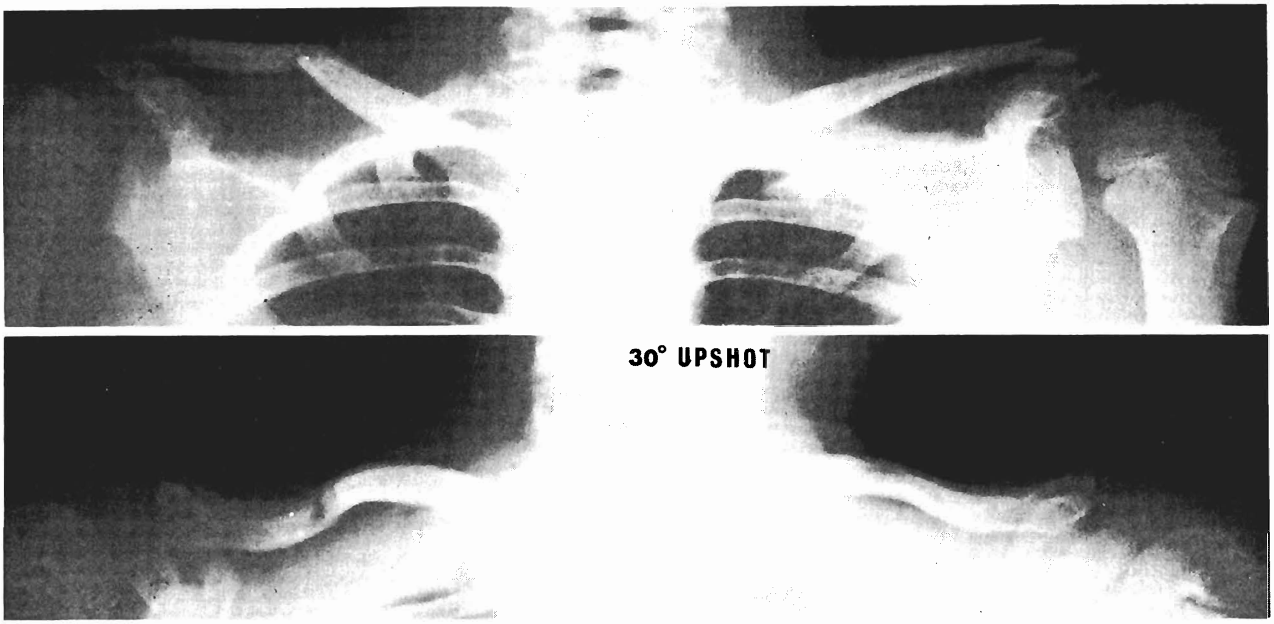
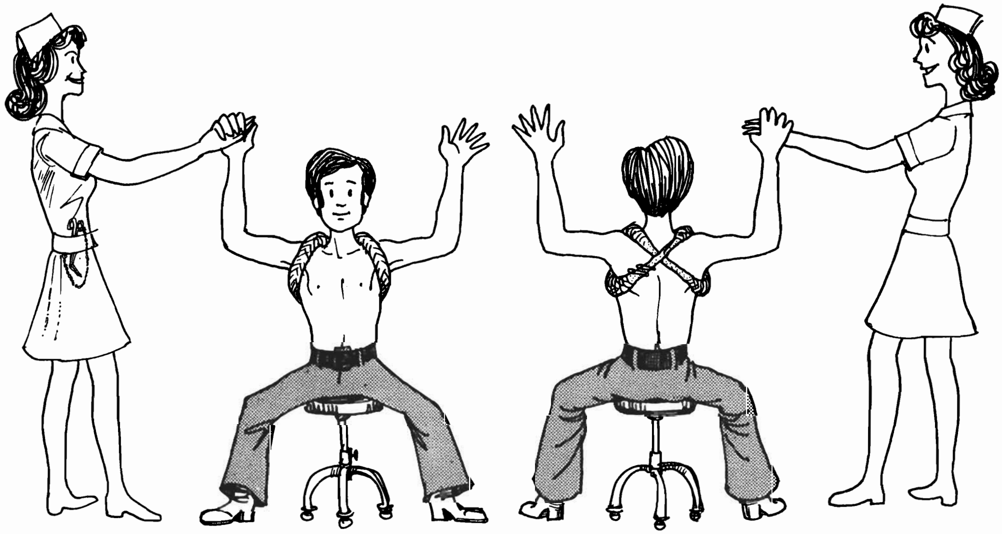


Fig. 10-3. Perhaps the easiest way to apply a snug figure-of-eight bandage without tears.



with making a decision. The bandage is for comfort, not for union. Prepare the parents to expect a large lump at the site of the fracture for about a year. If you tell them it is healing bone, rather like a plumber's joint, they will be happy.

Internal fixation has no place in this injury. It will only produce a bad scar, interfere with union, and provide a point of entry for infection. The only pseudarthroses of the clavicle that I have encountered are the result of internal fixation or are congenital in origin (Fig. 10-4).

MEDIAL END

The medial end of the clavicle has an epiphysis that forms a center of ossification about the age of 18 and that fuses at 25. Epiphyseal separation, usually regarded as a child's injury, can occur here in adults. Though rare, this injury mimics a sternoclavicular dislocation, which occurs only in the skeletally mature. Separation of the medial end of the clavicle is difficult to diagnose. Pain and swelling in the region of the sternoclavicular joint is obvious to all, but many are put off the diagnosis by a normal anteroposterior radiograph of the clavicle. Ask for a Rockwood view—a 45-degree upshot view, which will allow you to compare the position of the injured and uninjured joints. It is easier and better than tomography (Fig. 10-5). However, the unossified epiphysis of the child will not show. The diagnosis will not leave you in doubt if you remember that epiphyseal separations are invariably the cause before the age of 18 and that dislocations are invariably the cause after the age of 25.

Anterior Displacement. There is forward prominence of the clavicle.

Posterior Displacement. Compression of the trachea may produce dyspnea.

Although it is said that closed reduction can be obtained by traction, in my experience the reduction cannot be maintained. Internal fixation is required. At operation, the joint and its meniscus are intact, but the periosteum over the medial end of the clavicle is torn. Simurda drills a hole in the medial end of the clavicular shaft and sutures the epiphysis in place with a strong suture.[1] The periosteum is repaired, and the sternomastoid is sutured over the repair. I have used a transarticular Kirschner wire (with a hook on one end to prevent migration) to fortify the periosteal suture. The results in terms of reduction are satisfactory, but the scar is ugly.

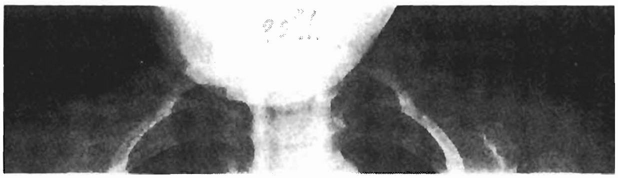
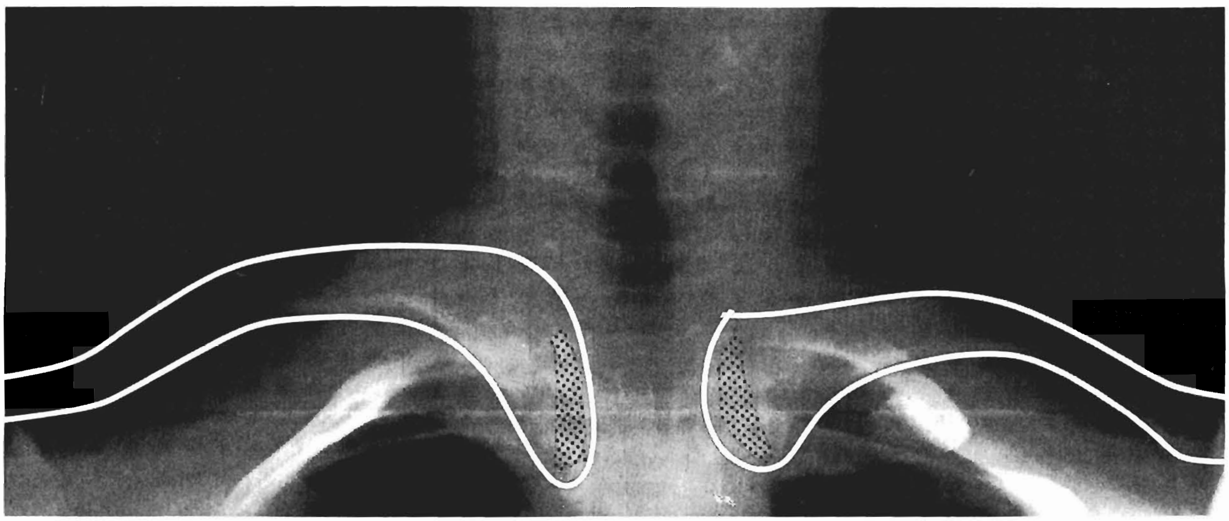


Fig. 10-4. Cleidocranial dysostosis: not strictly speaking, a pseudarthrosis.

Fig. 10-5. Rockwood view. The anterior displacement of the right clavicle is obvious. Here it is due to malunion of an epiphyseal separation. Retrosternal displacement is just as easily recognized in this view.



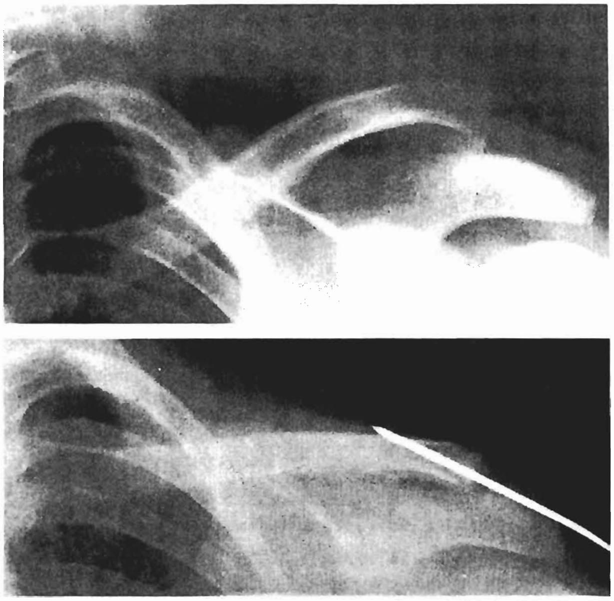


Fig. 10-6. Fracture of the lateral end of the clavicle.

OUTER END

Dislocations of the acromioclavicular joints are rare in children. Children sustain a little-recognized fracture of the distal quarter inch of the clavicle. The coracoclavicular ligaments remain intact, so that there is no depression of the shoulder tip. Marked anteroposterior instability is present, suggesting that the injury is due to a backward blow on the shoulder (Fig. 10-6).

As at the medial end, maintenance of reduction may be a problem. Anteroposterior alignment may be most difficult to maintain. In one case I have treated, a percutaneous Kirschner wire was inserted to hold the position for 3 or 4 weeks. This may be overtreatment, but in another case left untreated, an ugly lump remained, which did not remodel. The shaft of the clavicle moved forward, leaving a periosteal tube posteriorly, which formed a second clavicle. Unfortunately, the two did not unite.

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11/ Injuries of the Shoulder and Humeral Shaft

Shoulder and humeral shaft injuries are easy to treat and produce excellent results. The temptation to operate should be strongly suppressed.

A stiff shoulder following a difficult delivery should suggest a posterior obstetric dislocation and requires CT scan.

FRACTURES OF THE SCAPULA

Great violence occasionally fractures the scapula, and usually there are other injuries. A shattered glenoid and other obscure glenohumeral problems may be clarified by CT. The apophysis of the coracoid may be avulsed. When this accompanies complete acromioclavicular dislocation, the apophysis should be fixed back; otherwise, a sling is sufficient treatment (Fig. 11-1).

ACUTE SERRATUS ANTERIOR PARALYSIS

Pain, shoulder weakness, and scapular winging may follow acute or repetitive injury to the long nerve of Bell. The diagnosis is obvious as soon as the child does a press-up against a wall. The most likely cause is a traction injury to the nerve. Recovery takes an average of 8 months and may be helped by avoidance of the activities that initiated it.

DISLOCATION OF THE SHOULDER

Traumatic dislocation is only seen in older adolescents after the epiphysis have closed. This is an adult type of injury and will not be considered further.

"Party trick" dislocation or voluntary dislocation occurs in the loose-jointed when they suppress the activity of one of the muscles (Fig. 11-2). It begins without injury. Avoid operation; promote exercise.[4]

SEPARATION OF THE PROXIMAL EPIPHYSIS

Birth injury may separate the upper epiphysis and produce a clinical picture resembling that of Erb's palsy. Callus seen on a radiograph at 10 days will make the distinction. A Type-I separation is occasionally seen in a toddler (Fig. 11-3). These injuries should be managed by the methods described on the following pages.

Fig. 11-1. Fracture of the coracoid process in a 13-year-old boy.

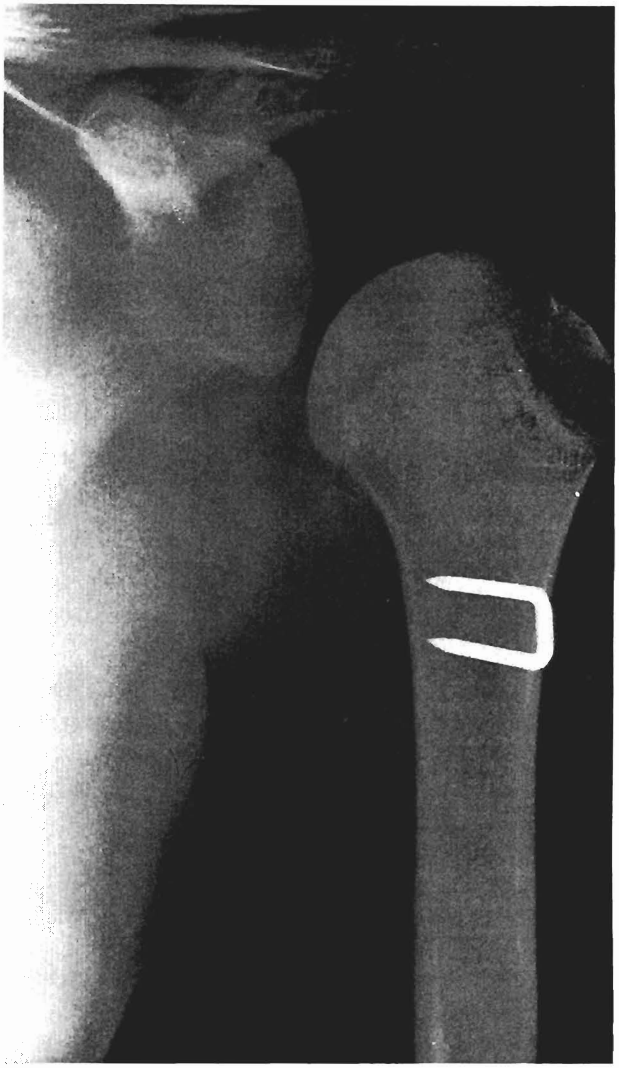


Fig. 11-2. Voluntary dislocation of the shoulder. Two repairs had been unsuccessful. What would you do now?

Fig. 11-3. Type I injury in a child of 2 years. The patient in Fig. 11-2 was treated by faradism to the inactive deltoid. The dislocation then reduced. With a simple exercise programme and explanation the shoulder stopped dislocating.

ADOLESCENT TYPE-II INJURY

Adolescent Type-II injuries are most common in teenaged girls who fall from a horse and sustain a hyperextension injury of the shoulder on landing (Fig. 11-4).

Dameron and Reibel produced the injury experimentally with the shoulder adducted and extended.[1] The tent-shaped growth plate and the thick posterior periosteum prevented separation by any other mechanisms. Rotation has been proposed recently by Williams and may play a role in the exceptional case.[6] Moore's description of 100 years ago cannot be improved upon:

> The symptoms of this fracture are striking and uniform. The shaft of the humerus is so inclined as to carry the elbow a little backward and outward, while the superior end of the shaft is brought forward, so as to make a prominence less rounded than the head and lower down. This is usually found about an inch and a half below the acromion (the distance varying a little with the size of the youth) and near the coracoid process. The curved line from the acromion down to this projection has a long sweep, instead of the small sphere of the natural head. This appearance is pathognomonic, and may be safely trusted in diagnosis without insisting upon crepitus. As in other epiphyseal fractures, this is not clear and sharp, as when the fracture is of bone, but is muffled. In addition to these striking symptoms we may add the fact of a shortening of half an inch or a little more in the length of the humerus.[2]

At the fracture there is anterior and lateral bowing. The metaphysis buttonholes through the anterior periosteum and may tangle with the tendon of biceps. The fracture lies too far laterally to damage the neurovascular bundle.

Radiographs are often difficult to interpret. An axillary view is painful, and a shoot-through lateral is often obscure. Two oblique radiographs taken at 45 degrees to the frontal plane are better. The relationship of the fracture to the growth plate may become apparent only after reduction.

Management

Reduction, and maintenance of reduction, can be difficult, but good results are the rule when these fractures are treated conservatively. It would seem unwise to strive officiously to reduce the fracture for the sake of a good-looking radiograph.

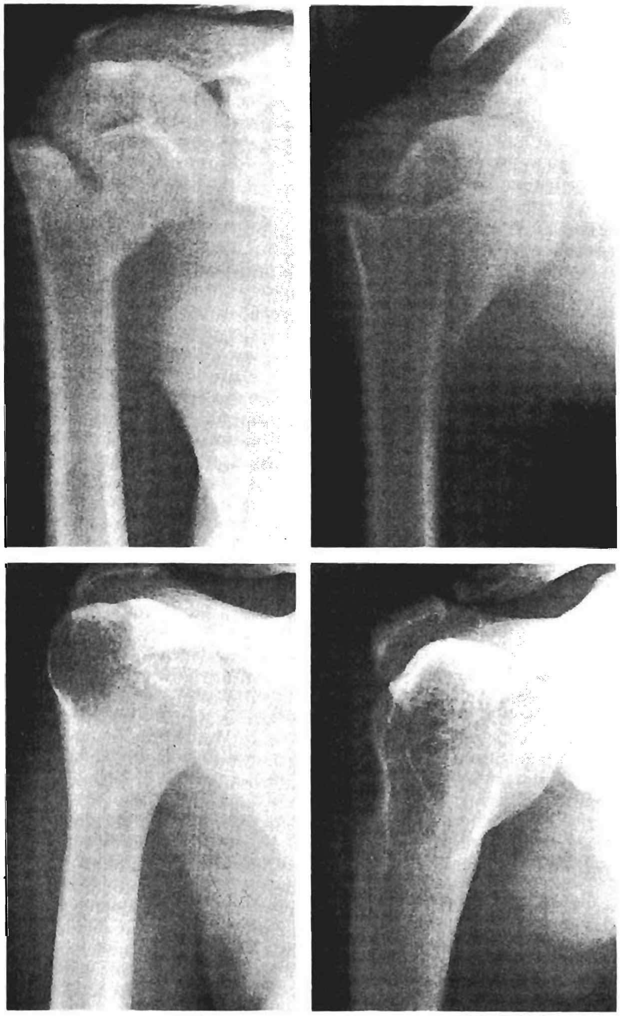


Fig. 11-4. Type II injury in a girl of 13 years. The position was accepted, and the lower films made 3 years later show excellent remodelling. Movements and appearance were normal.

Neer has classified the degree of displacement into four grades[3]:

I. Less than 5-mm displacement
II. One-third displacement
III. Two-thirds displacement
IV. More than two-thirds displacement

About 70% of patients have Grade-I or Grade-II displacement and require no more than a sling. Several methods of treatment have been advocated for the more severe grades of displacement.

Fig. 11-5. Statue of Liberty cast.

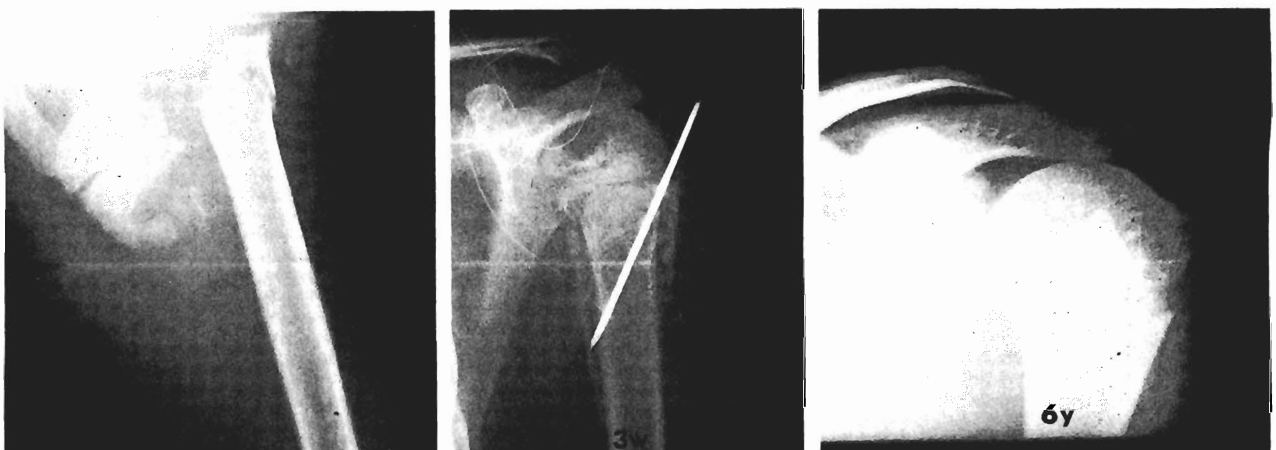
A Sling. This region has a great capacity for remodeling, and malunion does not limit movement. There is no cosmetic blemish, because the shoulder has thick muscle cover. Eighty percent of humeral growth occurs at the upper end, and within a year or two, all signs of angulation will disappear. Movement should be commenced at about 3 weeks.

Traction. The position can be improved by manipulation of the fracture under anesthesia, by the method described by Moore. The arm is moved forward and upward into a vertical line. Skin tape traction can be used to maintain the arm in this position for about 2 weeks. Not all fractures will stay, and any degree of slip must be accepted. After 2 weeks, the fracture is sticky, and the arm can be mobilized for a few days before being placed in a sling.

Cast Immobilization. After reduction by Moore's method, a shoulder spica can be used to hold the arm in the Statue-of-Liberty position. This gives excellent control of the reduction (Fig. 11-5). Nevertheless, the position should be checked radiologically after a few days, because overreduction and slip have been known. At 3 weeks, the child has to be admitted to the hospital for cast removal, because the arm is stiff in abduction and requires some time to come down to the side again. Bed rest is needed during this time. Never leave this cast on for more than 3 weeks if you wish to avoid prolonged stiffness.

A Statue-of-Liberty cast puts the child in a very inconvenient position, as he cannot get into a car. Also, my enthusiasm for this position was dampened by a case of incomplete brachial plexus palsy that

Fig. 11-6. This 5-year-old sustained a fracture of the odontoid in addition to this metaphyseal fracture. Internal fixation was required for nursing.

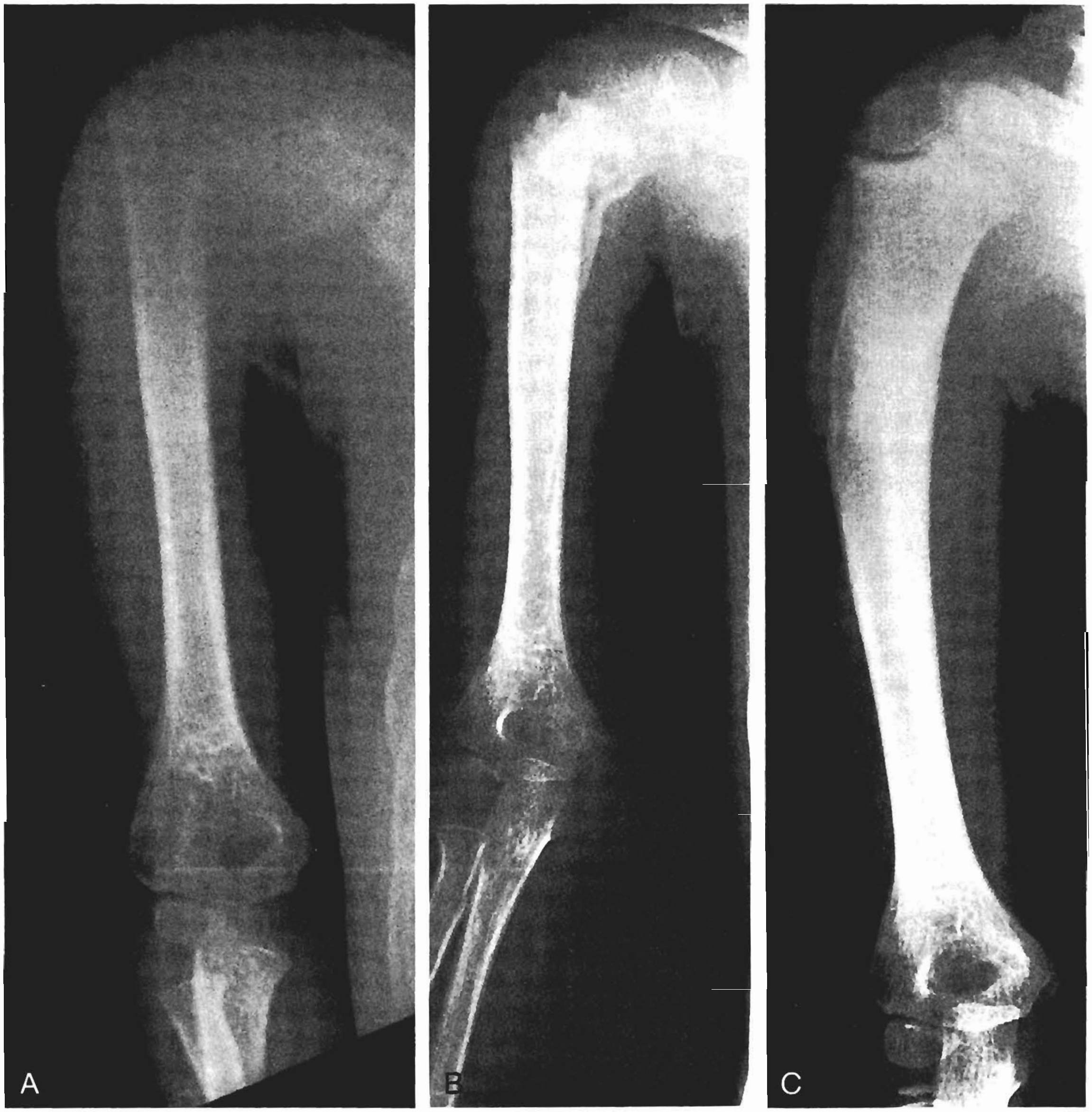


developed after a few days and took a long time to recover. A colleague had a similar experience with one of his cases. Another child was unstable in this position, and reduction could only be maintained with the arm in full internal rotation and extension—in the "Napoleon position." For these reasons, I prefer traction if the fracture cannot be held in apposition with the arm at the side after reduction.

Closed Reduction and Percutaneous Pinning. Pinning permits the arm to be brought down to the side again and avoids the overhead position. Enthusiasts like this, but I have not tried it.

Open Reduction. Results of *laissez-faire* treatment are at least as good as those of open reduction. Open reduction leaves a large scar (an important considera-

Fig. 11-7. Laissez-faire treatment for fractures of the upper humerus is hard to beat in a rapidly growing child. This injury was treated with a sling. *(A)* Initial position. *(B)* After 3 weeks. *(C)* After 7 months.



tion in girls). It is not an easy operation. The internal fixation may pull out and occasionally produces a growth disturbance.

At operation, the tendon of biceps may be found interposed, and this finding has been the justification for surgery in the past. The only justification for it today is in the minds of surgeons who harbor the illusion that anatomic reduction is important in this fracture. I mention it only to condemn it.

Results

All children recover full movement and a normal-looking arm. Shortening owing to premature closure of the growth plate is common. Neer found 1 cm to 3 cm of shortening in 10% of children with undisplaced fractures and in 40% with severely displaced fractures.[3] Smith found shortening in 20%, regardless of the method of treatment used.[5] This degree of shortening is seldom noticed by the patients.

Hippocrates wrote, "It sometimes happens that the head of the humerus is fractured at its epiphysis; and this, although it may appear to be a much more troublesome accident, is, in fact, a much milder one than the other injuries at this joint."

After reviewing a large series, Smith concluded that this was an overtreated fracture and hoped that in the future the routine treatment should border on *laissez-faire*.[5]

FRACTURES OF THE UPPER METAPHYSIS

Greenstick fractures are common and are seldom displaced. A Velpeau bandage, smartened up with a roll of plaster so that it will last for 2 to 3 weeks, provides a comfortable solution.

Completely displaced metaphyseal fractures are more difficult than Type-II injuries. The shaft penetrates the deltoid to lie subcutaneously. A short incision may be required to disengage the distal fragment and push it back into place. This is a stable reduction in a sling without internal fixation (Figs. 11-6, 11-7).

Fig. 11-8. Spiral fracture of the humerus. If a bulky pad is placed between the body and the arm, the deformity will be increased. Did you notice the bone cyst?

FRACTURES OF THE HUMERAL SHAFT

Transverse humeral shaft fractures are the result of a direct blow. Spiral fractures are produced by a twist; even muscular violence will do this. Spiral fractures are a common injury in soldiers learning to throw hand grenades.

Fractures are easily treated because they reduce themselves under the influence of gravity (Fig. 11-8). The only important part of treatment is to maintain good public relations with the family. There are many ways of treating the fracture. A Velpeau bandage held in place with one roll of plaster or a stockinette Velpeau (Fig. 11-9) is simple for minimally displaced stable fractures. A **U**-slab provides better fixation. For very unstable fractures we use a thoracobrachial box, because it prevents crepitus, which families find very disturbing (Fig. 11-10).

Fig. 11-9. Stockinette Velpeau.

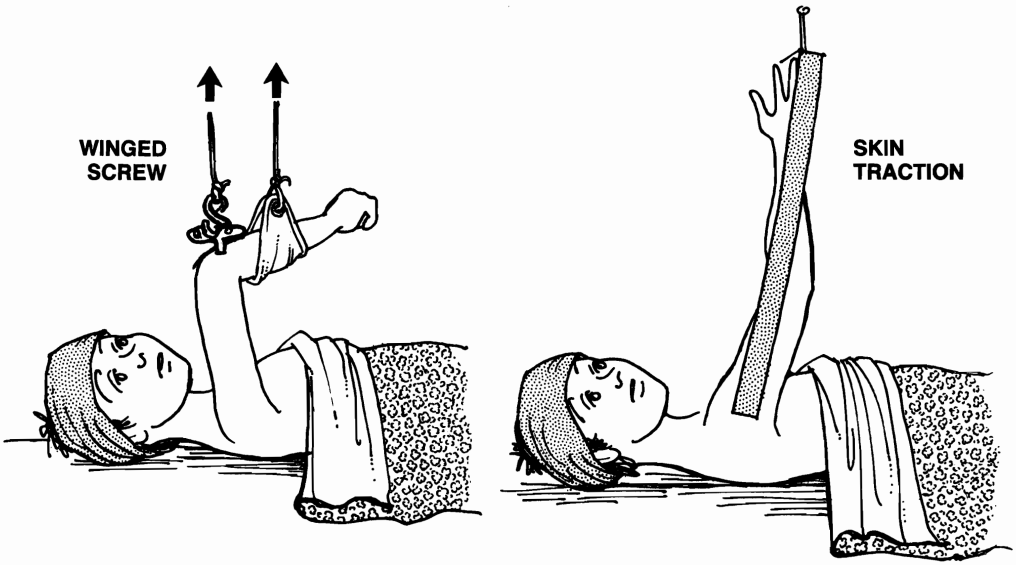
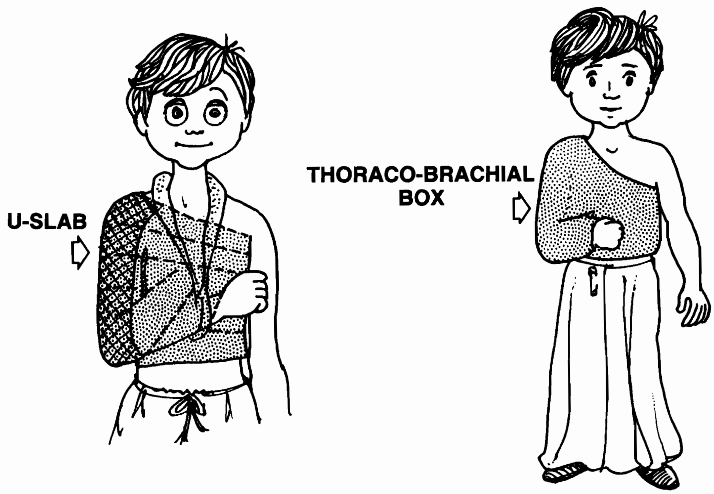


Fig. 11-10. The upper figures show the methods of treating a fracture of the humerus in a child with a head injury. We now prefer winged screw traction to a transverse ulnar pin. The methods in the lower figures are suited to ambulant children.



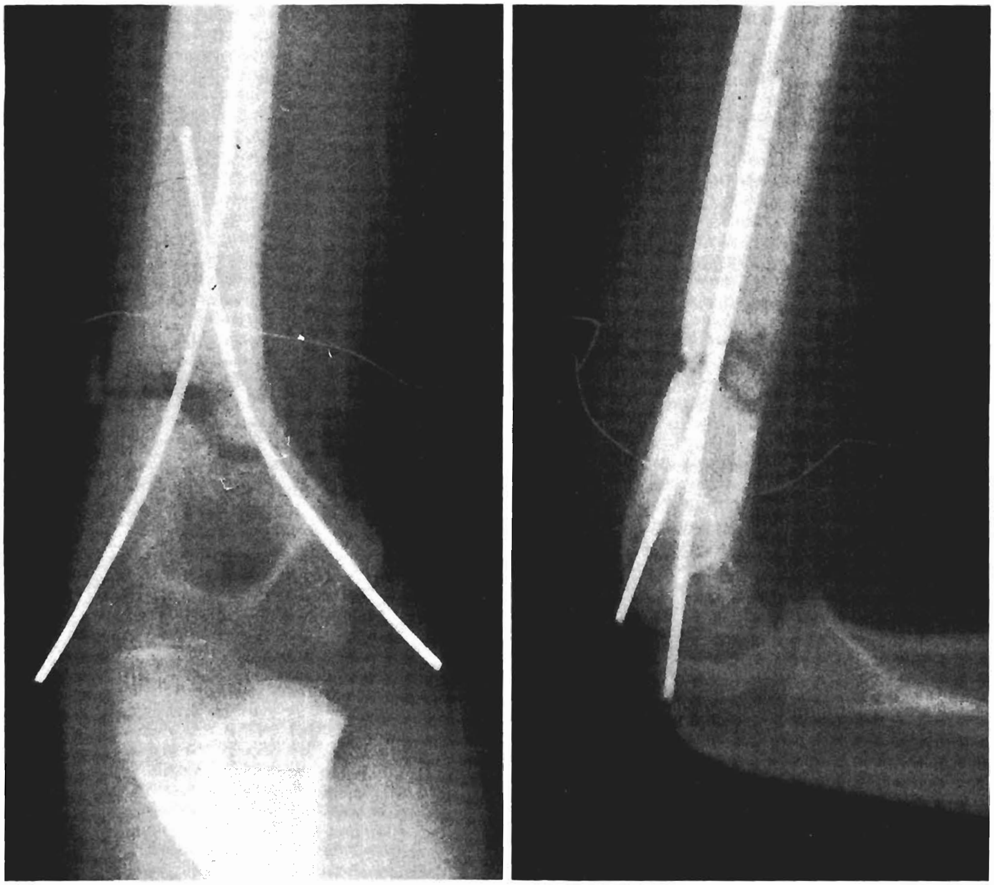


Fig. 11-11. Greenstick fractures at this level are easily held, but widely displaced fractures may be hard to control. This was a grossly unstable open fracture that required debridement. Internal splinting produced an excellent result with a quick return of movement.

For a week, an attempt should be made to prop the child up at night for sleep. Bayonet apposition is satisfactory because overgrowth of about 1 cm can be expected. Varus angulation is common and can be kept at less than 20 degrees. At the lower end, angular malunion may show and should be corrected; this is accomplished by manipulating the cast a bit. Immobilization for 3 to 4 weeks is sufficient (Fig. 11-11).

Open fractures with bone loss at the lower end may not unite. Grafting and compression plating may be reqired and should be carried out before the elbow becomes stiff.

SPECIAL PROBLEMS

Multiple Injuries

The combination of a fracture of the femur, a fracture of the shaft of the humerus, and a head injury is not unusual as a result of a car striking a child. It is not possible in such cases to use the dependent weight of the arm to keep it straight. Some form of overhead traction should be used. Most popular is skeletal traction through the proximal ulna. The pin is inserted about 1 inch distal to the olecranon from the medial side, and the ulnar nerve is carefully avoided. Since one boy had a temporary ulnar nerve palsy after this, I prefer to use skin traction; the arm is pulled upward in the position of a fascist salute. When skeletal traction is required, a winged screw into the subcutaneous border of the ulna, as advised by the ASIF group, seems safer.

Radial Nerve Palsy

In children, a supracondylar fracture is more likely to produce a radial nerve palsy than a fracture of the shaft. Spontaneous recovery can be expected; look for this first in the brachioradialis. Radial nerve palsy is particularly likely to occur in fractures at the junction of the middle and lower thirds of the shaft. The nerve may become trapped between the fracture fragments. If the fracture remains separated by soft-tissue interposition, or if a radial nerve palsy follows manipulation, explore right away; otherwise, save exploration for the child with no signs of recovery after 3 months.

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12/ Elbow

"Pity the young surgeon whose first case is a fracture around the elbow." Though written 200 years ago, these words still ring true, because at every stage these fractures present difficulties: difficulties of diagnosis and reduction, vascular and neurologic problems, slippage in the cast, malunion, and stiffness.

GENERAL PRINCIPLES

Diagnosis

Though most fractures are obvious on radiographs, there are some that are not apparent on routine anteroposterior and lateral views (Fig. 12-1). Some radiology departments deliver a "looser's" view. This is an anteroposterior (AP) view of an elbow flexed about 90 degrees, which makes diagnosis impossible. Don't be bashful about insisting on true AP of the distal humerus and of the proximal forearm, even if two more views must be taken. Correct diagnosis is everything. Sometimes only the conviction that there must be a fracture will drive the clinician to obtain oblique films of the joint, radiographs of the normal elbow, or even stress films (Fig. 12-2). Growth plates cause much confusion. Most people cannot memorize ossification charts. There is no need to do this, as the opposite elbow can be radiographed as a control. Even when radiographs demonstrate an injury, there are occasions, perhaps only once or twice a year, when it is difficult to be sure of the exact diagnosis. This is most likely in young children in whom much of the elbow is still radiolucent cartilage. Pass these cases on to someone older and wiser, because only experience will enable the perfect treatment to be instituted. (See Hugh Thomson's definition of a consultant on page 70.)

Reduction

It is generally accepted that open reduction is indicated for displaced fractures of the lateral condyle and the medial epicondyle and irreducible fractures of the radial neck. For supracondylar fractures, however, closed reduction is *de rigeur*. But after one or two attempts, during which the ragged, potentially locking, bone fragments are grated smooth, the realization may slowly dawn on a surgeon that without inside help he is going to be beaten.

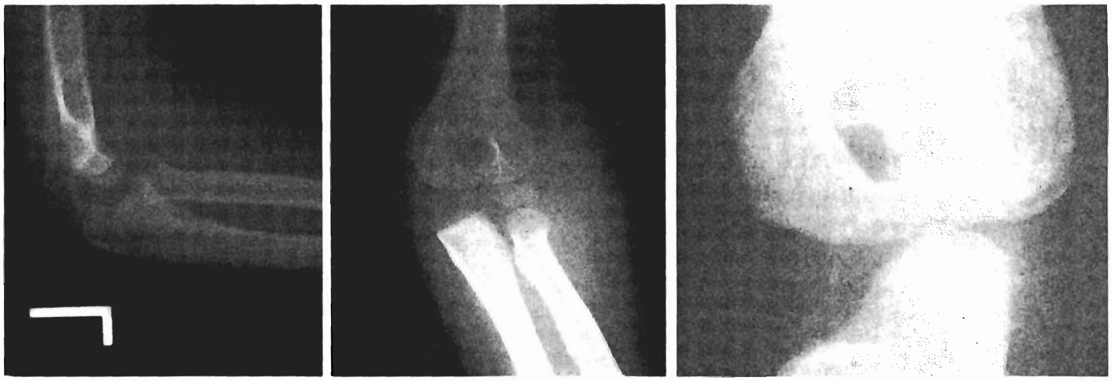


Fig. 12-1. The elbow was swollen and painful; anteroposterior and lateral radiographs showed no fracture. But the oblique film disclosed a fracture of the lateral condyle.

Vascular Problems

There has been so much emphasis placed on Volkmann's contracture that it should be a thing of the past. Never splint an unreduced elbow in flexion; be alert to white hands. Split or remove the cast of any child with muscle pain, and vascular complications will vanish from your practice.

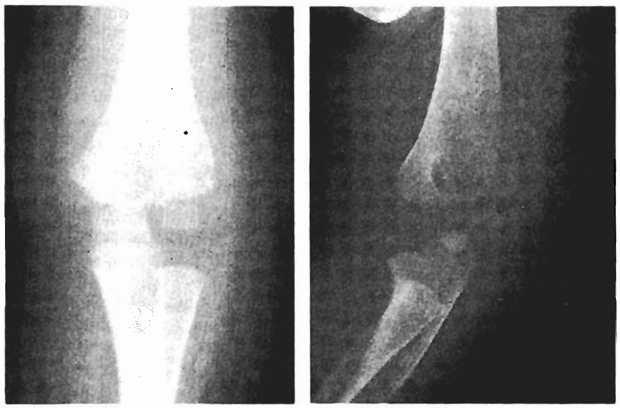
Neurologic Problems

Look carefully for neurologic deficits at the first consultation. Test motor radial by asking the child to extend the thumb. Test motor anterior interosseous by asking for flexion of the distal interphalangeal joint of the index and the interphalangeal joint of the thumb. Motor median is judged by observing grasp and motor ulnar by finger spread. Test sensation in each digit and over the dorsum of the thenar web. Remark on them to the parents, and make a written note. In our series of supracondylar fractures, 14% had transient nerve palsies.

Slippage in Cast

A few fractures may slip in casts; in my experience, however, most of these fractures were only partially reduced initially. Early radiographs from one angle may cast a rosy shadow, but subsequent radiographs, taken from a different angle, produce the truer image. However, it is customary to blame slippage within a cast on instability of the fracture, a poorly applied cast over a lot of swelling, or lack of support of the cast by a sling.

Fig. 12-2. The only way to make the diagnosis was to obtain a stress film.



Malunion

Full extension of the elbow is usually only possible some weeks after the cast comes off. This may be the first time that everyone becomes aware that the arm is crooked. It is impossible to tell whether an arm is straight or crooked when it is flexed. Some blame this—unjustly—on a growth disturbance; it is always due to malunion. Properly interpreted radiographs will preserve you from this trap.

Stiffness

Never immobilize the elbow in full flexion for more than 3 weeks. Disregard radiographic signs of union or absence of union at this time. Remember that supracondylar fractures do not displace after 3 weeks (unlike radiographs, which may be misplaced at almost any time).

Armed with these general principles, we will now examine the individual injuries.

SUPRACONDYLAR FRACTURES

A supracondylar fracture of the greenstick type is produced experimentally by forcibly hyperextending the elbow to nearly 90 degrees. The level of fracture is determined by the olecranon forming a fulcrum in the supracondylar region, while the collateral ligaments of the elbow, attached to the metaphysis, prevent a dislocation. Fractures are transverse, signifying an angulatory, not a rotatory force.

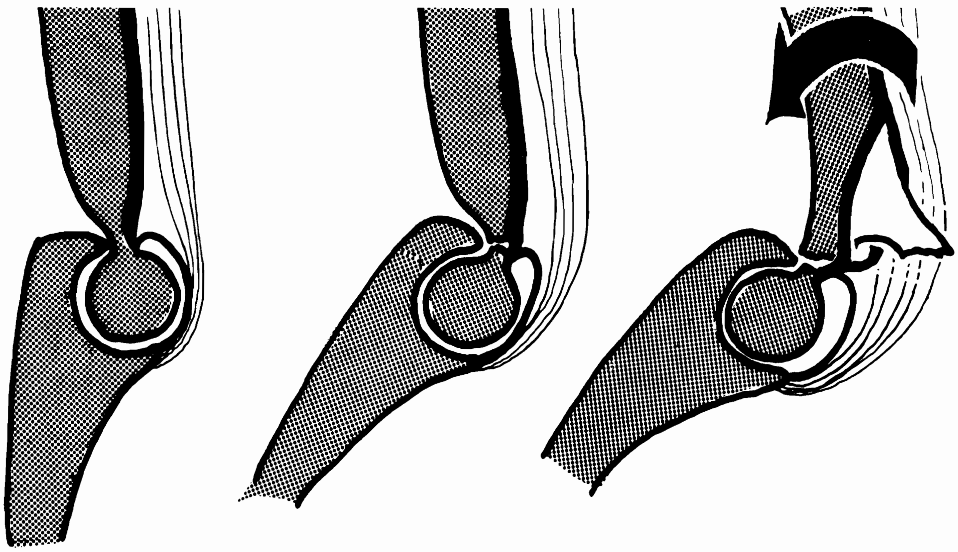
In experiments, the periosteum remains intact so long as the force is pure hyperextension (Fig. 12-3). When the fracture is forcibly rotated, the sharp corner of the proximal fragment tears the periosteum, permitting gross displacement. With progressively more force, the sharp edge will first tear the brachialis and then the skin.

The rent in the periosteum is L-shaped and leaves two-thirds of the periosteum around the fracture intact to form a useful hinge that aids reduction. The periosteum is stripped off the shaft for several inches depending on the degree of displacement at the time of injury. The humerus at the level of fracture is shaped like a fish tail: its sharpness produces the damage already described and may in addition interfere with the radial nerve, the brachial artery, and the median nerve: its narrowness can turn a stable reduction into a balancing act (Fig. 12-4).

ANGULATED GREENSTICK FRACTURES

A small crack or a fat-pad sign may be all there is to see of this injury (Fig. 12-5). While it is probably sufficient to apply a collar-and-cuff sling for 3 weeks in order to produce union, anxious parents and children require an arm cast in order to be convinced that there is a fracture that needs protection.

Fig. 12-3. Experimental production of an extension type of supracondylar fracture. The olecranon forms a fulcrum when the elbow is hyperextended. The periosteum remains intact until the arm is twisted. Then the sharp corner of the metaphysis tears the periosteum to allow displacement.



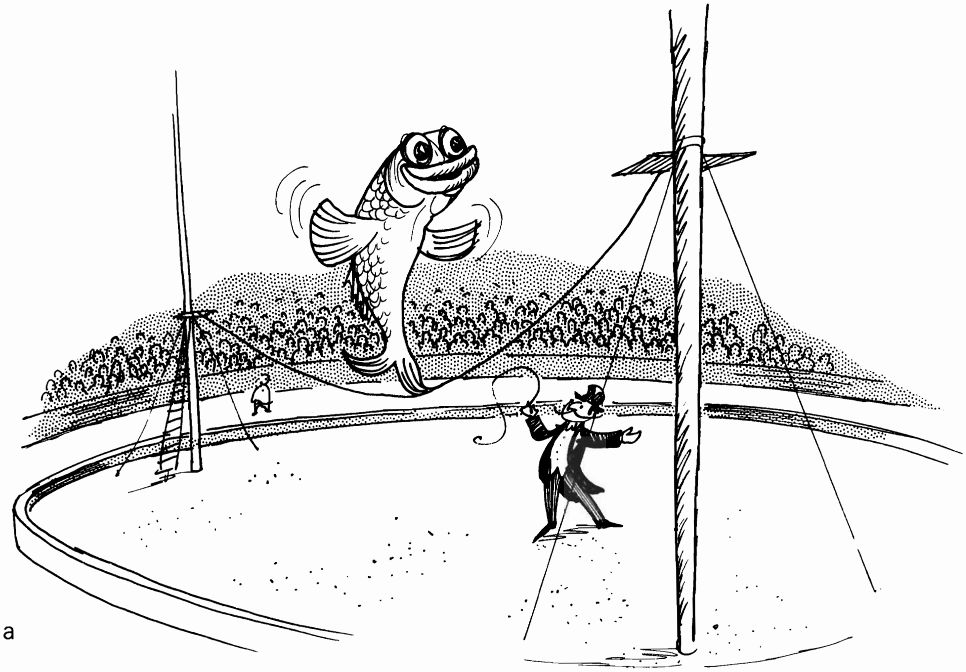


Fig. 12-4. Reduction can be a balancing act.

If the fracture is angulated more than about 20 degrees, the child should be anesthetized, so that the elbow can be flexed above a right angle to facilitate reduction. Radiographs should be taken before the cast is applied. In our series of supracondylar fractures, cubitus varus has occurred in this group because the initial displacement was underestimated and treatment was perfunctory.

THE CLASSIC DISPLACED SUPRACONDYLAR FRACTURE

Initial Care

Look first for signs of ischemia and then for signs of nerve palsies (Fig. 12-6).

Choice of Definitive Treatment. No method is right for every child and every surgeon. A cast is suitable for an undisplaced fracture; but it must be remembered that these are the very fractures most likely to become varus because they are treated offhandedly. Traction is safe but expensive in terms of bed stay. Percutaneous pinning is time consuming, requires an image intensifier (preferably with a memory), and requires a surgeon with a keen sense of direction.

Fig. 12-5. Fat pad sign. Blood in the joint pushes the fat pads away, causing radiolucencies anterior and posterior to the distal humeral metaphysis.

Table 12-1. Varus Deformity After Supracondylar Fracture

TECHNIQUE	AUTHOR	PIN SITES	VARUS CARRYING ANGLE
Percutaneous pinning	Flynn and associates, 1974[8]	Medial + lateral	4%
	Arino and associates, 1977[1]	2 Lateral	12%
	Fowles and Kassab, 1974[9]	2 Lateral	8%
	Prietto, 1979[26]	Medial + lateral	5%
Open reduction and pins	Gruber and Hudson, 1964[12]	Medial + lateral	0%
	Weiland, 1978[36]	Medial + lateral	4%
Dunlop traction	Prietto, 1979[26]	—	33%
	Dodge, 1972[6]	—	8%

Fig. 12-6. The median and radial nerves lie anterior to the elbow and are equally liable to injury in extension fractures.

In choosing treatment, the main consideration should be given to *avoiding a catastrophe,* such as compartment syndrome, and *minimizing embarrassments,* such as cubitus varus and stiffness. Compartment syndrome is related to casts and particularly to the diligence of care. Stiffness is related to the duration of immobilization. The incidence of varus malunion is much the same for all methods (Table 12-1).

As first aid, splint the fracture in extension. Flexing a displaced supracondylar fracture in a sling only compresses the artery. It is foolish to have a child waiting for radiographs with an ischemic limb. Put the splint on before the radiographs are taken to prevent the technicians from twisting the arm through the fracture.

Reduction should be undertaken as soon as a child's stomach is legally safe for anesthesia, because reduction is easiest before edema is added to hematoma.

Treatment Options

Traction. Skin and skeletal traction (Fig. 12-7) have the following advantages:

1. Safety. Volkmann's ischemia is less of a hazard than with closed reduction.
2. Good results. Varus and valgus deformities are very infrequent.
3. Traction is applicable to fresh fractures and to fractures a few days old.
4. It is suitable for stable and unstable or irreducible fractures.

Traction should be set up after the fracture has been reduced under general anesthesia. Traction requires prolonged hospitalization and a considerable amount of attention in order to keep it in good shape. Dodge reviews his results with Dunlop traction and describes the method in detail.[6]

Closed Reduction and Cast. Cast fixation is satisfactory for minimal displacement. When there is moderate displacement with a circumscribed, firm, anterior hematoma, the antecubital fascia is intact; elbow flexion is particularly likely to lead to disappearance of the pulse with risk of Volkmann's ischemia. Marked displacement with a diffuse swelling means that the hematoma is not contained. Flexion is less likely to affect the circulation.

In the first edition of this book, closed reduction and cast was the method of choice for severely displaced fractures, because good results were obtained in 90% of fractures with brief hospitalization. Vascular problems and malunion did not occur in our patients. However, I have given up cast fixation in favor of percutaneous pin fixation on the grounds of safety. For secure cast fixation, the elbow must be flexed more than 90 degrees. Less than 90 degrees of flexion carries the risk of slip; more than 90 degrees of flexion carries the risk of Volkmann's ischemia. For me, cast fixation became a method of the past after being referred two patients with complete late Volkmann's contractures who had been treated by closed reduction and cast immobilization.

Closed Reduction and Percutaneous Kirschner Wire Fixation. This method was introduced for all supracondylar fractures to prevent redisplacement, particularly when the elbow cannot be flexed beyond a right angle. After the fracture has been reduced by closed methods, two thin Kirschner wires are inserted lateral to the olecranon (Fig. 12-8).

Open Reduction and Internal Fixation. This method has been tried and condemned by a number of surgeons because of the frequency of stiffness. For older adolescents with T-shaped fractures, open reduction with ASIF fixation may be the ideal method. The results of exposing the fracture through a short anteromedial incision (just sufficient to insert a finger) followed by percutaneous K-pinning are good.

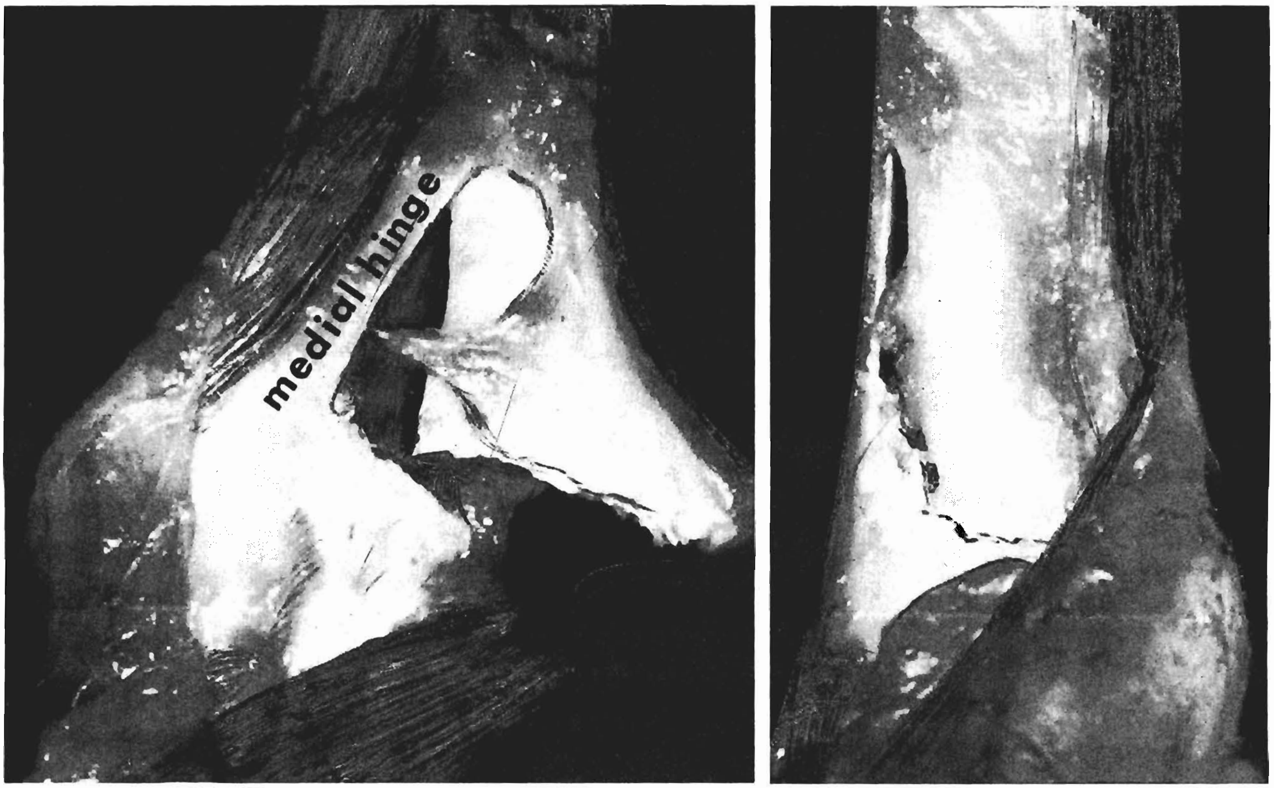
The degree of proficiency with which any of these methods is followed is probably more important than the method used.

The Technique of Closed Reduction and Percutaneous Pinning. There is no lack of advice about reduction. In 1894 Smith evolved a method, based on his anatomic dissections, that still works well for us.[31] The use of intact periosteal hinges to aid and maintain reduction is the key to success. Everyone knows that there is a posterior hinge of periosteum in a posteriorly displaced fracture. After the fracture is reduced, the fracture gap is impacted by flexing the elbow strongly.

Fig. 12-7. Traction for difficult problems. A winged screw is preferred to a transverse pin because there is no risk to the ulnar nerve. Furthermore, the problem of side-to-side slip does not arise.

Fig. 12-8. Two fractures in the same arm are an indication for percutaneous pinning.

Fig. 12-9. An experimentally produced fracture shows the medial hinge and offers a glimpse of the posterior hinge. After reduction, the soft tissues hold the fragments in place. The better the reduction, the greater the security.



Similar collateral hinges are present to permit control of valgus and varus, though they are less well known. When there is medial displacement, a medial periosteal hinge is always present (Fig. 12-9). When the fracture is reduced, this hinge can be tightened to impact the lateral part of the fracture. If the fracture remains open laterally, a varus deformity owing to malunion will be evident. But how can this medial hinge be tightened? Smith originally pointed out (and others have confirmed) that pronation of the forearm tightens the medial periosteal hinge.[31] Figures 12-10 and 12-11 elucidate the mechanics of this maneuver.

The few fractures that have lateral displacement have a lateral hinge. These fractures are best held in supination.

Equipment. Fine K-wires can be driven in with one hand and little pressure, using a minidriver. An image intensifier speeds up the procedure. Do not forget the pin cutter!

With the child under general anesthesia, go through these steps (Fig. 12-12):

1. Palpate the bony landmarks. Check the direction of displacement.
2. Apply traction with the arm flexed to about 10 degrees. The proximal fragments will be returned into the periosteal tube. Correct any lateral displacement.
3. Push the olecranon anteriorly to correct the posterior displacement. Flex the elbow to about 40 degrees.
4. Externally rotate both arms to correct the usual internal rotation deformity. Both arms should rotate an equal amount.
5. Continue to flex the elbow above a right angle while maintaining pressure on the olecranon. Be sure that the posterior displacement is reduced *before* this is done, otherwise the brachial artery will be crushed in the fracture. In order to use the posterior hinge to close the fracture completely, the elbow should be flexed until the olecranon lies anterior to the epicondyle (Fig. 12-13).
6. If the displacement was initially medial, pronate the forearm to lock the fracture. About 10% of supracondylar fractures are laterally displaced; these should be set in supination.

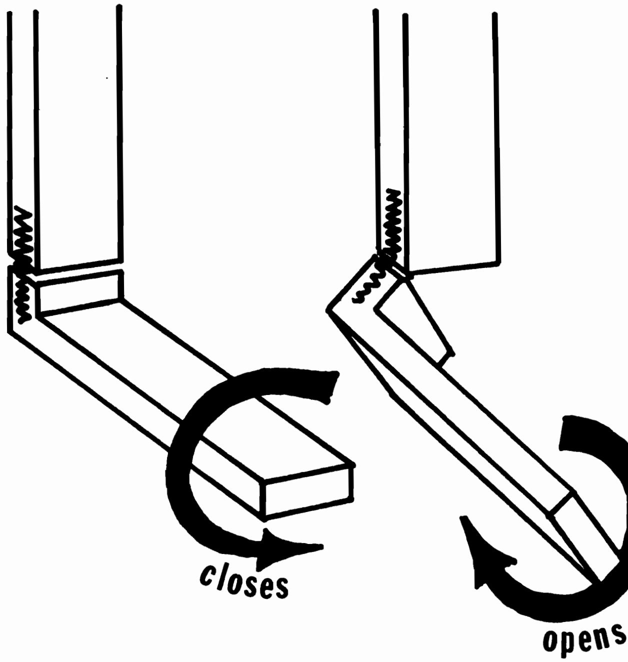
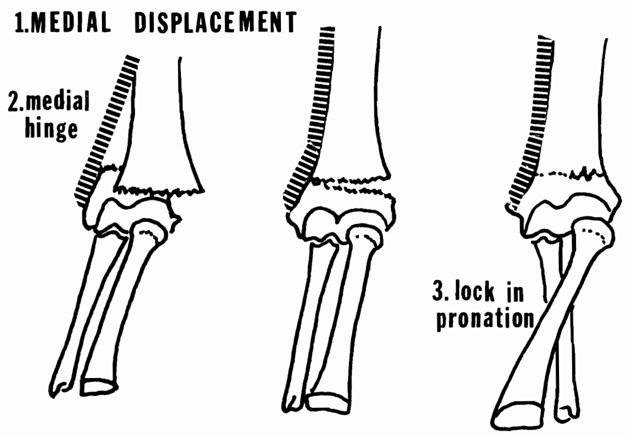


Fig. 12-10. The forearm is used to control the position of the distal fragment.

Fig. 12-11. When the bone ends have been brought into contact (and not before), rotation of the forearm will close the fracture using the medial hinge. If the fracture remains open laterally, cubitus varus is the result.



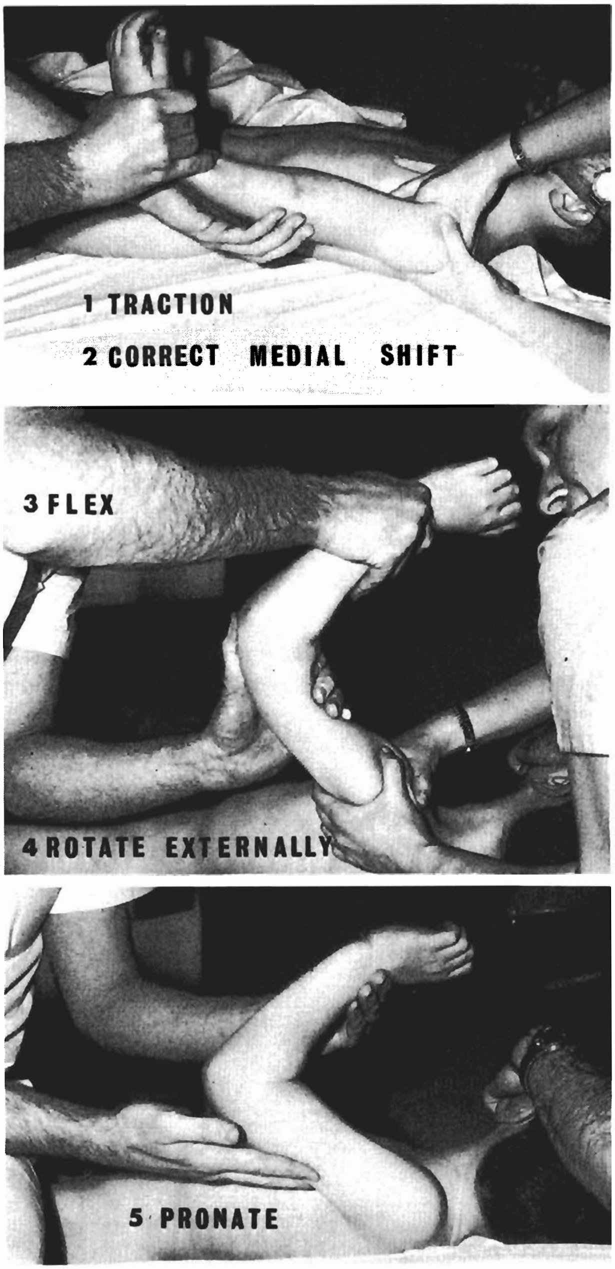


Fig. 12-12. The steps in reduction of a supracondylar fracture. At the final stage the elbow should be flexed more acutely.

7. Hold the fracture in preparation for percutaneous K-wire fixation by applying a figure-of-8 bandage. If the circulation is temporarily occluded, do not worry (Fig. 12-14).
8. Check the position with an image intensifier. Do not obtain the lateral by twisting the arm. You may lose position. Move the C-arm. An accurate reduction is essential (Fig. 12-15).
9. Prepare the skin and put on gown and gloves. Throw a drape with a central hole over the elbow.
10. Drive two 1.4-mm K-wires across the fracture, using the Judet technique. One pin is inserted into the lateral condyle just lateral to the olecranon. Aim for the shoulder so that the pin runs an intramedullary course. The second pin should be aimed for the medial cortex and engage it.
11. Check position on an image intensifier.
12. Cut the pins so that they lay deep to the skin to avoid organisms tracking into the elbow joint.
13. Extend the arm to about 70 degrees and apply a light, padded cast.
14. Admit overnight.

Another Technique of Percutaneous Pinning. The fracture can be reduced with the patient prone; gravity tends to maintain position while the pins are inserted (Fig. 12-16).

Fig. 12-13. Flex the elbow until the olecranon lies anterior to the epicondyles in order to lock your reduction.

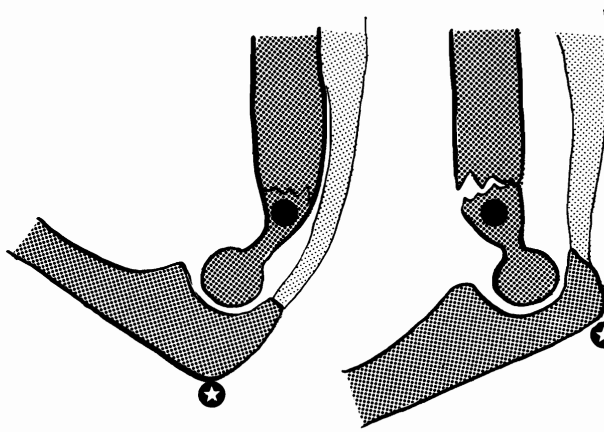
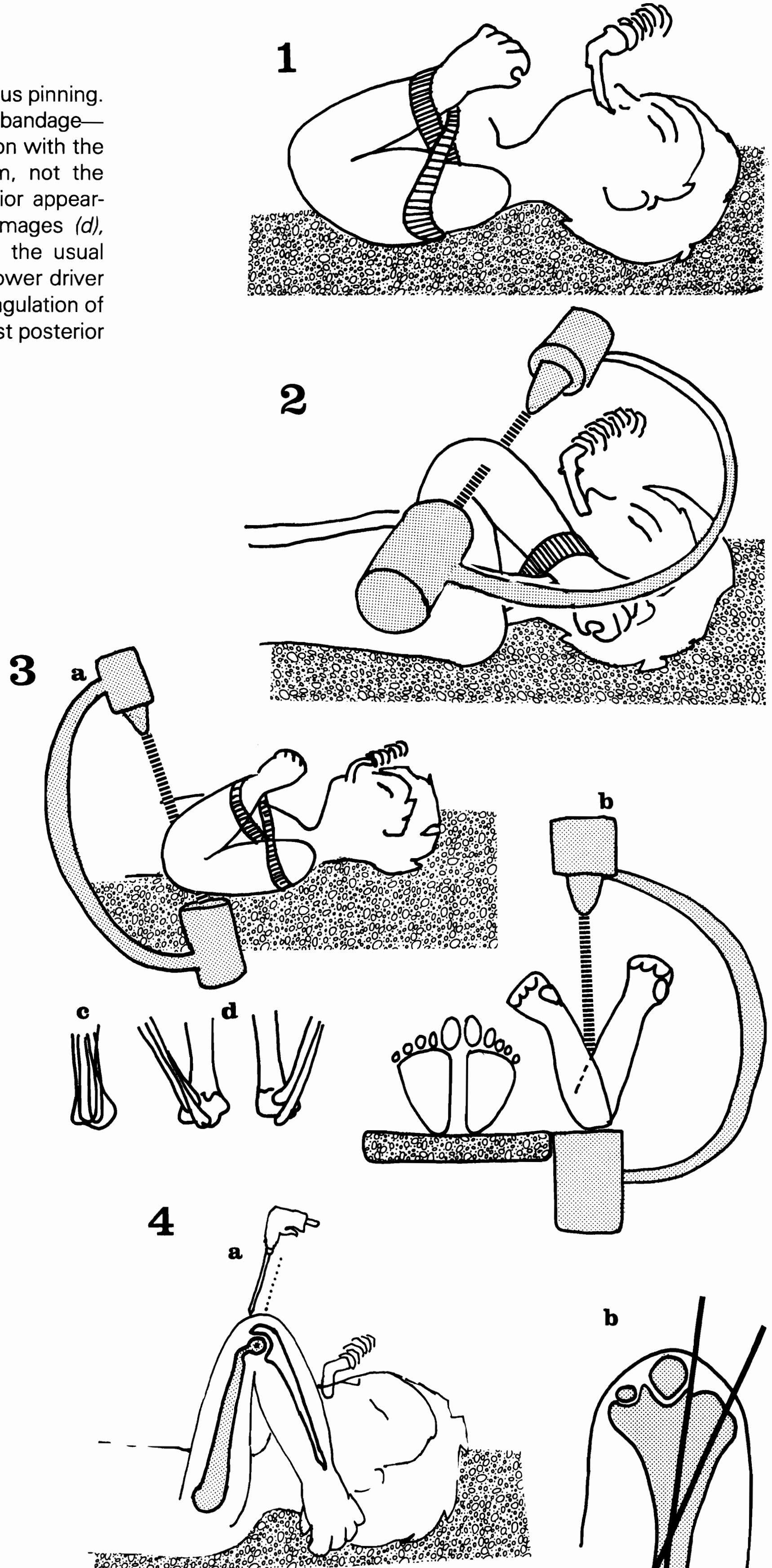


Fig. 12-14. The steps in percutaneous pinning. 1. Hold reduction with a figure-of-8 bandage—use several turns. 2. Check reduction with the image intensifier. Twist the C arm, not the child's arm. 3. Check anteroposterior appearance—use two obliques to yield images *(d)*, which are easier to interpret than the usual superimposed view *(c)*. 4. Use a power driver to insert the pins. Due to anterior angulation of the distal humerus, start the pins just posterior to the intercondylar line.



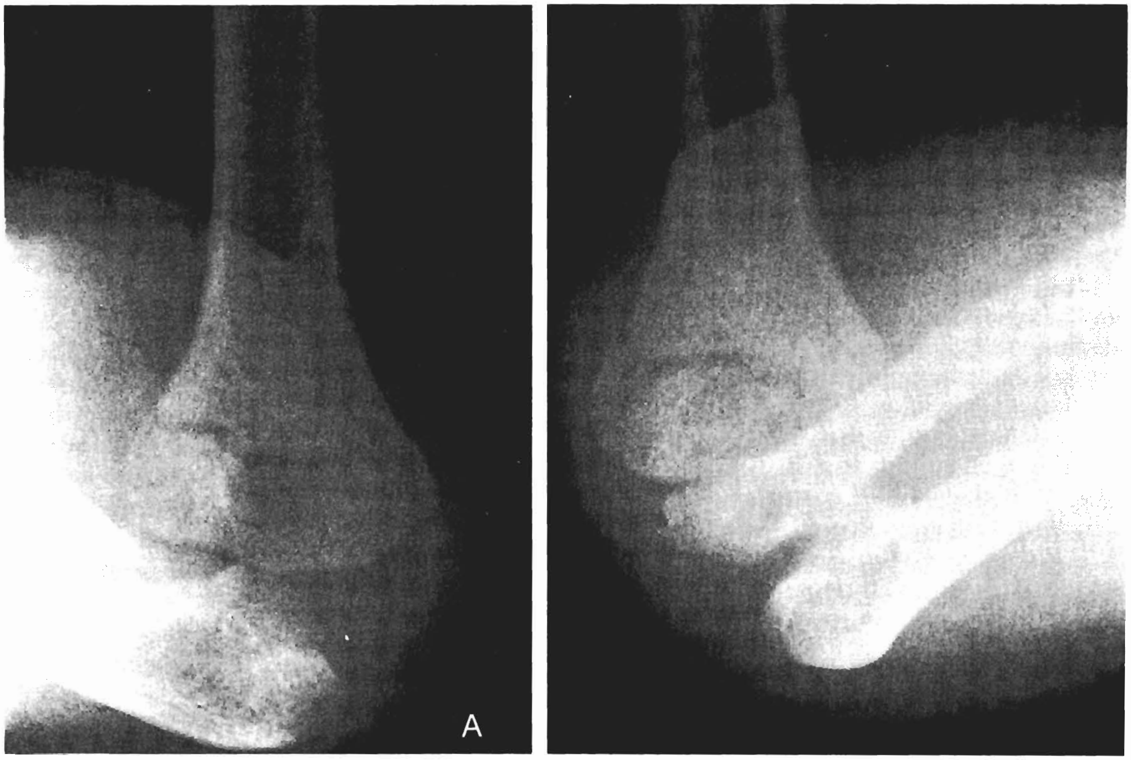


Fig. 12-15. *(A)* Two anteroposterior (AP) obliques are so much better than one true AP radiograph *(B)*. Clear films are an important guard against malunion.

Cast Technique. Follow the previous technique to step 6. About 110 degrees of flexion is necessary to ensure stability (Fig. 12-17). (If this occludes the circulation, insert pins and extend the elbow.) Next:

1. Put a gauze square in the elbow crease to prevent blistering and intertrigo. Apply an Ashurst bandage to avoid compression of the front of the elbow (Fig. 12-18).
2. Radiograph the elbow. Do not obtain a lateral by twisting the arm. You may lose reduction.
3. If the radiograph is satisfactory, apply a very light shell of plaster and a collar-and-cuff sling. The sling takes the weight of the cast off the fracture and prevents rotation of the limb.
4. Admit the child for 48 hours, and order observation of the circulation, sensation, and movement of the hand. Do not give analgesics. Check active and passive extension of the fingers. Pain on passive extension of the fingers is the early sign of Volkmann's ischemia.

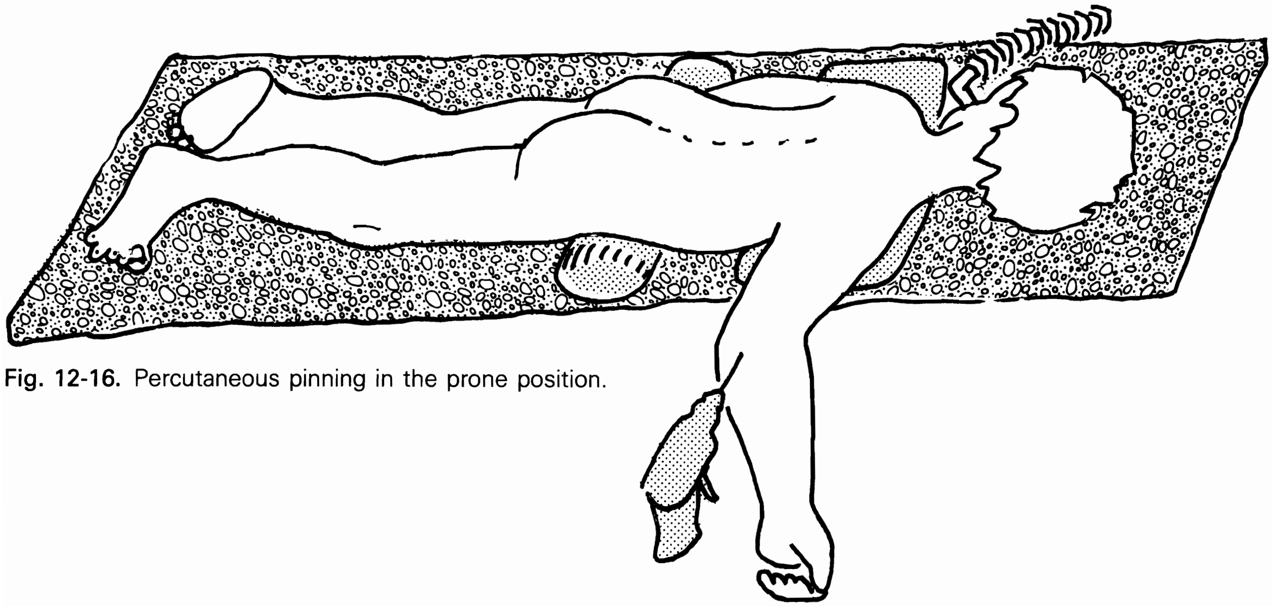
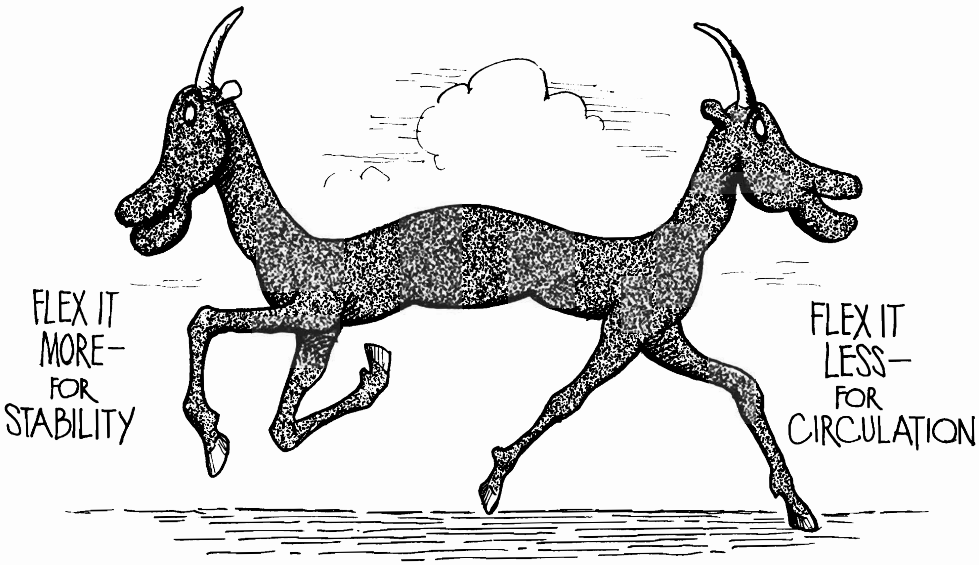


Fig. 12-16. Percutaneous pinning in the prone position.

Fig. 12-17. Dr. Dolittle's analysis of the problem of closed reduction in supracondylar fractures of the elbow. (Adapted from Lofting H: The Story of Doctor Dolittle. Philadelphia, JB Lippincott, 1920. Copyright 1920 by Hugh Lofting. Copyright 1948 by Josephine Lofting.)



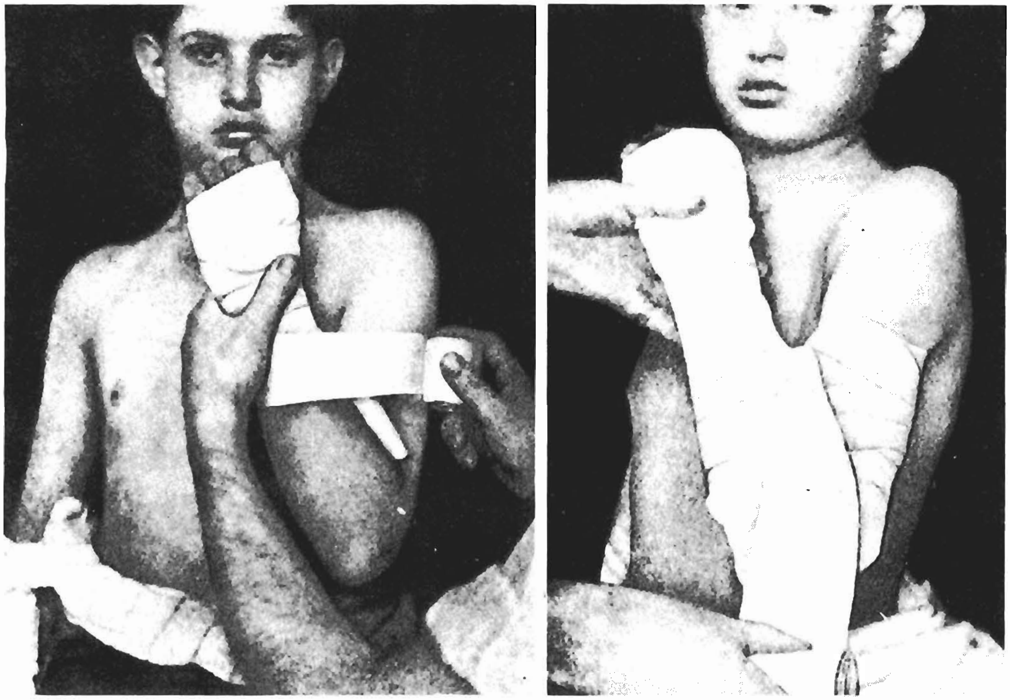


Fig. 12-18. Hold the reduction with a flannel bandage. (From Ashurst APC: Fractures of the Elbow. Philadelphia, Lea & Febiger, 1910.)

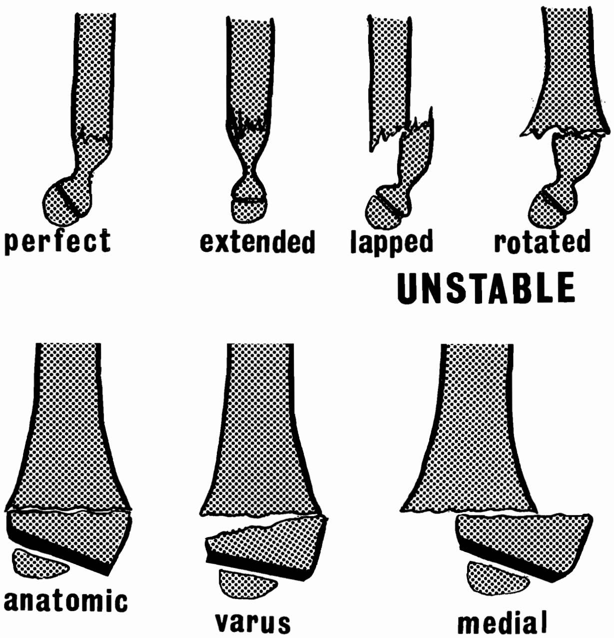


Fig. 12-19. Possible appearances in the anteroposterior and lateral radiographs. In the anteroposterior film, look at Baumann's angle; the thick, black line should be at 70 degrees to the humeral shaft.

Decisions to Be Made During Reduction. *What Do the Radiographs Show?* The radiographs are difficult to interpret in the heat of the moment. Oblique films sometimes help. Figure 12-19 shows the various possible appearances and may help you to recognize faults.

Entrapment. If the elbow is flexed before the fracture surfaces are apposed, nerves and vessels may be trapped. Interposition may prevent reduction.

Irreducibility. If you believe in irreducible fractures, you will find quite a number. They will become a talking point. "Do you know, I had another of those irreducible supracondylar fractures last night. This time I had everything ready to open it." There have been times when I have come close to this, but so far

I have yet to see an irreducible supracondylar fracture.

Follow-up. Repeat radiographs should be taken before the child goes home. Radiograph the fracture again a week after injury. If the position is unsatisfactory, a further attempt at reduction should be made, or the child should be placed in traction. (This is almost never necessary.)

Remove the cast and pins at 3 weeks and radiograph again. Do not leave the cast on for longer than 3 weeks. Warn the parents that it may take at least 3 months for the elbows to regain full movement, and perhaps longer. A small proportion of children have permanent limitation of elbow movement.

Problems and Variants

In a review of 200 consecutive patients with supracondylar fractures requiring reduction, the following features emerged. After closed reduction two-thirds of the patients had no problems, whereas one-third of the patients had early problems: nerve palsy, poor position, instability, two fractures in the same limb, or fracture variants.

Soft-Tissue Problems. *Nerve Injuries* (14%). Half of these were noted before reduction and half, after. Perhaps some were missed initially, but others developed progressively. The radial nerve and median nerve each accounted for 6.5%, while the ulnar nerve was injured in 3.5%. The majority recovered com-

Fig. 12-20. The flexion type of supracondylar fracture.

pletely within a few months. This has been the experience of most authors. An occasional case does not recover. I have seen one radial nerve disappear into the bone at the time of supracondylar osteotomy (in a child with a complete radial palsy and malunion). This was 4 years after injury. Another child with a partial median palsy had no recovery after a year.

Vessels. In this series of 200 cases, only one case of Volkmann's contracture occurred, and that patient was referred to the hospital with the condition already established. If Volkmann's contracture is a common problem at your hospital, it would suggest that the treatment of this fracture should be improved. Volkmann's contracture is largely a preventable condition. When it does occur, radical, urgent fasciotomy and exploration of the vessels is required (as described in Chap. 5). Absence of a radial pulse is not an indication for exploration if the fingers are pink and can be painlessly extended.

Skin (1%). The occasional open fracture requires surgical toilet and may then be managed in the same fashion as a closed fracture. We have had no problems of infection.

Bone Problems. Comminution of the medial column occurred in a few fractures and rendered the reduction less stable. Closed treatment is still usually possible.

A flexion injury produced anterior displacement in 2%; these injuries were treated in extension (Fig. 12-20). In children of 15 and 16, fractures of the adult type occurred. Comminuted Y and T fractures present problems with reduction. In some, a good reduction can be obtained by wrapping an Esmarch bandage around the arm for a few minutes and then using skeletal traction for 3 weeks (Fig. 12-21). Others can be treated by open reduction and internal fixation using ASIF equipment (Fig. 12-22).

Two fractures in the same limb were seen in 4%, mostly involving the distal forearm, but occasionally through the shaft of the humerus. Diagnosis was easily missed. At least one radiograph should include the entire humeral shaft and the forearm bones. The forearm fractures were held satisfactorily in a supracondylar-type cast. Those fractures involving the humerus required skeletal traction.

Problems with Reduction

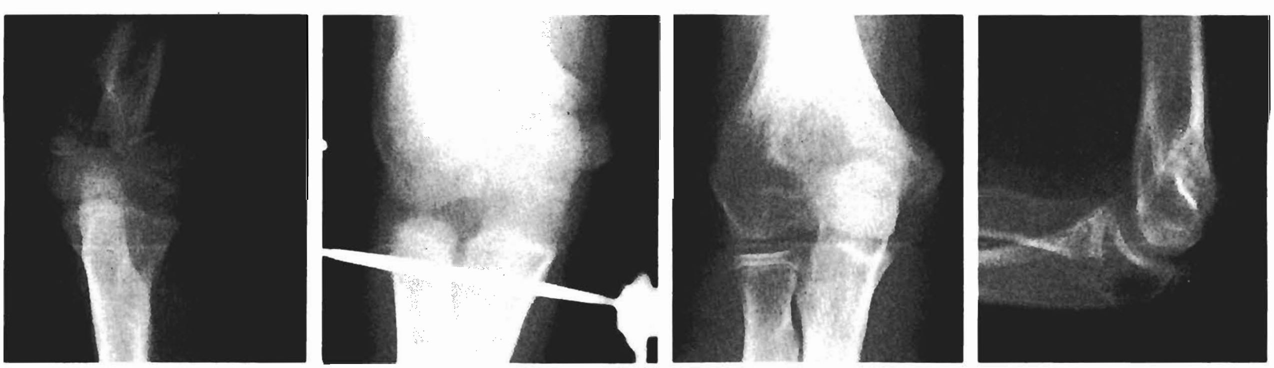
Closed reduction is possible in the majority of fractures. If the elbow is very swollen, traction may be wise. The winged screw developed by Palmer and associates is safer than a transverse ulnar pin, because it avoids risk to the ulnar nerve.[25] A small stab incision over the subcutaneous border of the ulna is made at the level of the radial head. The screw goes in like a corkscrew. The screw is attached to overhead, balanced traction, using the hole that best corrects valgus/varus angulation.

When radiographs are taken, be there to ensure that the beam is centered on the distal humerus.

After 3 weeks the device is removed and active movement may begin.

Before we used percutaneous K-wires we found that 9% of fractures treated by closed means required further "alterations." (A tailor introduced me to this useful term.) A few of the unsatisfactory reductions were corrected by traction. In others—those in which insufficient flexion was obtained initially—the arm was flexed further at about 5 days. Most of those

Fig. 12-21. This comminuted T fracture in a 13-year-old boy was treated in traction. Follow-up films, taken 6 months later, show anatomical union. He had a full range of movement. This is a risky method.



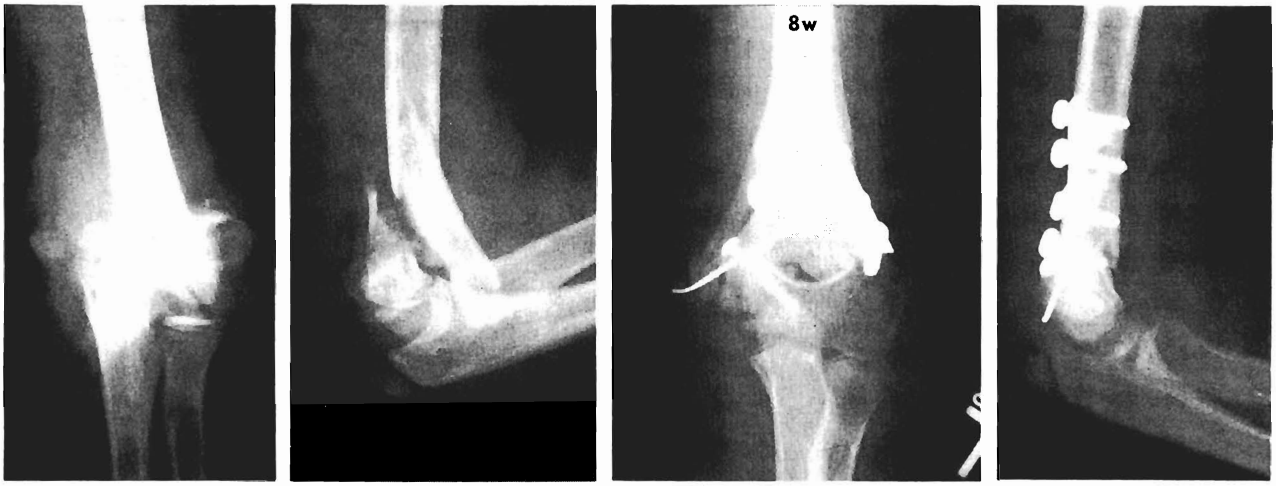


Fig. 12-22. Even through a posterior approach this was a tedious operation, and the patient, a 12-year-old boy, lost the last 20 degrees of extension.

thought to have slipped had, in fact, either a poor initial reduction, which was not appreciated, or a poor cast. Do not expect to reduce this fracture after a week. With wires we have traded these problems for the need to remove pins under anesthesia. The chief causes of stiffness are immobilization beyond 3 weeks and forced movement thereafter.

Varus and Valgus Deformity

The techniques of management described are very effective in preventing malunion (Fig. 12-23). The only patient of ours who required treatment for malunion was wrongly thought to have no displacement initially, and the fracture went unreduced.

The deformity is only recognized when the arm is fully mobile again. It is due to malunion and not to a growth disturbance. A gunstock deformity consists of varus, medial rotation, and extension deformity (Fig. 12-24). It should be corrected only after the elbow has regained full mobility. Though corrective supracondylar osteotomy is frequently dismissed as an easy operation, our results in 28 cases suggest that the problems have been underestimated. For a varus deformity, a lateral incision should be made over the supracondylar region, and the periosteum lifted. A lateral wedge is removed, leaving a medial hinge intact. The medial hinge should be cracked to obtain the desired position. Do not try to correct rotation; the shoulder can compensate, and attempts to correct rotation will only make the osteotomy unstable. Correct hyperextension; it may even be wise to aim for a few degrees of fixed flexion, because this will hide any inaccuracy in the osteotomy. The problem comes in holding the position. We have tried fixation in a cast with the elbow flexed and the forearm fully pronated and found that the position was lost in three out of eight patients while in the cast, and required further correction.

In 20 patients the osteotomy was held by a single Kirschner wire. Seventeen of the 20 were satisfactory, but several dangerous complications ensued. One patient developed an aneurysm of the brachial artery because the Kirschner wire penetrated the artery. Another developed gross swelling of the arm, suggesting a similar injury to the artery, and had nerve palsies and skin loss as a result. Another developed infection of the bone. The overall results are shown in Figure 12-25 and in Table 12-2.

Other methods of fixation have been advocated. Langenskiold and Kivilaakso used a four-hole plate, but found 2 out of 11 osteotomies required further correction.[17] This is my current favorite. French advocated a wire loop wound around two screws, as illustrated in *Campbell's Operative Orthopaedics*.[5,10] No results have been published. Other surgeons have used the staple, and some have immobilized the arm in full extension for 3 weeks. Tachdjian advocates external pin fixation with Roger Anderson apparatus.[33]

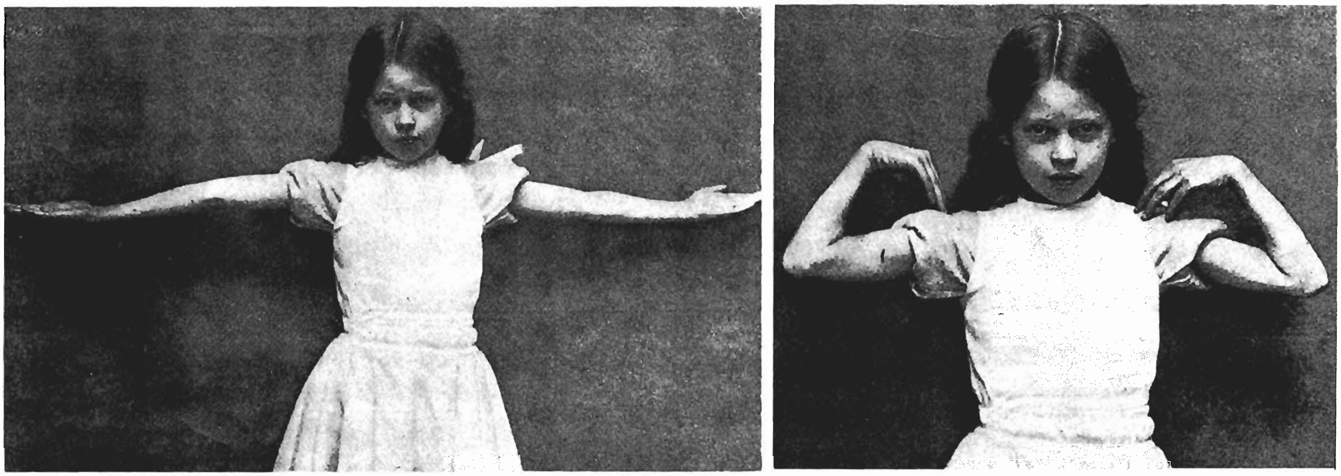


Fig. 12-23. Minor degrees of malrotation do not matter. Hey Groves' (1916) illustration shows the frequent result of a right supracondylar fracture. Slight hyperextension, slight loss of flexion, and slight external rotation are present.

Fig. 12-24. A typical gunstock deformity.

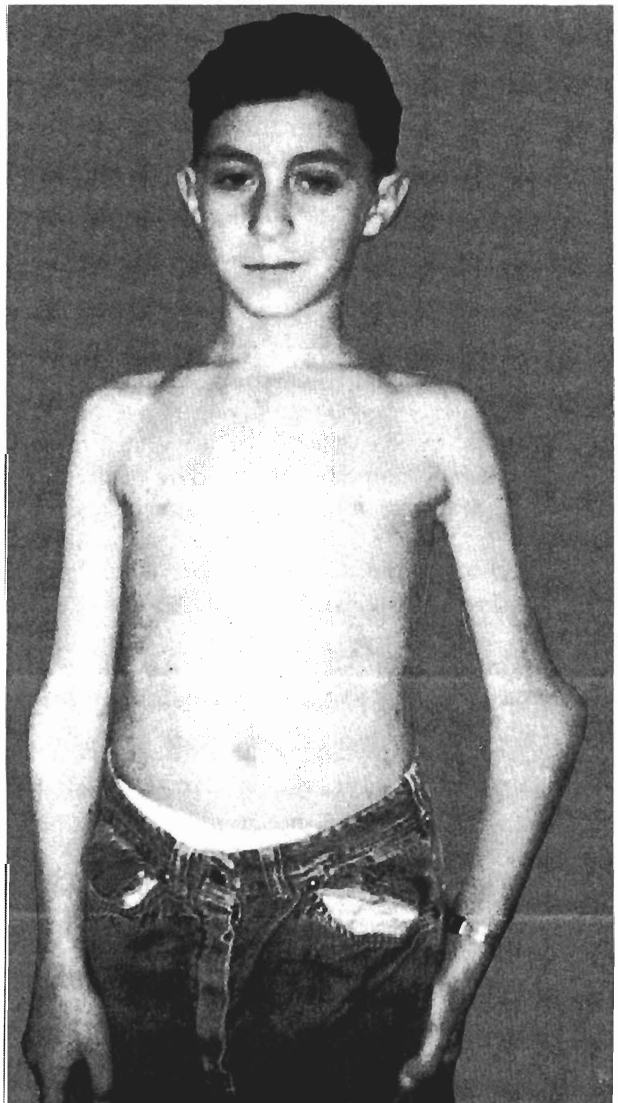


Fig. 12-25. The results of supracondylar osteotomy in 25 patients. The osteotomy was held by a Kirschner wire in the shaded columns; in the white column, a cast provided the only fixation. The carrying angle was restored in only half the patients.

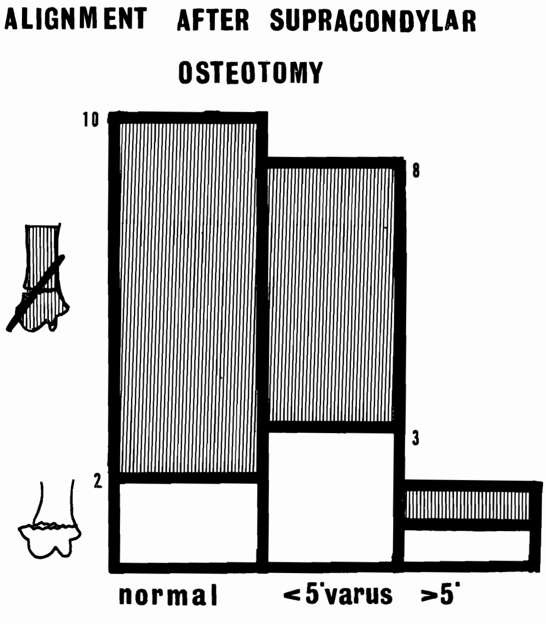


Table 12-2. Supracondylar Osteotomy

14 COMPLICATIONS IN 25 PATIENTS	
General	
Poor scar	3
Stiffness	2
No internal fixation	
Displaced	3/7
Neuropraxia	1/7
Internal fixation	
Displaced	2/18
Pin problems*	3/18
	14/25

*Aneurysm, pin-track infection, hematoma, skin loss, and neuropraxia

Malunion is obviously more difficult to correct than to prevent. A foolproof method of correction has yet to be established.

MEDIAL EPICONDYLE

Valgus strain applied to the elbow of a cadaver fractures the radial neck. A medial epicondyle seems likely to be avulsed, either by the contraction of the flexor muscles at a time when the valgus strain is applied or by a dislocation.

In children between the ages of 5 and 15, the clinical signs of a medial hematoma may be more obvious than the radiographic ones. A film of the normal elbow will eliminate doubts.

The degree of displacement should be assessed (Fig. 12-26) and the presence of other injuries noted, such as fracture of the radial neck and injury of the ulnar nerve, which lies close by.

Diagnostic traps do exist; the unossified apophysis in a child less than 5 years old casts no shadow, and avulsion is a matter of conjecture (Fig. 12-27). Until the age of 11 or 12 years, separation of the medial *condyle* may masquerade as an epicondylar separation, and because the ossific nucleus of the medial condyle does not appear until this age, the diagnosis may be overlooked. A neglected fracture of the medial condyle is as bad as a neglected fracture of the lateral condyle. It may be possible to avoid this trap in children under the age of 5 who have soft-tissue swelling on the medial aspect of the joint by examining the elbow under anesthesia. Instability should be treated by exploration.

Fig. 12-26. The varieties of medial epicondyle separation.

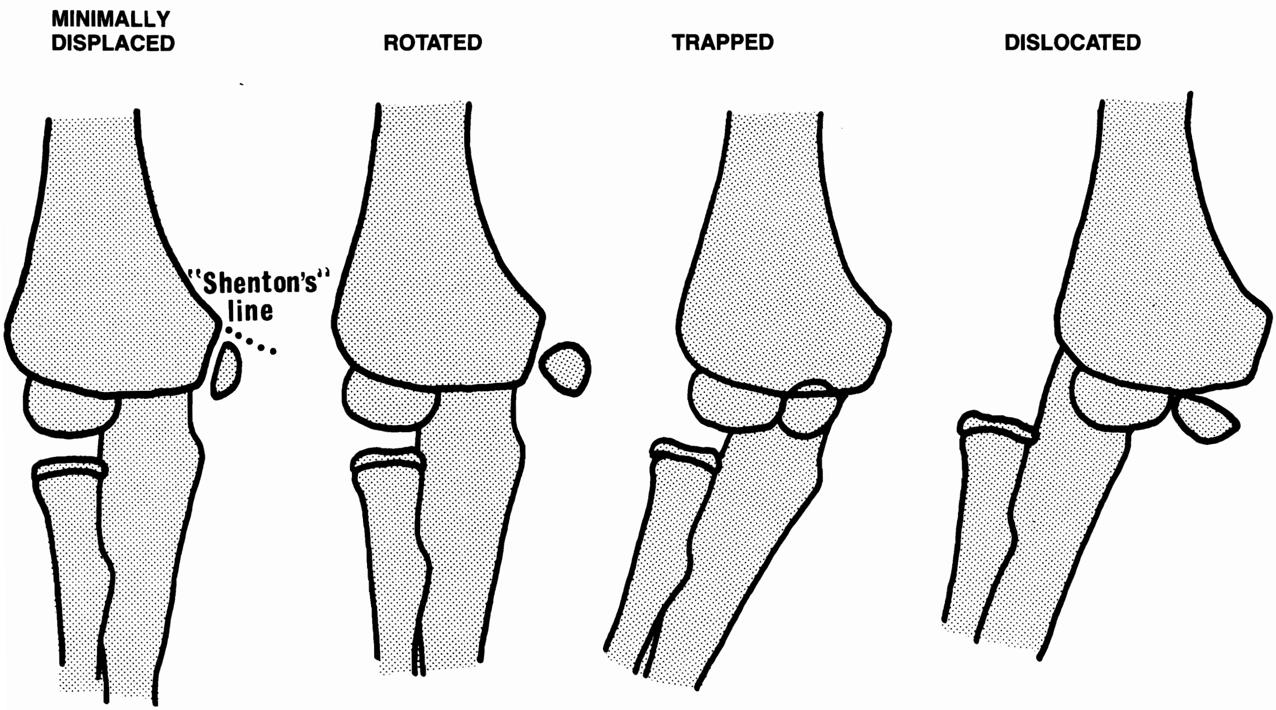


Fig. 12-27. This child had an open dislocation of the elbow joint. Air is in the joint. Though there is no sign of injury to the medial epicondyle, it was found to be separated during joint toilet.

Treatment

The choice of treatment is somewhat emperic, because convincing comparisons between operative and nonoperative treatment have yet to be made. After reviewing 50 cases, Bede and associates favored closed treatment in the majority; I find these conclusions difficult to accept.[2] Stiffness in 71% overall seems excessive and may be attributed to 5 weeks average immobilization of the elbow. No elbow should be immobilized this long. Protzman has shown that the permanent loss of motion in adults following elbow dislocation is related directly to the duration of immobilization; the same seems true in children and leads most of us to aim for early movement in elbow injuries.[27] Furthermore, nonunion was common even after surgery in Bede's series, which is not typical.

Wood and Tullos noted elbow weakness owing to medial ligament instability and stiffness in isolated patients treated nonoperatively.[37] They advocated a policy similar to the one given here. Open reduction was advised for a throwing arm or an athlete.

Prior to 1950 the majority of patients at this hospital were treated by closed reduction under anesthesia. The elbow was held at 90 degrees in full pronation, with the wrist flexed to relax the flexor muscles; local pressure applied over the medial epicondyle helped to secure reduction. Fibrous union was common. It is my understanding that elbow movement returned more slowly than with open reduction. Some require late excision of the fragment because of discomfort. But instability was not noticed. Since 1950 open reduction has been the most popular. Our current practice is as follows:

Minimal Displacement and Soft-Tissue swelling. Apply a cast to protect the fracture.

Definite Displacement. Under anesthesia, test the stability of the medial side of the elbow. If the injury is the result of a valgus strain, the elbow is unstable, and an open reduction is carried out. Separation owing to a posterior subluxation tears the anterior attachments of the medial epicondyle but not the superior attachments. The elbow is stable after the dislocation is reduced and may be casted. The variety was found in only 2 out of 100 cases (Fig. 12-28).

Displacement and Dislocation. Quickly reduce the dislocation under Demerol in order to assist the circulation and relieve pain. Perform open reduction as soon as the child is fit for anesthesia.

Trapped Fragment. The fragment can be extricated by applying a valgus strain or by supinating the forearm, but it will seldom return to its bed. Perform open reduction.

Open Reduction. If you operate with the child lying on his back, you will be wrestling; either you cannot see the fracture, or you will be engaged in a tug-of-war to hold the fragment in position. Have the child prone, with the arm in the half-Nelson position (in other words, behind the back) with a tourniquet in place. A transverse incision leaves a better scar, but a longitudinal incision (slightly posterior so that the child cannot see the scar) has tradition behind it. Divide the skin and subcutaneous fat, and then you will find fracture hematoma. The tissues will be so stained with blood that identification of important structures is difficult. Wash everything clean and milk the blood out of the joint. The fragment then comes into sight. Hold it with a towel clip and pull distally in order to find the ulnar nerve. The nerve can and must be found by looking through the tear in the posterior periosteum. Often stained red, the nerve is easily recognized by the nutrient artery on its surface. Do not dissect the nerve free or put tapes around it. About 5% of our cases have had a transient postoperative ulnar nerve palsy that was associated with overelaborate displays of the nerve.

The fragment will usually fall back into position. The fracture surfaces are easily recognized, and the rotation can be checked by lining up the flexor muscle fibers with the line of the forearm. Hold the fragment in place with a superficially placed towel clip while it is secured with a Kirschner wire (Fig. 12-29). A few absorbable sutures around the periosteum will complete the fixation. I prefer a Kirschner wire because I do not completely trust absorbable sutures, but some surgeons are content with sutures alone. An above-elbow cast is applied with the elbow flexed to 90 degrees, the forearm pronated (to relax pronator teres), and the wrist slightly flexed. At 3 weeks

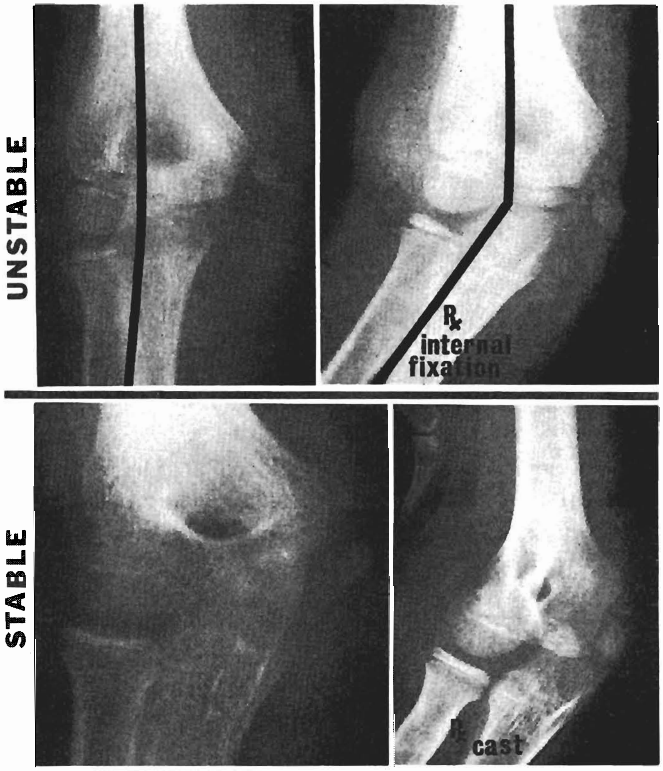
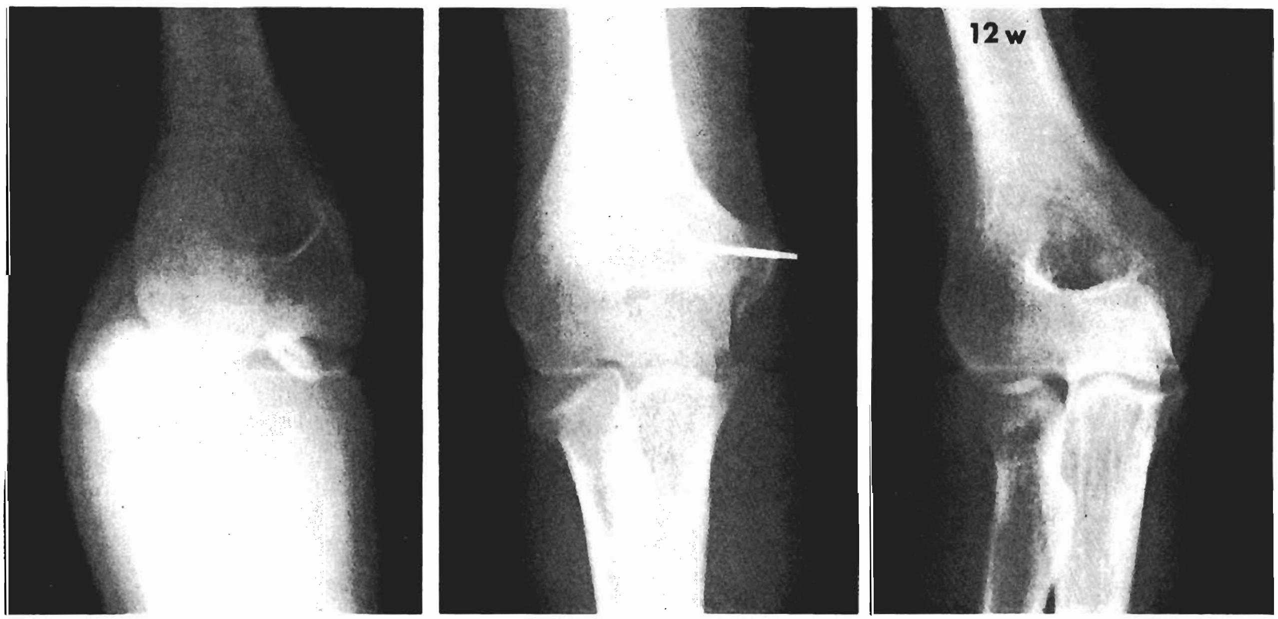


Fig. 12-28. Assess the stability of the medial epicondyle under anesthesia.

Fig. 12-29. Separation of the medial epicondyle accompanied by dislocation and by a fracture of the radial neck. The fragment is pinned back. Three months later the growth plate is closing.



the cast is removed. The pin has often worked through the skin by this time, because there is so little subcutaneous fat over the condyle to hide it after the swelling has receded. The pin is removed. If it is still subcutaneous, remove the pin at 4 to 5 weeks under local anesthesia.

Problems. A review of the charts of about 150 patients (and a search of my conscience) brought very few problems to light.

Movement. Full extension is often slow to return and may never be achieved. A word of warning to the parents in advance is better than a thousand words of explanation afterwards.

Complications After Closed Reduction. One child had been immobilized for 6 weeks and had persistent stiffness treated by two manipulations under anesthesia with some benefit. No elbow should be immobilized this long.

Another child had a posterior dislocation with avulsion of the epicondyle treated by closed reduction. About 3 months after injury the elbow was still very stiff, and signs of median-nerve impairment were noted. The nails of the index and middle fingers developed clubbing, and the girl began to bite her nails. Nearly a year later, the median nerve was explored because the signs were unchanged and the elbow had only 40 degrees of movement. The nerve was found to pass into the humerus at the fracture site and through a bony tunnel into the elbow joint before resuming its normal course. The nerve was freed and restored to its anatomic position.

We encountered only one ununited medial epicondyle producing pain and requiring late excision of the sesamoid-like bony nodule.

A Problem Encountered at Open Reduction. A child presented with an acute dislocation of the elbow and a widely displaced epicondyle. The dislocation was reduced with difficulty. Attempts to carry out an open reduction of the medial epicondyle met with even more difficulty until it was realized that this child had a fresh dislocation and an old ununited separation of the medial epicondyle. The fragment was excised and the soft tissues repaired.

In conclusion, medial epicondylar fractures seem to have good prognoses. We favor open reduction if the elbow is unstable under anesthesia.

Fig. 12-30. Simple dislocations are rare; always look hard for a fracture as well.

DISLOCATION OF THE ELBOW

Dislocation, unaccompanied by fracture, is rare in children. Always look for a fracture. Figure 12-30 is an example of a simple dislocation, but, even here, we suspected an occult separation of the medial epicondyle.

Differential Diagnosis of Elbow Dislocation

Does an infant's elbow ever dislocate? A Type-I separation of the distal humeral epiphysis in an infant with an unossified epiphysis looks like a dislocation (Fig. 12-31). Muffled crepitus on examination confirms the separation. An arthrogram may be helpful.

I have encountered a Type-I injury twice, and both times I was fooled. The parents neglected to mention trauma in the history. The hot, swollen, painful elbows in these two infants suggested septic arthritis. One I tried to drain; the other was aspirated. Both were examples of child abuse. Straight-arm traction is probably the best treatment, because cubitus varus is a hazard.

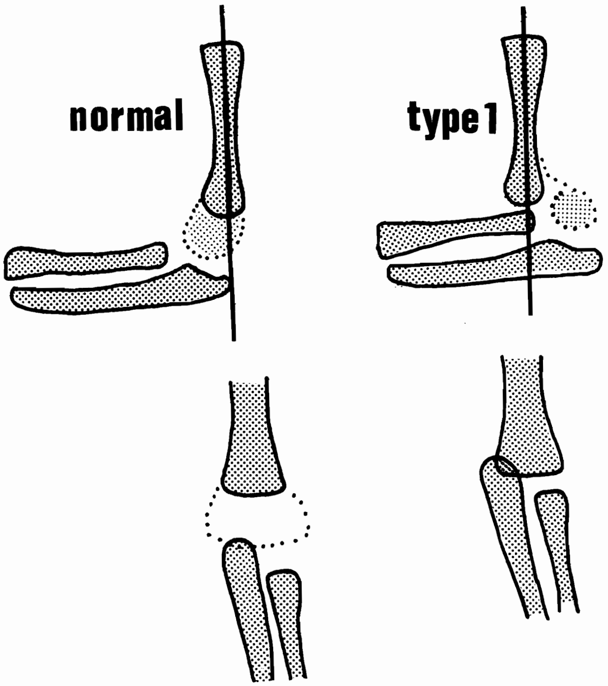


Fig. 12-31. X-ray film signs of a Type-I injury in the newborn. The olecranon moves posteriorly.

FRACTURES OF THE LATERAL EPICONDYLE

An ossification center appears at the age of 12 and fuses with the lateral condyle at the age of 14. The center for the lateral epicondyle is often irregular, and beginners often confuse it with a fracture. We have encountered only one patient with separation of this epiphysis. It was explored because it looked so like a fracture of the lateral condyle.

FRACTURES OF THE LATERAL CONDYLE

Fracture of the lateral condyle has an evil reputation. However, most of the children we treat do not come back to the clinic more than once following cast removal. For most orthopaedic surgeons, this is a solved fracture.

The mechanism of the fracture is controversial. Dr. Roland Jakob has produced the fracture experi-

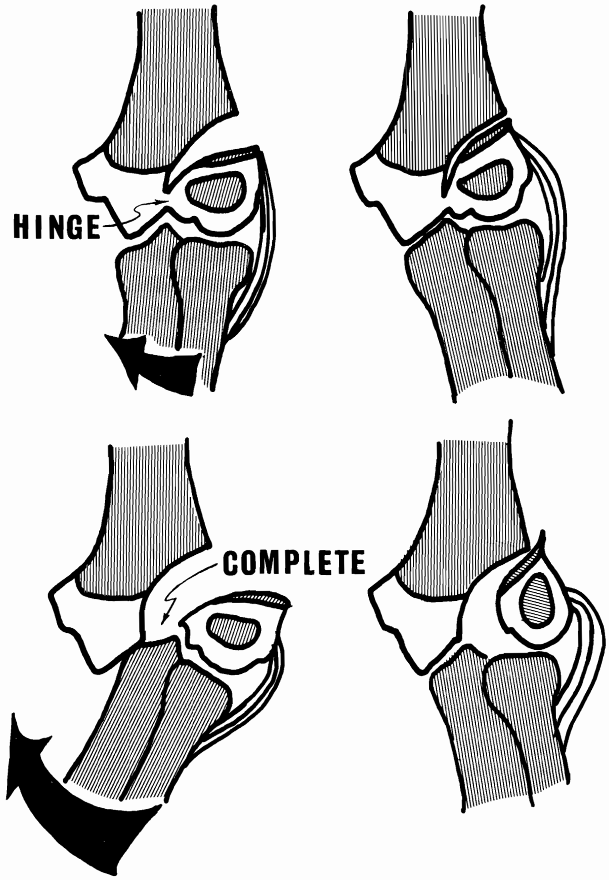


Fig. 12-32. The experimental production of a fracture of the lateral condyle in a cadaver. *(Top)* A varus force avulses the later condyle but leaves a hinge of cartilage intact. When the elbow is released, the fracture reduces. *(Bottom)* When the force is greater, the hinge tears and the elbow dislocates. When the elbow is released, the fragment rotates and does not reduce. (Courtesy of Dr. Roland Jakob.)

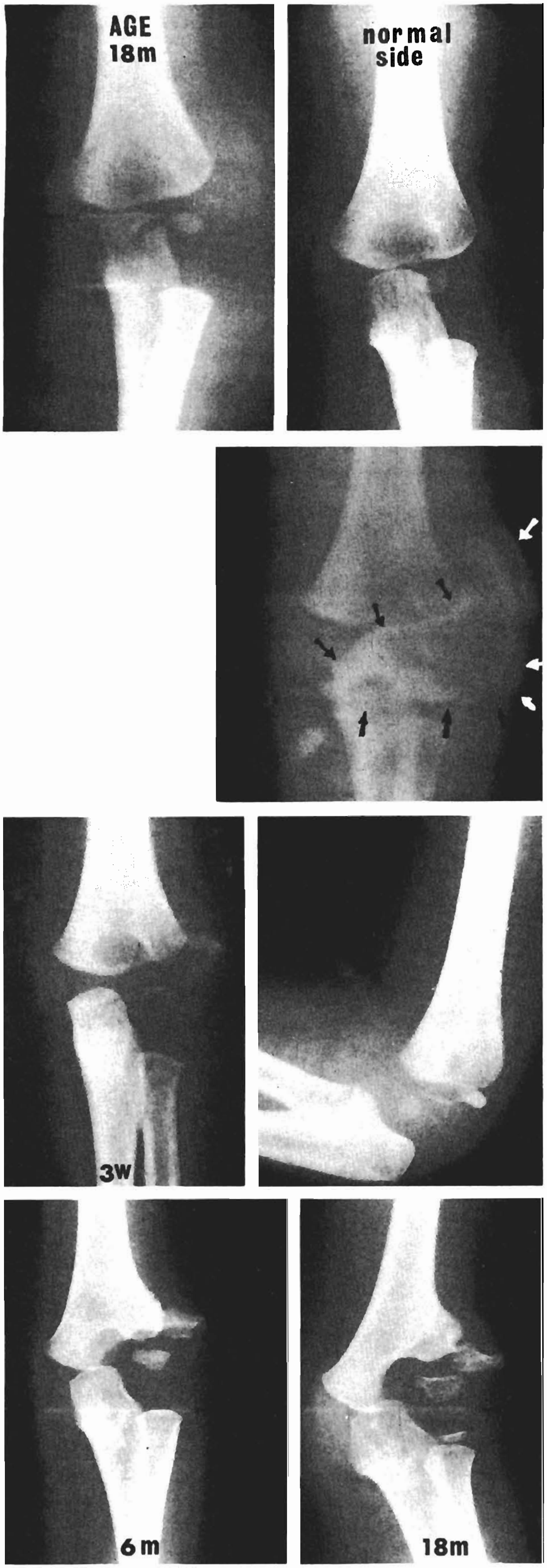


Fig. 12-33. This child, aged 18 months, was admitted with the diagnosis of a fracture of the lateral condyle. At rounds, the surgeon was persuaded to carry out an arthrogram to confirm the diagnosis, and this was wrongly interpreted as normal. The elbow was placed in a cast. Later the child revealed all the problems of an ununited displaced fracture of the lateral condyle. The varus fracture of the olecranon seen in the initial film is a clue to a fracture of the lateral condyle.

mentally in a cadaver by applying a varus strain to the extended elbow at this hospital.[15] The trochlear ridge on the ulna behaves as a fulcrum for avulsion of the lateral condyle by the lateral ligament (Fig. 12-32). The bone separates, but the articular cartilage remains intact as a hinge. The fracture reduces when varus angulation is corrected. But if, instead, the angulation is increased, the cartilage hinge tears, the fracture displaces, and the elbow may dislocate. The fragment displaces through 90 degrees in two planes.

The child with a fracture of the lateral condyle has a swollen, tender area over the lateral part of the elbow. Circulatory and neurologic complications were unknown in our series of 100 displaced lateral condyles.

Grossly displaced fractures are obvious on radiographs, but hairline fractures can be missed easily (see Fig. 12-1). When there is clinical evidence of a fracture but no radiographic signs, you should take further views until the fracture shows up. Stress films are a last resort. In a very young child, the center of ossification may be so small that the nature of the injury may be misunderstood (Fig. 12-33). The only problems we have encountered in recent years were in children in whom the diagnosis was overlooked.

Lateral condylar fractures are Type-IV injuries. The majority, however, pass through the cartilaginous epiphysis and are unlikely to affect growth for the reasons explained on page 14. About 5% pass through the ossific nucleus of the capitellum, and the risk of growth arrest is theoretically higher in these.

The complications an orthopaedic surgeon should keep in mind are malunion resulting in stiffness and cubitus valgus, and nonunion, the most common problem when treatment is inadequate. There are several reasons for nonunion: lack of immobilization, synovial fluid bathing the fracture, and soft-tissue

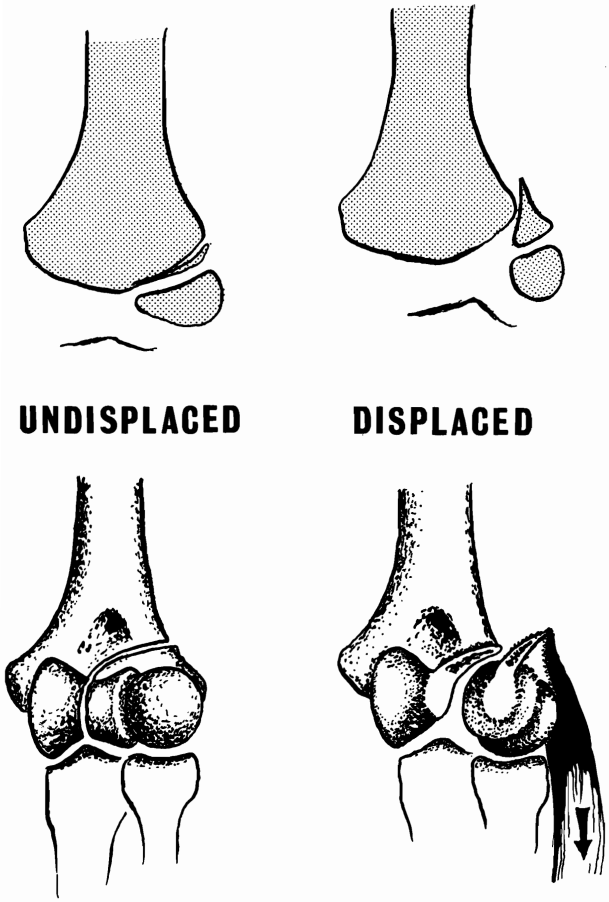


Fig. 12-34. Undisplaced and displaced fractures. Because the apex of the fracture is the trochlear notch, displaced fractures are often accompanied by lateral subluxation of the ulna.

interposition. The elbow looks ugly, and there is marked cubitus valgus, which inevitably leads to a tardy ulnar nerve palsy. Smith recently reported an 84-year follow-up study of a patient with nonunion.[30] The functional disability was minimal, but the ulnar nerve palsy was complete!

Classification

From the practical point of view, fractures of the lateral condyle are displaced or undisplaced (Fig. 12-34). The undisplaced fractures appear horizontal and are moderately stable; the cartilage hinge is intact. The displaced fractures appear oblique and are widely displaced (Fig. 12-35).

Treatment

Undisplaced Fractures. Undisplaced fractures may be immobilized in an above-elbow cast with the elbow at 90 degrees. Further flexion tends to displace the fragment. Radiographs should be obtained every 3 to 4 days for the first 2 weeks, because displacement is not unknown. Some may prefer percutaneous pinning in situ.

Three, or at most 4, weeks in a cast is sufficient to achieve union and to avoid stiffness.

Displaced Fractures. Twenty-five years ago closed reduction had its advocates, who based their view on adequate results in about two-thirds of children. McLearie and Merson noted that reduction was possible if the elbow was first dislocated again.[21] Then the fragment was pushed into place, and the dislocation was reduced. If nonunion and redisplacement occur, however, they are difficult to correct.

For this reason, all these fractures must be treated

Fig. 12-35. Associated injuries are common in all fractures of the elbow. The 8-year-old *(left)* has a medial dislocation. The 5-year-old *(right)* has a varus type of olecranon fracture associated with a lateral condylar fracture.

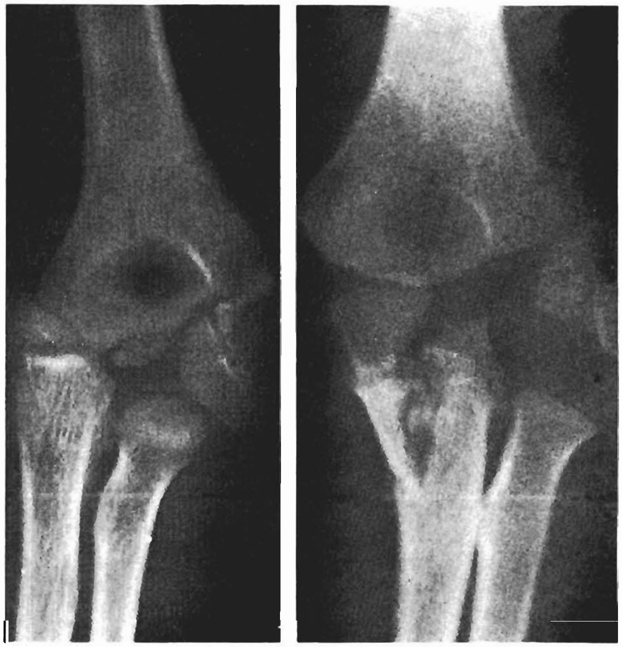


Fig. 12-36. Despite the best intentions, it is often impossible to close the fracture line completely, but always use two pins. Union was delayed in this 5-year-old child. When seen 3 years after fracture, he had a full range of movement and no deformity.

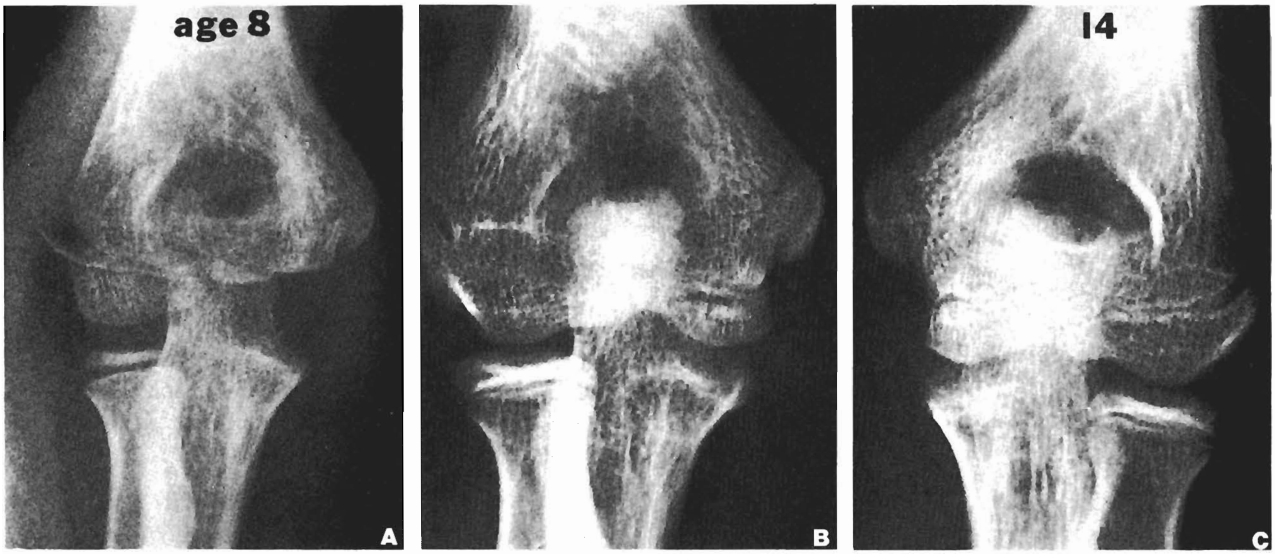


Fig. 12-37. *(A)* Displaced fracture of the lateral condyle, which was replaced and held with two pins. *(B)* The same elbow 6 years later. It was perfect clinically, but there is premature closure of the growth plate. *(C)* A view of the normal elbow for comparison.

by immediate open reduction and internal fixation. The results are consistently better.

Technique. With the patient supine and a tourniquet inflated, an incision is made directly over the lateral condyle. As soon as the subcutaneous layer is incised, fracture hematoma will flow out. Mop this up and milk clots out of the elbow joint. Irrigate the joint to obtain a clear view. The fragment requires no dissection (which carries the risk of avascular necrosis), but it will be found rotated through 180 degrees. Slip a long-bladed retractor into the joint anteriorly, in order to visualize the head of the radius and the fracture bed. Now try to set the fragment back in place. The periosteum of the humeral shaft may need to be lifted in order to define the bed. It is easy enough to get the lateral margin replaced, but it is very difficult to see that the joint surface is repositioned. It may be helpful to divide a little synovium to get a better view. If the joint surface is not perfect, stiffness and delayed union are more likely to be a problem. Hold the fragment in place with one or two towel clips while it is transfixed with two parallel Kirschner wires. Engage the opposite cortex.

At this stage, take radiographs to be sure that reduction is anatomic. While everything is exposed, you will be prepared to strive for perfection; when the dressing is in place, you will be content with anything short of disaster.

Suture the periosteum. Cut the pins below skin level, and apply a cast with the arm at 90 degrees.

Three weeks in a cast is sufficient. Leave the wires in place until they penetrate the skin, but not over 6 weeks (Fig. 12-36).

Results of Treatment

Hardacre and associates have demonstrated clearly that open reduction and internal fixation yield much better results in displaced fractures than traction or closed reduction.[13] Wadsworth has observed, however, that premature growth-plate closure is not uncommon, even in undisplaced fractures.[34]

I wrote to 100 patients who had had immediate open reductions for displaced fractures. Twenty-seven were examined and radiographed. The most common age for this injury was between 4 and 8 years. The average length of follow-up was 6 years (2–12 years).

Range of Movement. Perfect in 24 of 27; the remainder had lost no more than 10 degrees.

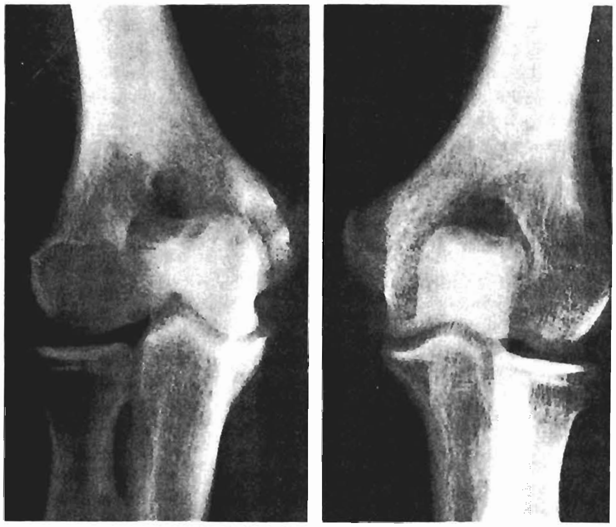
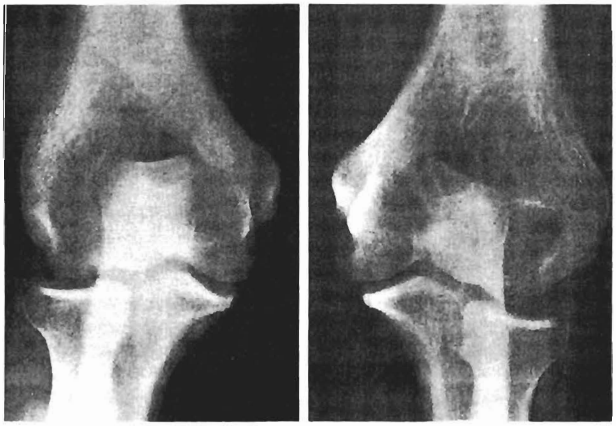


Fig. 12-38. John, aged 19, sustained a fracture of the lateral condyle at the age of 7, and the fragment was sutured in place. He now has a full range of movement and no symptoms. The lateral condyle is prominent. The radiograph *(left)* shows deepening of the trochlear notch—almost a universal finding some years after this fracture. Compare the normal elbow *(right).*

Fig. 12-39. *(Left)* The normal elbow. *(Right)* Ten years after pinning there is a slight lateral subluxation. Clinically the elbow is perfect.



Carrying Angle. Normal in 26 of 27; one had slight varus that had not been noticed.

Lump. The lateral condyle was larger in 15 of 27. This area is subcutaneous, and several patients had noticed the lump.

Scars. All acceptable; the most posterior scars were the narrowest.

Method of Fixation. Suture, one pin, or two pins were used in equal numbers and made no difference to the outcome. Obviously an absorbable suture inserted through a drill hole in the metaphysis and then through the extensor mass circumvented the need to pull out pins.

Radiographs. In only five patients was it impossible to judge which elbow had been fractured. All the remainder had telltale signs. In children aged 10 to 11 at time of follow-up, premature fusion of the growth plate was seen (Fig. 12-37). In all nine skeletally mature patients, the trochlear notch was deepened (Figs. 12-38, 12-39). This was due to a failure of growth of the epiphysis at the site of the fracture line. Crushing at the time of injury is a possible cause. Delayed union had occurred in at least two patients and did not seem to affect the result.

The Late Case

Occasionally a child presents after several weeks with a displaced fracture of the lateral condyle. Should this be accepted or corrected? The results of later surgery are not good because of stiffness and avascular necrosis. It is probably wiser to accept some lateral displacement. Figure 12-40 and 12-41 provide some evi-

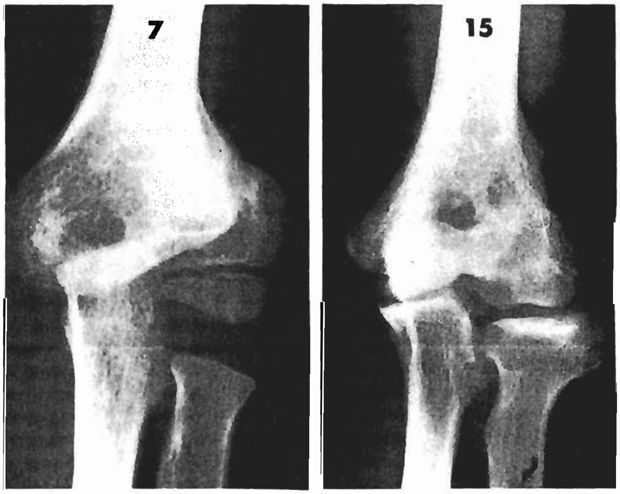


Fig. 12-40. Radiograph of an 8-week-old fracture previously treated by closed reduction. Because there is malunion, an open reduction and pinning were carried out, and postoperatively a transient ulnar nerve palsy was noted. Eight years later, the elbow is pain-free but lacks 35-degree extension and 30-degree pronation, and the radial head shows posterior subluxation. The enlarged radial head and capitellum are due to prolonged hyperemia.

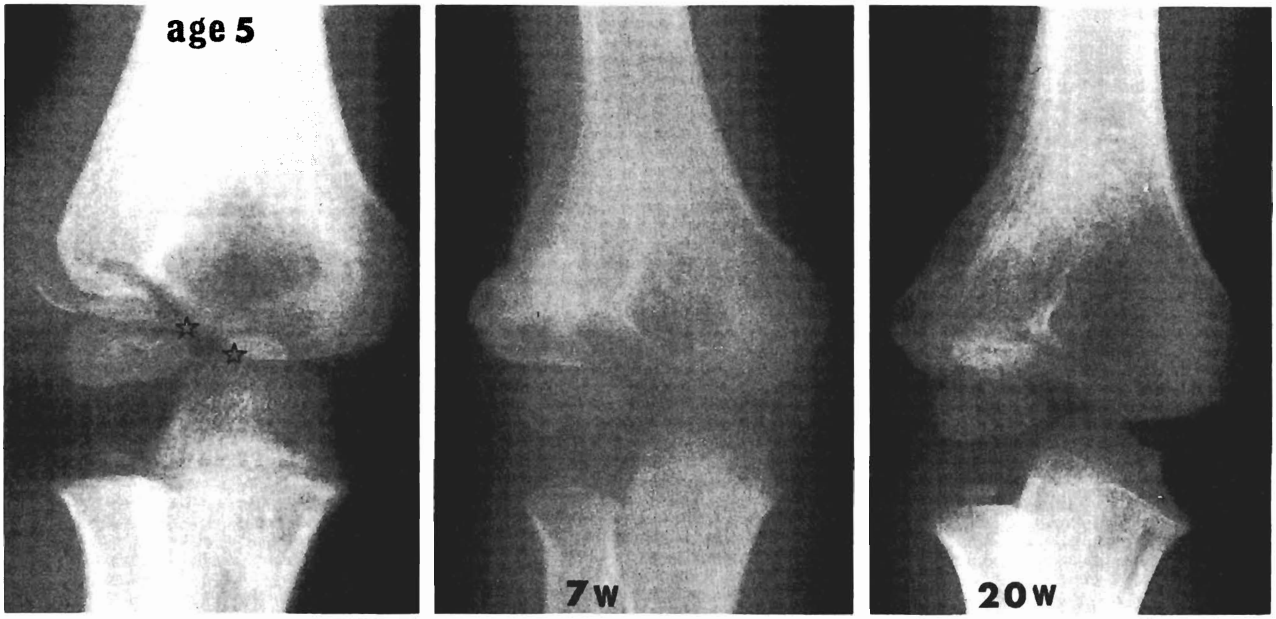


Fig. 12-41. This displaced fracture was first treated 2 weeks after injury. Manipulation did not alter the position, and the position was accepted. One year later the elbow is clinically normal.

dence for this point of view. Old ununited fractures are not surgically rewarding, either. Instability is replaced by some limitation of movement. Which would you prefer? After reviewing the results of operation in displaced fractures more than 12 weeks old and comparing them with similar fractures that had gone untreated, I would favor a "hands-off" policy.

The problem, of course, is the tardy ulnar palsy. The earlier the nerve is transposed the better. Plans should be made to transpose the nerve when a nonunion is seen for the first time, to avoid nerve damage.

Differential Diagnosis of Lateral Condylar Fractures

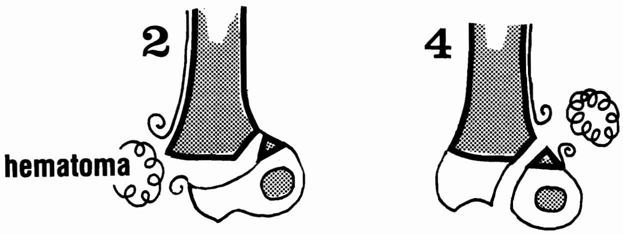
A Type-II fracture separation of the distal humeral epiphysis is a radiologic mimic but not a clinical mimic. Lateral condylar fractures produce lateral swelling, whereas Type-II injuries produce medial swelling (Figs. 12-42, 12-43).

Conclusion

Undisplaced fractures (about half the total) heal well with cast immobilization.

There is no place for a trial of conservative treatment in displaced fractures. Immediate open reduction and internal fixation is mandatory and provides excellent results.

Fig. 12-42. A Type-II injury may be distinguished from a Type-IV injury by the site of the hematoma.



FRACTURES OF THE CAPITELLUM

Replacement should be the aim (Fig. 12-44).

FRACTURES OF THE MEDIAL CONDYLE

Fractures of the medial condyle are rare (Fig. 12-45). They usually occur in older children and may be overlooked if only two views of the elbow are accepted. Fractures of the medial condyle produce the same problems as fractures of the lateral condyle (Fig. 12-46) and deserve the same treatment—rigid internal fixation.

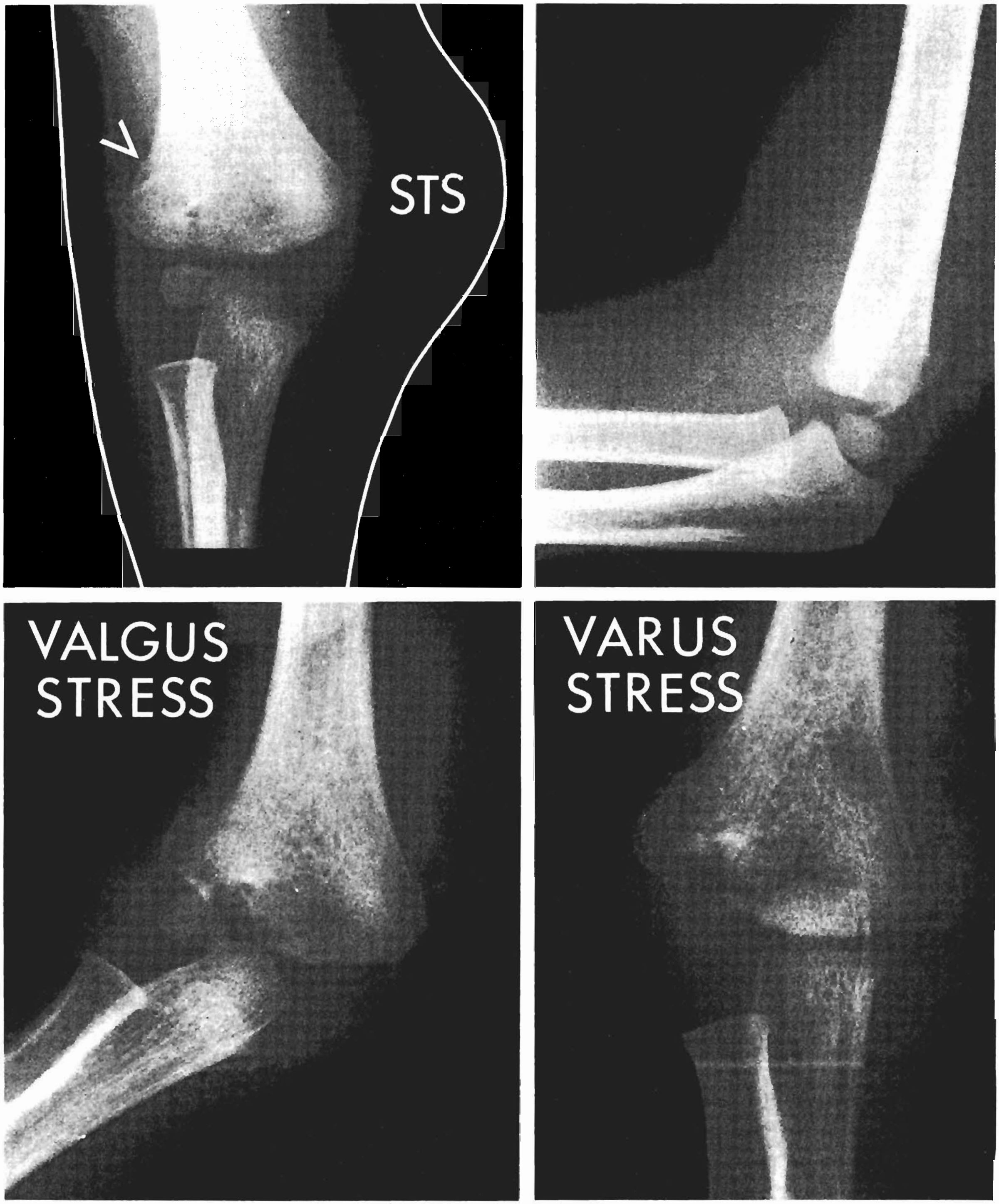


Fig. 12-43. A Type-II injury. The fracture line through the lateral humeral metaphysis is arrowed. Soft tissue swelling (STS) is present. The fracture displaces on valgus stress—the reverse of a lateral condylar fracture. Open reduction would be a mistake. Type-II injuries are controlled by applying varus molding to the extended elbow as the cast sets.

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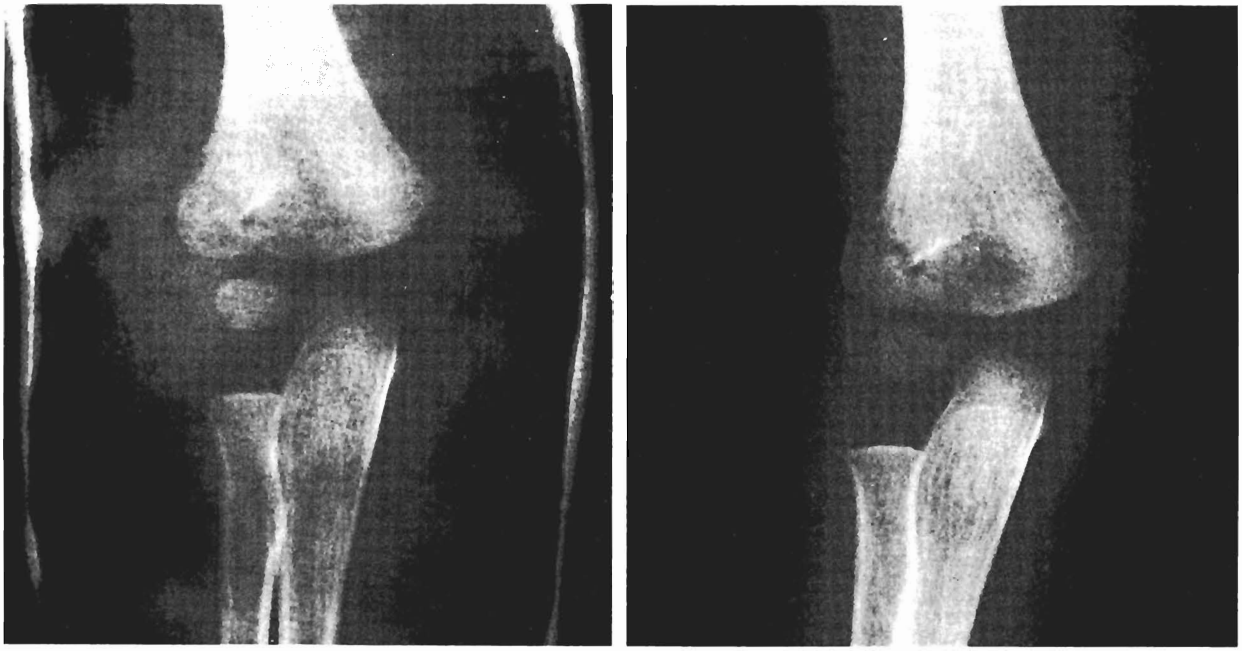


Fig. 12-44. Fracture of the capitellum. Early movement is possible with this technique.

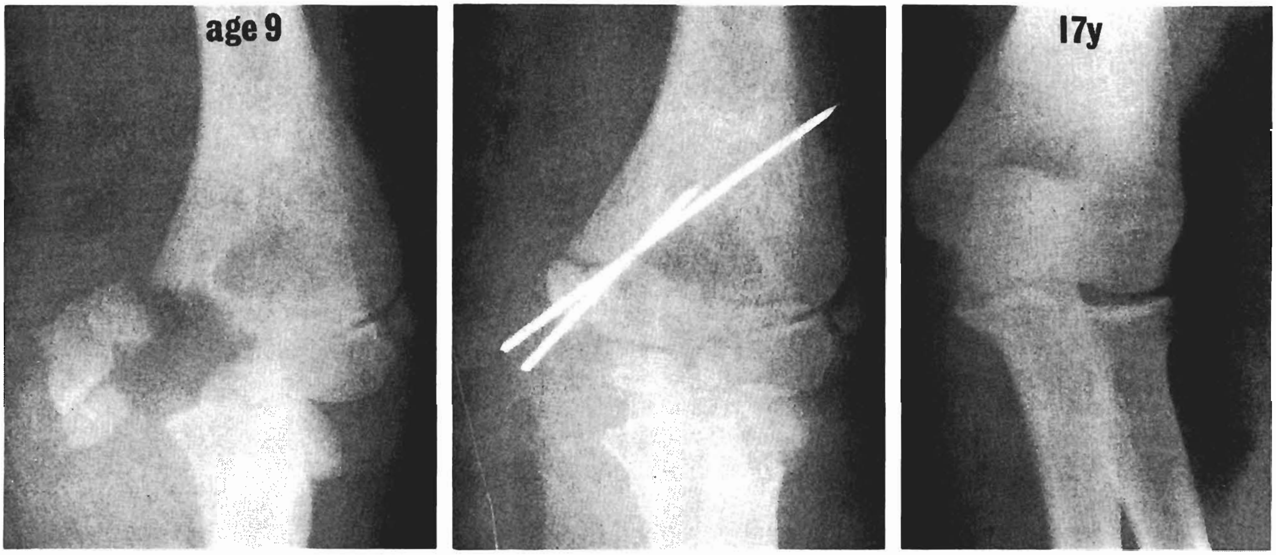


Fig. 12-45. Though rare, fractures of the medial condyle require internal fixation. Did you notice the fracture of the radial neck?

Fig. 12-46. Nonunion of a neglected fracture of the medial condyle.

FRACTURES OF THE PROXIMAL RADIUS

Adults sustain radial-head fractures; children injure the radial neck. The majority are due to a valgus injury; some are a sequel to posterior dislocation[16]; and the remainder are accompanied by fractures of the ulnar shaft, reminiscent of a Monteggia fracture.

Other fractures around the elbow are present in nearly half the children with displaced radial-neck fractures, and they influence management.

Mechanism of Injury

Valgus Radial-Neck Fractures. The normal carrying angle of the elbow makes valgus injury likely in any fall on the outstretched arm. Anatomically, it can be demonstrated that the position of the elbow determines whether the ulna will be fractured too. In full extension the elbow is close packed: the ligaments around the elbow are tight, and the olecranon keys into the olecranon fossa so that valgus and varus movements are prevented. In this position, a pure valgus force fractures the radial neck, and the olecranon sustains an oblique fracture (Fig. 12-47). In a little flexion, the olecranon is no longer held within the olecranon fossa and is free to rotate slightly: a solitary fracture of the radial neck results from valgus force.

If great displacement is produced, the ulna may fracture anywhere.

Bayonet Displacement. The radial shaft moves medially in the direction of the ulna. Manoli describes this going so far that the shaft of the radius locked medial to the coronoid.[20] Lesser degrees are common.

Posteriorly Displaced Fractures. If a child sustains a simple posterior dislocation of the elbow and then falls down, landing on the same elbow, a posteriorly displaced fracture of the radial neck is produced. Open reduction is usually necessary, because it is almost impossible to reduce by manipulation (Fig. 12-48). Wood has demonstrated that manipulation carries the risk of replacement upside down.[38] This is probably the cause of nonunion, which Bohler illustrates as a complication of radial neck fractures.[4]

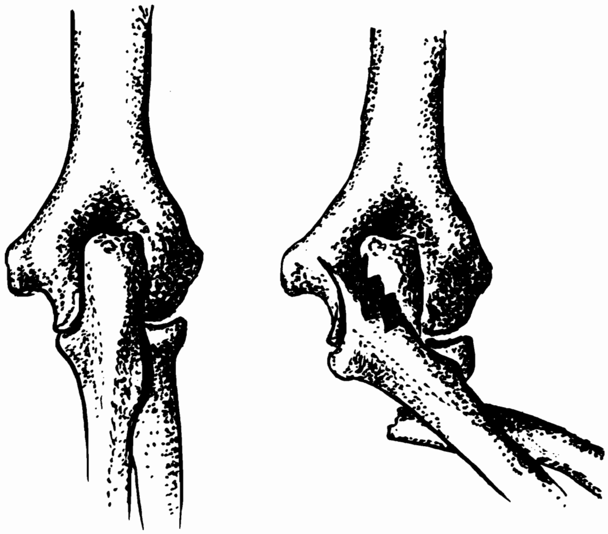


Fig. 12-47. In full extension the olecranon keys into the olecranon fossa. Valgus injury produces a characteristic oblique fracture of the olecranon, and a radial neck fracture.

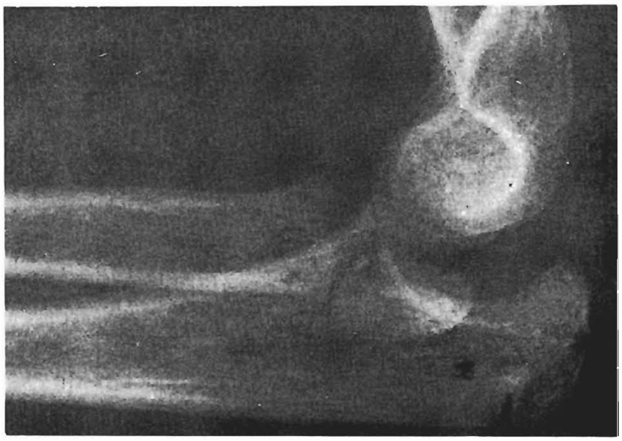
Other Features of Fractures of the Radial Neck

Displacement. The annular ligament hugs the radial metaphysis to the shaft of the ulna. The displaced radial head is not merely angulated but is also shifted laterally, and the shaft is shifted medially.

Assessment of Displacement. Very often radiographs of the flexed elbow are compromise views of the upper forearm and the distal humerus. Well-centered anteroposterior and lateral views of the radial neck should be obtained. The exact degree of tilting and shift can only be measured on films taken at right angles to the plane of angulation.

The Site of Fracture. The cartilaginous head of the radius fits the metaphysis like a bottlecap. For this reason, the majority of fractures are metaphyseal, and only a few are epiphyseal separations. The lateral part of the metaphysis is crushed (Fig. 12-49).

Blood Supply. The epiphysis of the radial head is completely cartilage covered so that the blood supply may be damaged by epiphyseal separation. However, the usual level of injury through the metaphysis is distal to the entry of the vessels, and for this reason



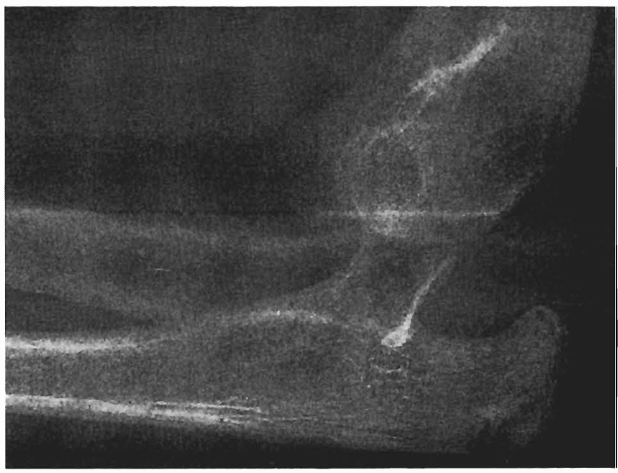
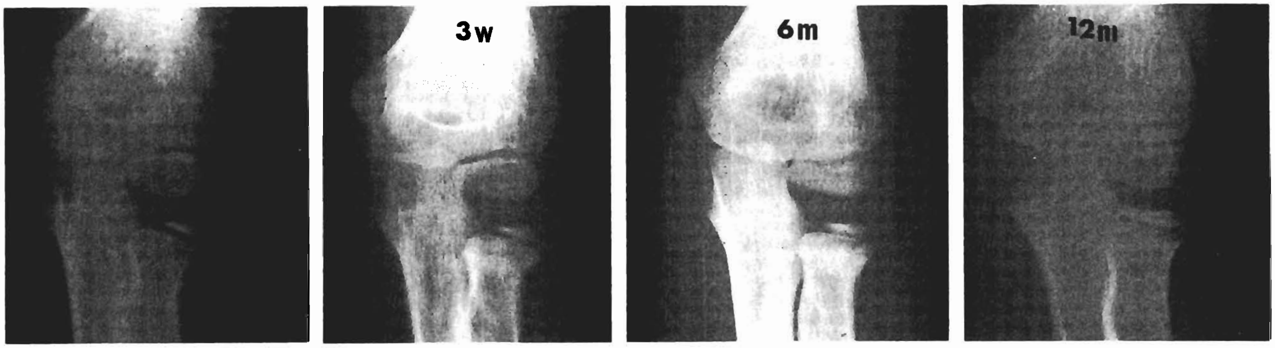


Fig. 12-48. Posterior displacement of the radial neck in an 11-year-old girl. *(Top)* A dislocation with partial separation of the radial head. *(Bottom)* When the elbow is reduced, the radial head is pushed completely off. The articular surface faces inferiorly. Open reduction is required.

Fig. 12-49. The typical metaphyseal fracture of the radial neck in a 13-year-old boy. Seven years after closed reduction there is no sign of a previous injury.

Fig. 12-50. Remodeling will take care of minor degrees of angulation.



avascular necrosis is seldom seen. Even when the head is completely separated, avascular necrosis is not necessarily a major problem, because revascularization of such a small volume of tissues is quickly accomplished, and because this is not a weight-bearing joint.

Associated Injuries. In a group of 48 radial-neck fractures requiring reduction that we followed, exactly half had associated injuries: olecranon, 15; ulnar shaft, 3; medial epicondyle, 2; and one example each of a posterior dislocation, and intercondylar, supracondylar, and medial condylar fractures.

Treatment

Treatment depends on the degree of displacement and the presence of other injuries. The aim of treatment is to restore a normal range of forearm rotation. Twenty or 30 degrees of tilting of the radial head is compatible with a normal range of motion.

Minimally Displaced Fractures (up to 20 degrees). The majority fall into this category. Reduction is not necessary because the fracture will remodel (Fig. 12-50). It is customary to protect the arm in an above-elbow cast for 3 weeks. Function rapidly becomes perfect.

Moderately Displaced Fractures (more than 30 degrees). Reduce these fractures under general anesthetic with facilities available for open reduction (Fig. 12-51). Put a varus force on the elbow, and rotate the forearm back and forth until the maximal prominence of the radial head is felt. Push hard with the thumb on the radial head while rotating the forearm gently. *Then push the shaft laterally*. Often there is no sense of reduction. If reduction is unsuccessful, it is useful to take anteroposterior radiographs with the forearm in various degrees of rotation. In this way the best position can be determined for application of a reducing force. Sometimes winding an Esmarch bandage around the arm during preparation for open

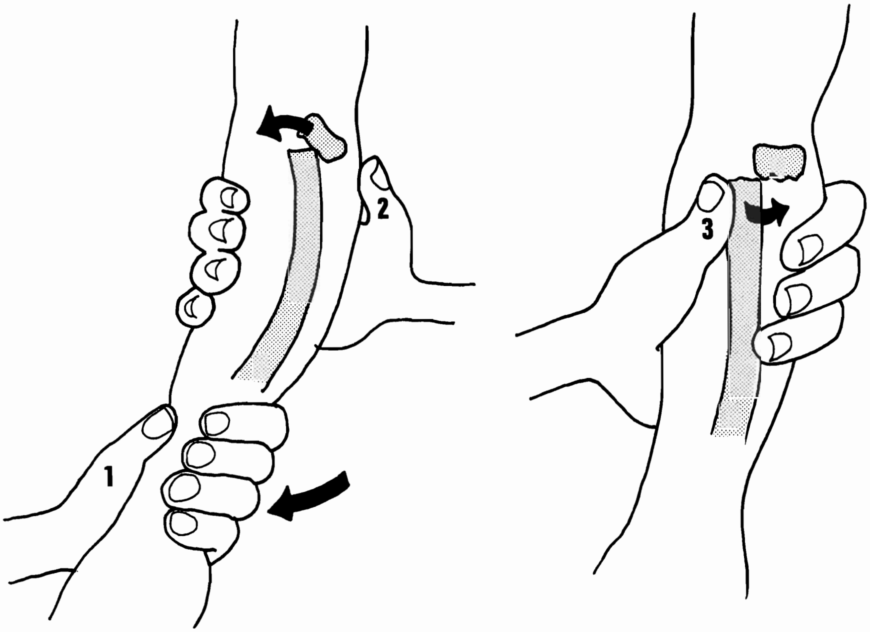


Fig. 12-51. Reduction of a radial neck fracture: (1) Apply varus stress and rotate forearm. (2) Push head medially and (3) push shaft laterally.

reduction accomplishes something that was not possible with the thumb alone.

Percutaneous repositioning of the radial head with a Steinman pin has been advocated by Fasol and associates. Métaizeau and associates describe inserting a K-wire into the medullary canal from the distal end of the radius.[22] Using a technique reminiscent of Ender's nailing, both reduction and fixation can be secured without an open reduction. I have no experience with these techniques.

When an epiphysis cannot be reduced to within 30 degrees of the normal position, open reduction should be carried out. The sooner it is done after the injury, the easier it is. Make an incision beginning just above the lateral condyle, aiming for a point 1½ inches distal to the tip of the olecranon. Enter the elbow joint between the extensor carpi ulnaris and anconeus. Do not venture distal to the annular ligament, and keep the forearm fully pronated to avoid damaging the posterior interosseus nerve. Open the synovium; wash out the joint with saline to clear the view. Visualize the radial head and lever it into position with a small periosteal elevator, rotating the forearm to aid this. Once the fracture is reduced, it is usually stable. However, there is a small incidence of redisplacement if no form of fixation, other than a cast, is used. Several methods of fixation are available for fractures that are unstable because of comminution.

1. Sutures are difficult (because there is no proximal periosteum) but possible.
2. Kirschner wire through the capitellum is secure but carries the risk of infection tracking into the elbow joint as well as fracture of the wire at the joint line (which makes removal almost impossible). This method is not recommended.
3. An oblique Kirschner wire avoiding the humerus is the method I favor. When the wire is removed at 3 weeks, movement may be commenced.

The radius of a growing child should never be decapitated. Although it may be completely separated, revascularization is the rule.

Concomitant Injuries. The presence of other injuries, which may themselves require open reduction, does not mean that the radial head will require open reduction.

The most common combination is a fracture of the radial neck and an oblique fracture of the olecranon. The obliquity of the olecranon fracture and the intact periosteum over it make closed reduction possible (in about half the children) when the elbow is extended. A quarter of the children required open reduction of both the radial head and the olecranon (Figs. 12-52, 12-53).

Fig. 12-52. Fracture of the olecranon and radial neck in a girl, aged 8 years. Treated by closed reduction and casted in extension, the elbow was perfect 10 years later.

Results

Following fracture, return of full rotation of the forearm may take several months. Very little permanent disability is seen after this injury. Full flexion and extension of the elbow can be expected, but forearm rotation may be limited in some.

In our series of 48 patients requiring reduction, 28 had clinically normal elbows, and 7 had lost 45 degrees or more of forearm rotation. Thirteen had minor sequelae.

The imperfect results were much more common in the operated cases (13 of 20) than in conservatively treated cases (7 of 28). There was a higher correlation with the method of treatment than with the severity of the injury. Henrikson, in a conservatively treated series, found that 15% of patients had a degree of restriction, whereas Reidy had 45% of patients with this degree of limitation in an operatively treated group.[14,28] The lesson to be learned is that you should not give up closed reduction until you have tried every trick you know.

Synostosis. Though rare, synostosis is a hazard of even closed reduction. The clearance between the proximal radius and ulna is very small, and the torn periosteum may bridge (Fig. 12-54). Not only does synostosis block rotation, but it may result in cubitus varus (Fig. 12-55).

Heterotopic Ossification. A flake of bone may form and lie parallel to the radial shaft in the vicinity of the

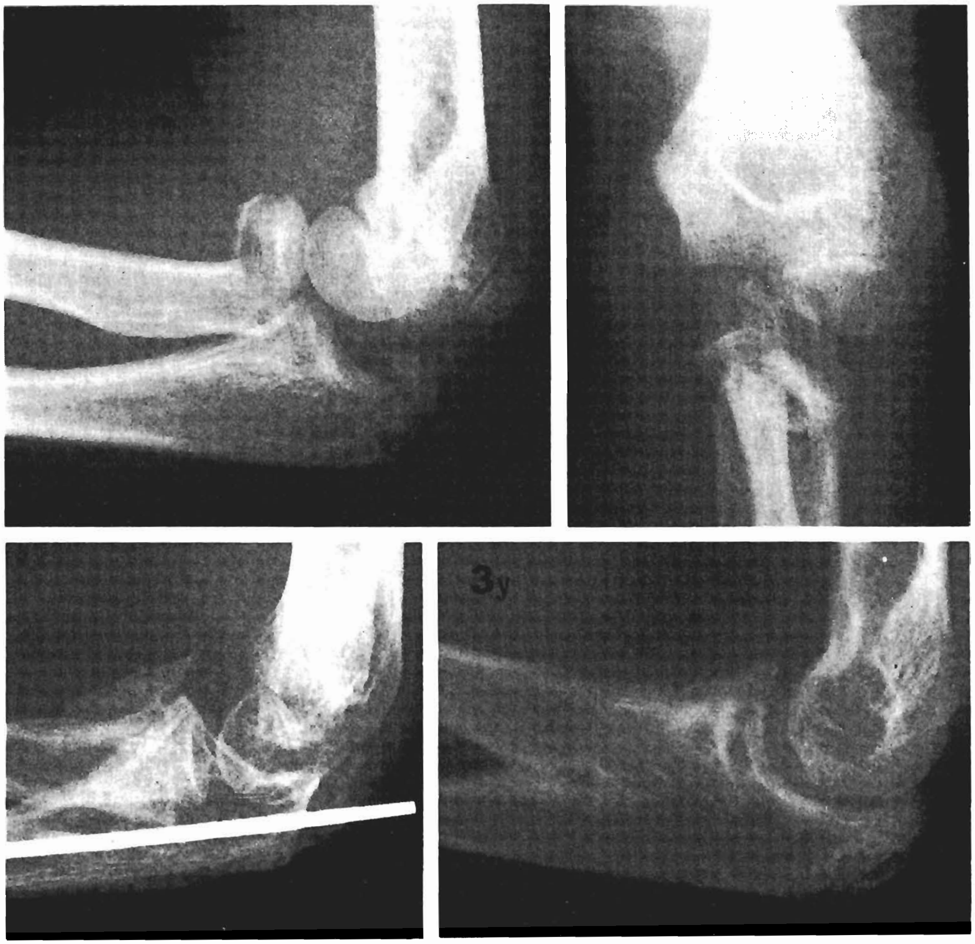


Fig. 12-53. A similar fracture to that in Figure 12-52, this in a 9-year-old girl. Open reduction has been followed by radioulnar synostosis. Do not open these fractures unnecessarily.

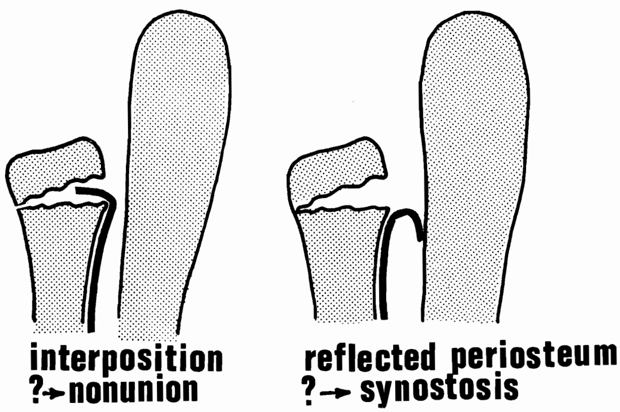
biceps tendon. Rotation is reduced; it was only seen after open reduction (Fig. 12-56).

Avascular Necrosis. Avascular necrosis of the whole head is rare, even when the head is completely displaced (Fig. 12-57). Necrosis of part of the head is more frequent (Fig. 12-58).

Irregularity of the head and premature closure of the growth plate are common. The carrying angle is increased in about 30% of children due to premature closure of the growth plate (Fig. 12-59). Irregularity of the head contributes to slight loss of rotation.

Nonunion. Rare but disastrous (Fig. 12-60). Bohler and Reidy have illustrated examples.[4,28] It may be due to the head having been replaced back to front but is more commonly due to periosteal interposition.

Fig. 12-54. Possible mechanisms for complications.



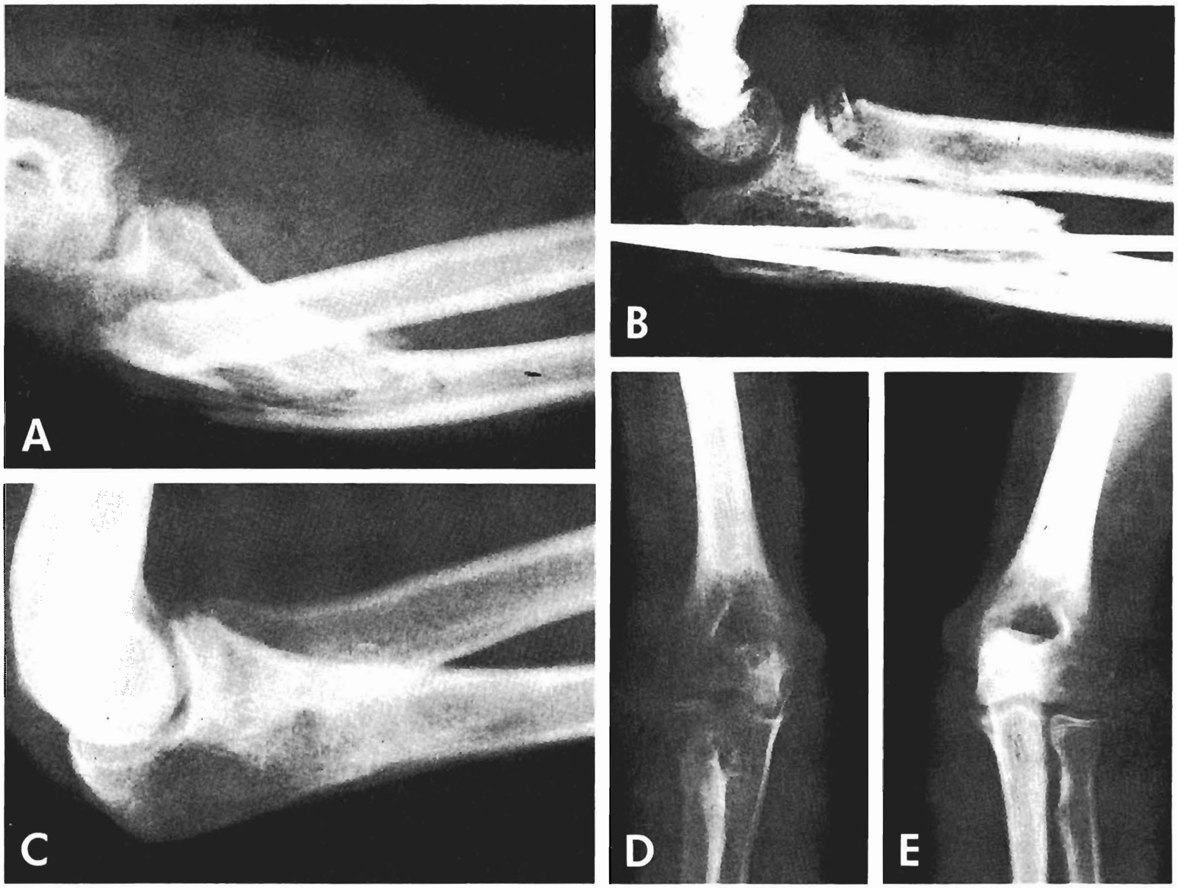


Fig. 12-55. *(A, B)* This 10-year-old had his arm out of a bus window. He sustained a degloving injury, and fractures of the radial neck and ulnar shaft. *(C)* A synostosis formed and recurred after excision. *(D)* At the age of 13 the carrying angle is reduced, because growth in the radial head has continued. Compare the normal elbow *(E)*.

Fig. 12-56. Heterotopic ossification after open reduction. Six years after injury, this patient had a full range of flexion and extension. Rotation was reduced by 10 degrees.

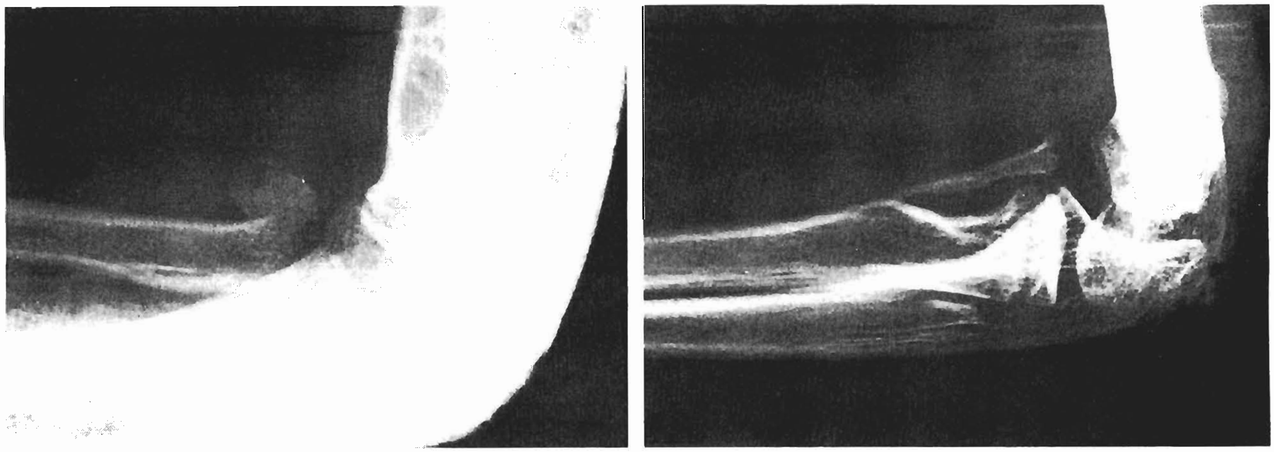


Fig. 12-57. Avascular necrosis after open reduction of a totally separated epiphysis.

Fig. 12-58. Partial avascular necrosis. This girl sustained fractures of the radial neck and proximal ulna at 10 years. Open reduction was carried out. Ten months later growth arrest and head irregularity is evident. Three years later the growth plate on the normal side was still open, but the injured plate had closed. Movement was full except for loss of 10 degrees of supination. The carrying angle was slightly increased.

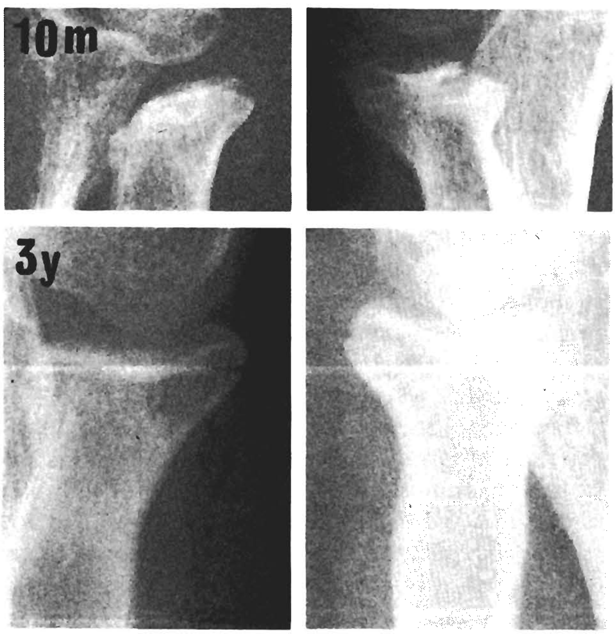


Fig. 12-59. At age 9 years this patient had fractures of the radial neck and olecranon reduced by manipulation. Premature closure of the plate occurred by the age of 13 years, leaving the radius 5 mm short. At 19 the carrying angle was increased.

Fig. 12-60. Ununited radial neck fracture. It is hard to believe that this had been reduced perfectly a year previously.

In our experience, the poor results are in cases that require open reduction, a fact that leads me to wonder whether it would be wiser to leave fractures in a displaced position rather than operate on them. Jeffrey is of the opinion that the degree of initial displacement determines the quality of the result.[16] In a child of 7 or 8, it may be wiser to accept 30 degrees of angulation after closed reduction than to carry out an open reduction. Henrikson has shown this amount of malunion will disappear during the remodeling process.[14]

FRACTURES OF THE OLECRANON

The structure of a child's olecranon is different from that of an adult. The bone appears more spongy so that the fracture line may be more difficult to identify. The layer of articular cartilage is thick and permits osteochondral fractures. An epiphysis forms posteriorly. It is often irregular and, though rarely separated, it frequently looks injured.

While solitary fractures of the olecranon are seen, the majority are associated with fractures or dislocation of the radial neck (Fig. 12-61). Oblique fractures and longitudinal split fractures are as common as transverse fracture.[23] The majority are undisplaced and require nothing more than a sling. Angulation can usually be corrected by manipulation. When the periosteum is torn, the fragments may separate. If the fracture is not reduced by extending the elbow, there may be interposed fragments. Open reduction and some form of internal fixation is required. We have found that the ASIF technique (two Kirschner wires and a figure-of-8 tension wire) is excellent (Fig. 12-62).

DISLOCATIONS OF THE ELBOW JOINT

In children elbow dislocations without fracture are decidedly unusual. Whenever you see a dislocation of the elbow, assume that there is an occult bony fragment that may become trapped in the joint after reduction or may prevent reduction.

Dislocations with Occult Fragments

Medial Epicondyle. The avulsed medial epicondyle is usually overshadowed by the humerus. The best sign that it has been avulsed is that you cannot see the epicondyle in its proper position. Radiograph the opposite elbow to confirm this. This ossification center is usually present at age 7.

The dislocation should be reduced soon to relieve pain and improve circulation. If the child has a full stomach, administer intravenous Demerol and place the child face down to reduce dislocation. The arm should rest on the stretcher with the elbow flexed over the edge so that the forearm hangs vertically downward. When the child relaxes, a little pressure over the olecranon with correction of any sideways displacement usually reduces the dislocation. Most of the pain will disappear. Radiograph the elbow again, and anticipate replacing the medial epicondyle operatively at a convenient time.

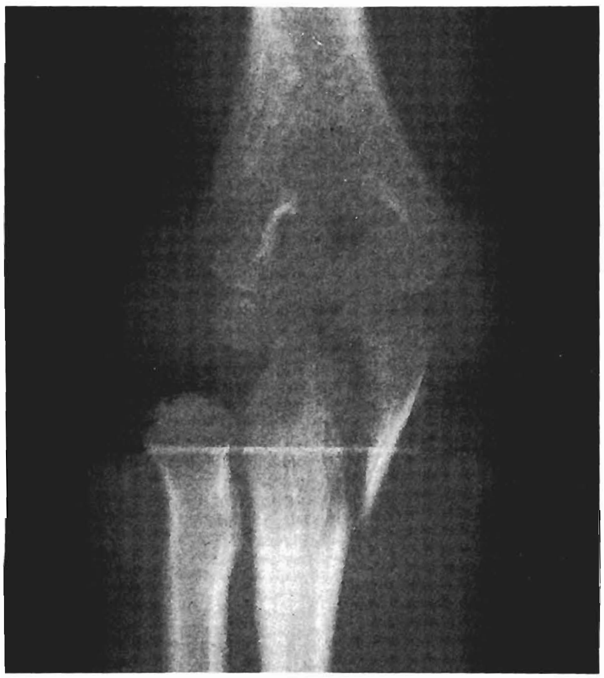
If the stomach is legally empty, the whole procedure can be carried out under general anesthesia.

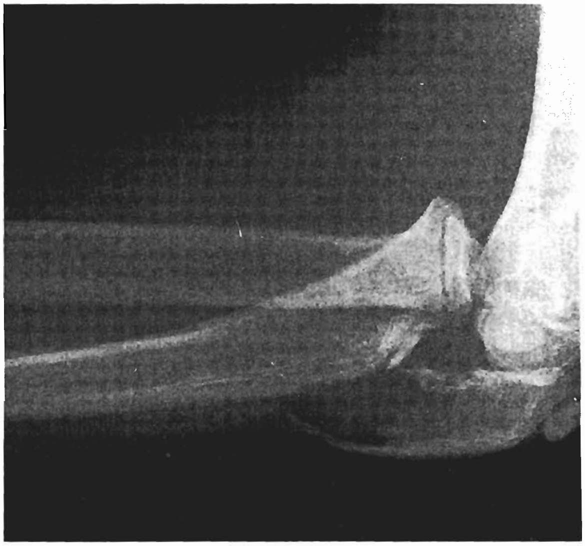
Articular Surface of Ulna. Dr. Robert Gillespie drew my attention to this injury. A flap of articular cartilage and subchondral bone is lifted up from the articular surface of the ulna. The osteochondral fragment is barely perceptible on initial radiographs. After reduction there is crepitus and a restricted range of movement. Arthrotomy is required to push down the flap or excise it in order to secure concentric reduction.

Dislocations with Obvious Fractures

Fractures of the lateral condyle, olecranon, and radial neck are commonly seen with dislocation and present no traps in management.

Fig. 12-61. Fracture of the olecranon is commonly accompanied by dislocation or fracture of the proximal radius. Girl aged 6 years.





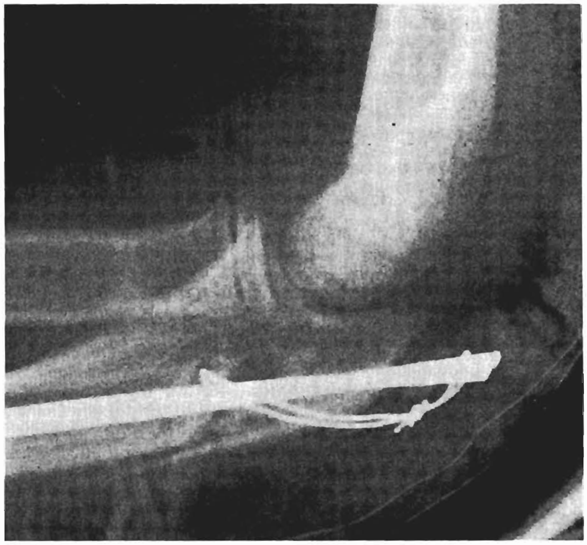


Fig. 12-62. Fracture of the olecranon with radiohumeral dislocation treated by ASIF fixation.

Separation of the Distal Humeral Epiphysis

This may masquerade as a dislocation (see page 172).

True Dislocations

These are less common than in adults and can usually be reduced easily, either by the method described above or under general anesthesia. It is our custom to protect the elbow in a cast for 3 weeks afterward to avoid the slight risk of recurrent dislocation.

Recurrent Dislocation of the Elbow

Making the diagnosis is no problem. But the condition is rare and little known. After a posterolateral dislocation the lateral ligament remains separated from the lateral condyle. A lateral pouch forms. Osborne and Catterill worked this out and developed an operation to reattach the lateral ligament and obliterate the pouch.[24] It is a brilliantly simple answer for a problem that is utterly baffling when first encountered.

DISLOCATION OF THE RADIAL HEAD

This is a rare injury in children because they rarely tear ligaments. Two varieties are seen, both accompanied by ulnar fractures.

1. The Monteggia injury is characterized by damage to the annular ligament, producing *radioulnar* dislocation (see Fig. 13-34).
2. Radiohumeral dislocation: fracture through the olecranon or coronoid allows the radial head to dislocate, leaving the radioulnar joint and the annular ligament undisturbed (see Fig. 12-62).

Both varieties of dislocation are reduced when the ulnar fracture is replaced. This subject is discussed in Chapter 13.

Solitary

Solitary dislocation of the radial head has been described, but the published radiographs show a bent ulna, suggesting that some of these cases are really Monteggia injuries (see Fig. 13-32).

Long-Standing

Confusion may arise when a child with a congenital or pathologic dislocation falls on the elbow. The ensuing radiographs may mimic an acute injury. Examine and radiograph both elbows. The diagnosis of a long-standing dislocation can be made (1) when the condition is bilateral or (2) if unilateral, when the affected radius is longer, the head misshapen, and ossification more advanced than on the opposite side.

Lloyd–Roberts and Bucknill doubt the existance of unilateral *congenital* anterior dislocation of the radial head.[18] Probably all are traumatic. The long-term future is pain and stiffness, whereas the results of surgery are good even when several years have elapsed between dislocation and repair. The lateral slip of triceps is used to reconstruct the annular ligament, an ulnar osteotomy corrects bowing, and a pin holds the radial head reduced.

Proximal Radioulnar Translocation

The elbow dislocates and the radius and ulna translocate (Fig. 12-63). The dislocation is obvious on radiographs, but the translocation is overlooked. After any dislocation is reduced, the range of movement should always be tested. Translocation blocks flexion, and the radiograph taken at this time provides a second opportunity to recognize the translo-

Fig. 12-63. *(A)* Proximal radioulnar translocation. The olecranon overlies the capitellum. *(B)* The normal side, for comparison.

cation. Reduction has been secured by supination and pushing the radius laterally.[19]

PULLED ELBOW

The most common elbow injury has been left until last. We see about two patients a week with pulled elbow. The clinical picture is characteristic. A child between 1 and 4 years suddenly refuses to move an arm and holds it slightly flexed and pronated. Often, parents think the arm is paralyzed or that the child has a fractured clavicle. They seldom mention that the problem began as the child was being pulled along by the wrist—the usual cause (Fig. 12-64).

Pathology

Salter and Zaltz found that when longitudinal traction is applied to the arm (with the forearm in pronation) the annular ligament tears at its attachment to the radius.[29] The head of the radius moves distally. When traction is released, the ligament is carried up and becomes impacted between the radius and capitellum (Fig. 12-65). Because the shape of the radial head is not completely regular, the ligament can be replaced by slight flexion and supination. Usually reduction is carried out by the radiographers as they supinate the arm to obtain a true anteroposterior radiograph of the elbow.

Treatment

Reduction is easy: supinate the slightly flexed elbow, and often you will hear a click. The child stops crying and starts to move the arm again. Warn the parents not to pull the arm again. Recurrence and irreducibility are both unusual. It is remarkable that not all children experience a pulled elbow.

Fig. 12-64. Pulled elbow is very common in children.

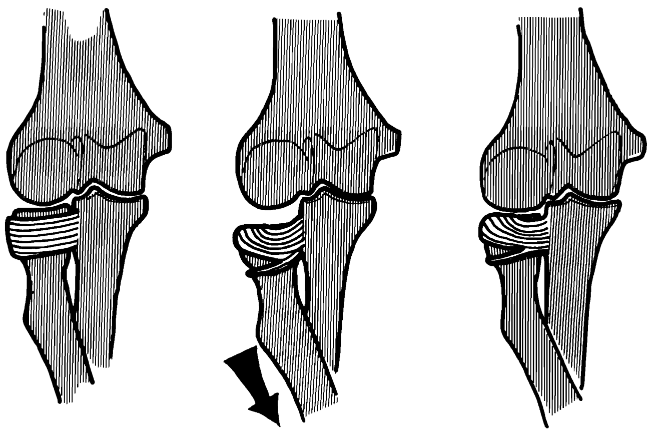


Fig. 12-65. The pathology of pulled elbow. The annular ligament is torn when the arm is pulled. The radial head moves distally and when traction is discontinued, the ligament is carried into the joint.

Post-Traumatic Elbow Stiffness

Elbow stiffness after injury can be prevented by accurate reduction of fractures, immobilization in a cast for no more than 3 weeks, and a self-help program when a cast is removed. Some children are scared to move when a cast is removed and they continue to immobilize the elbow for weeks. Swimming is the best exercise for mobilizing the elbow and should be started, if possible, within days of cast removal. Other resisted exercises are next best (Fig. 12-66). Passive stretching, as Blount pointed out, is the cause of stiffness, not an answer.[3]

When a child is referred with a stiff elbow, a cause should be found. Mechanical blocks, such as a malrotated supracondylar fracture, will improve slowly with growth. But blocks owing to scarring will tend to remain. Arthrography may help define the cause.[32] Turn-buckle orthotic correction has gained an average of 43% improvement in the range

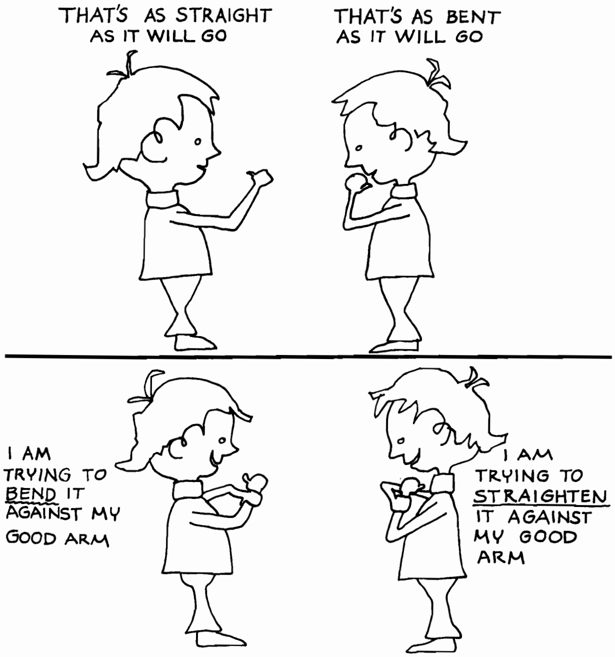


Fig. 12-66. Simple self-help exercises.

of movement in the hands of Green and McCoy.[11] Soft-tissue releases and manipulations under anesthesia are disappointing. Resection of a post-traumatic radioulnar synostosis and insertion of silastic membrane has been successful.[35]

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13 / Radius and Ulna

Fractures of the radius and ulna are common in children and somewhat different from those of adults. For example, shattering injuries of the articular surfaces of each end of the radius do not occur, and fractures are seen that have no adult equivalent. Union is certain. Treatment is different; fractures of the shafts of both bones of the forearm can usually be managed closed and represent a challenge that adult forearm fractures do not.

THE MECHANISMS OF INJURY

The parachute reflex generates the trauma surgeon's income. When a child puts out the palm of the hand to break a fall, he may sustain a greenstick fracture. As he falls all the muscles holding the forearm in pronation are tensed; landing on the thenar eminence first, a sudden supinational force is applied. This displacement of the fracture appears on radiographs to be anterior angulation, but the displacement is usually rotational. Test this for yourself with a strip of paper, as shown in Figure 13-1. If the tyro accepts the angulation at face-value and corrects it, the rotational deformity will remain uncorrected. The fracture should be reduced by applying a pronational force to the hand.

The radiographic appearance of greenstick fractures of the forearm can be very confusing until it is realized that the only fractures with true anterior or posterior angulation are produced by children doing cartwheels with an arm trapped in a drainpipe. All the rest owe this appearance to rotatory deformity.

If the violence is sustained, a complete fracture of both bones may be produced—an entirely different situation. The distal fragment may be in any position, but the proximal fragments take up a position dictated by the pull of muscles and other soft tissues.

The aim of treatment is to discover what this position is, so that the distal part of the limb may be lined up accurately: an old principle of fracture care. There is no other way to secure a reduction. It is useful to look at a few anatomic points to realize the importance of accurate reduction.

ANATOMY AND PATHOLOGY

The forearm bones are subcutaneous in the lower half of the forearm. The quality of reduction can be reasonably easily appreciated, not only by the surgeon, but also by the patient when the cast comes off.

Forearm rotation has a range of 180 degrees, perhaps the greatest range of rotation of any joint in the

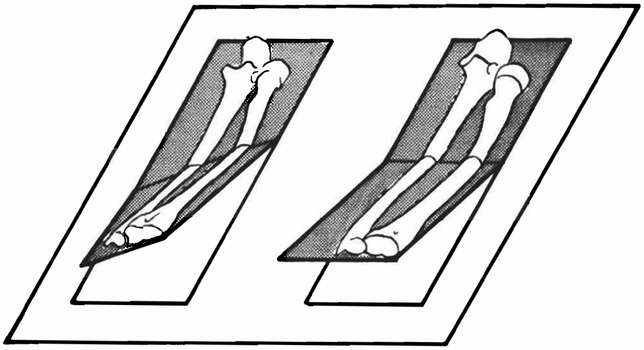
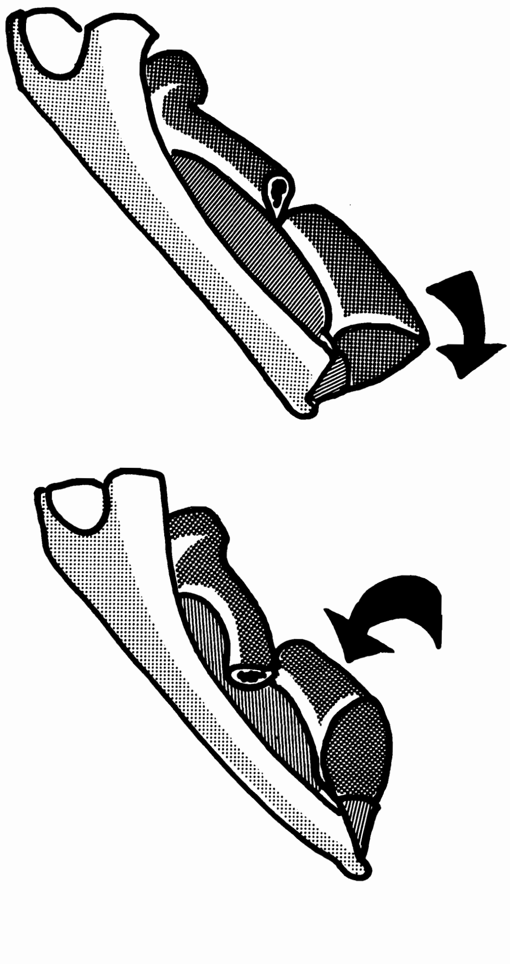


Fig. 13-1. Angulation is usually associated with rotation. Use a strip of paper to prove this yourself.

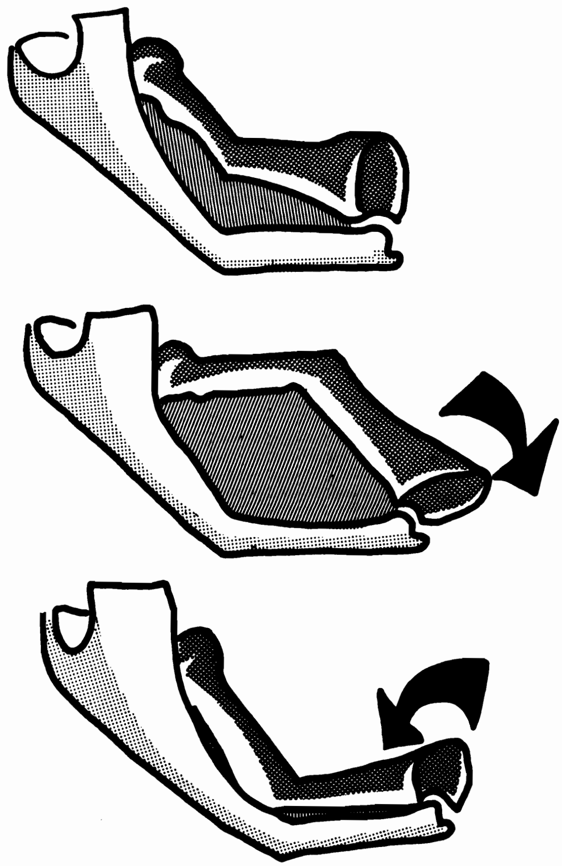
Fig. 13-2. Malrotation limits movement. Ninety degrees of pronation deformity, as shown here, limits pronation to the midposition, because the proximal radioulnar joint has reached the limit.



body. Although a decrease of motion by 50% may go unnoticed, fractures should be reduced well to avoid loss of motion. Fractures were produced in cadavers and plated with various types of malunion to determine the effects of each:

1. Ten degrees of malrotation limits rotation by 10 degrees (Fig. 13-2).
2. Ten degrees of angulation limits rotation by 20 degrees, because it produces widening and narrowing of the interosseous membrane during rotatory movements (Fig. 13-3).
3. Bayonet apposition does not limit rotation.
4. Pure narrowing of the interosseous distance is important in proximal fractures. Narrowing impedes rotation by causing the bicipital tuberosity to impinge on the ulna. Malalignment of fractures of the ulnar metaphysis increases the tension on the articular disc so that the head of the ulna is not free to rotate (Fig. 13-4).

Fig. 13-3. Angular malunion limits rotation, because the interosseous membrane cannot widen and narrow.



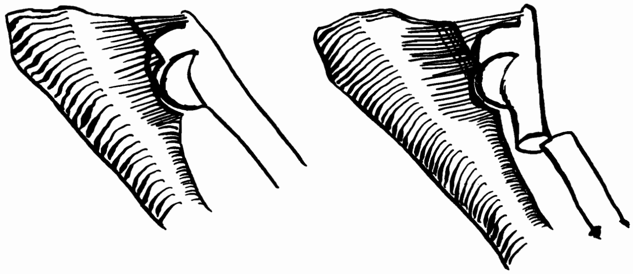


Fig. 13-4. Angulation of the distal ulna prevents the radius rotating around the head of the ulna.

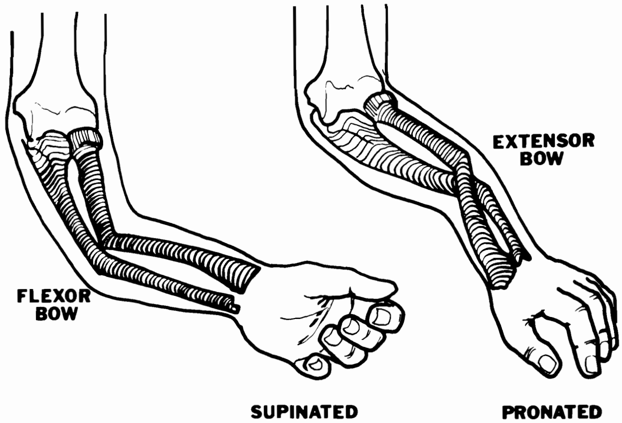


Fig. 13-5. Flexor bow indicates supinational deformity. Extensor bow indicates pronational deformity.

Loss of rotation is a common problem after forearm fractures. Knight and Purvis found residual rotational deformity of between 20 and 60 degrees in 60%.[6] Evans found malrotation *deformity* of more than 30 degrees in 56%[1] The distal fragment was pronated so that supination was lost. Let us see how this can be prevented.

RECOGNITION OF ROTATIONAL DEFORMITY

Clinical Examination

Look at the forearm in the position of displacement. You will be able to tell from the shape of the arm how the distal fragment lies in relation to the proximal part (Fig. 13-5). It sometimes helps if first the part of the arm below the fracture is blocked off from vision with a hand, and then the part above. If the upper part of the arm lies in supination, and the distal part looks as if it is pronated, all you should do to reduce the fracture is supinate the distal fragment. The first person who sees the child has a great advantage, because he is the only one who can see the limb as it lies.

Testing the Range of Movement. Occasionally, with a stable reduction, the range of movement can be tested before the cast is applied. A full range of movement indicates accurate reduction.

Radiographic Aids

The Radius. The radius is a curved bone that is pear-shaped in cross section. Malrotation of the radius is recognized by a break in the smooth curve of the bone and by a sudden change in the width of the cortex (Fig. 13-6).

Angulation. Angulation of the bones that produces a volar prominence is conventionally described as

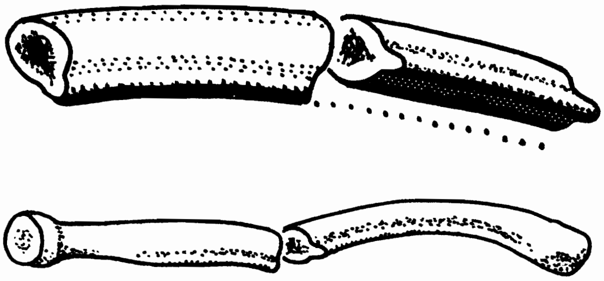


Fig. 13-6. A change in the diameter of the radius, the width of the cortex, and the smooth curve of the radius indicate malrotation.

volar angulation or bowing. The distal fragment is said to be dorsally deviated. This is worth stating clearly because telephone conversations about fractures are frequently bedevilled by semantic ambiguities. In greenstick fractures of the forearm, volar or flexor bowing is the outward and visible sign of a supinational deformity. Dorsal or extensor bowing signifies pronational deformity.

The Position of the Bicipital Tuberosity. Mervyn Evans, whose classic paper on forearm fractures is essential reading, drew attention to this radiographic sign.[1] The tuberosity normally lies medially when the arm is fully supinated; it lies posteriorly in the midposition, and laterally in full pronation (Fig. 13-7). Intervening positions can be judged to 30 degrees by reference to a carefully positioned radiograph of the normal elbow or by reference to the figure.

In complete fractures, the rotational position of the proximal fragment can be identified by this method, and reduction becomes a scientific exercise. The distal fragment is lined up in the same degree of rotation as the proximal fragment, which always returns to its own position. This takes the guesswork out of reduction—and the need for silent communications with the spirit of Nicholas Andry.

Prior to the discovery of x-ray films, surgeons had to guess the position of the proximal fragment, and some surgeons still do, using the traditional argument that muscle pull determines the position of the proximal fragments. "In the case of fractures above the insertion of pronator teres, the proximal fragment is invariably pulled into supination by supinator. The fracture should be immobilized in supination. Fractures below the insertion of pronator teres are invariably pulled into pronation by this muscle and should therefore be immobilized in this position." Though this theory is often repeated and has a certain logic, it is usually not true.

Interosseous Space. Narrowing should be avoided.

Combined Approach

Taking all these signs into consideration makes it easy to recognize whether or not a fracture is reduced.

OTHER EFFECTS OF INJURY

Nerves and Vessels

Nerves and vessels are seldom injured primarily in forearm fractures. The median nerve is protected from the radius by an intervening layer of muscles. The ulnar nerve is close to bone and may occasionally be damaged, especially in open fractures near the lower end. Despite the presence of closed fascial spaces in the forearm, the risk of ischemic contracture is low if well-padded casts are used.

The only fasciotomy I have had to do was the result of someone applying a forearm cast, flexing the elbow (so that the top of the cast dug in), and then completing the cast.

Growth

The distal end of the radius is a classic site for growth disturbance owing to bridging of the plate. At first the growth-plate injury may masquerade as a sprain without great radiologic evidence of injury. It is only later, when Madelung's deformity begins to appear, that the true nature of the injury is appreciated (Figs.

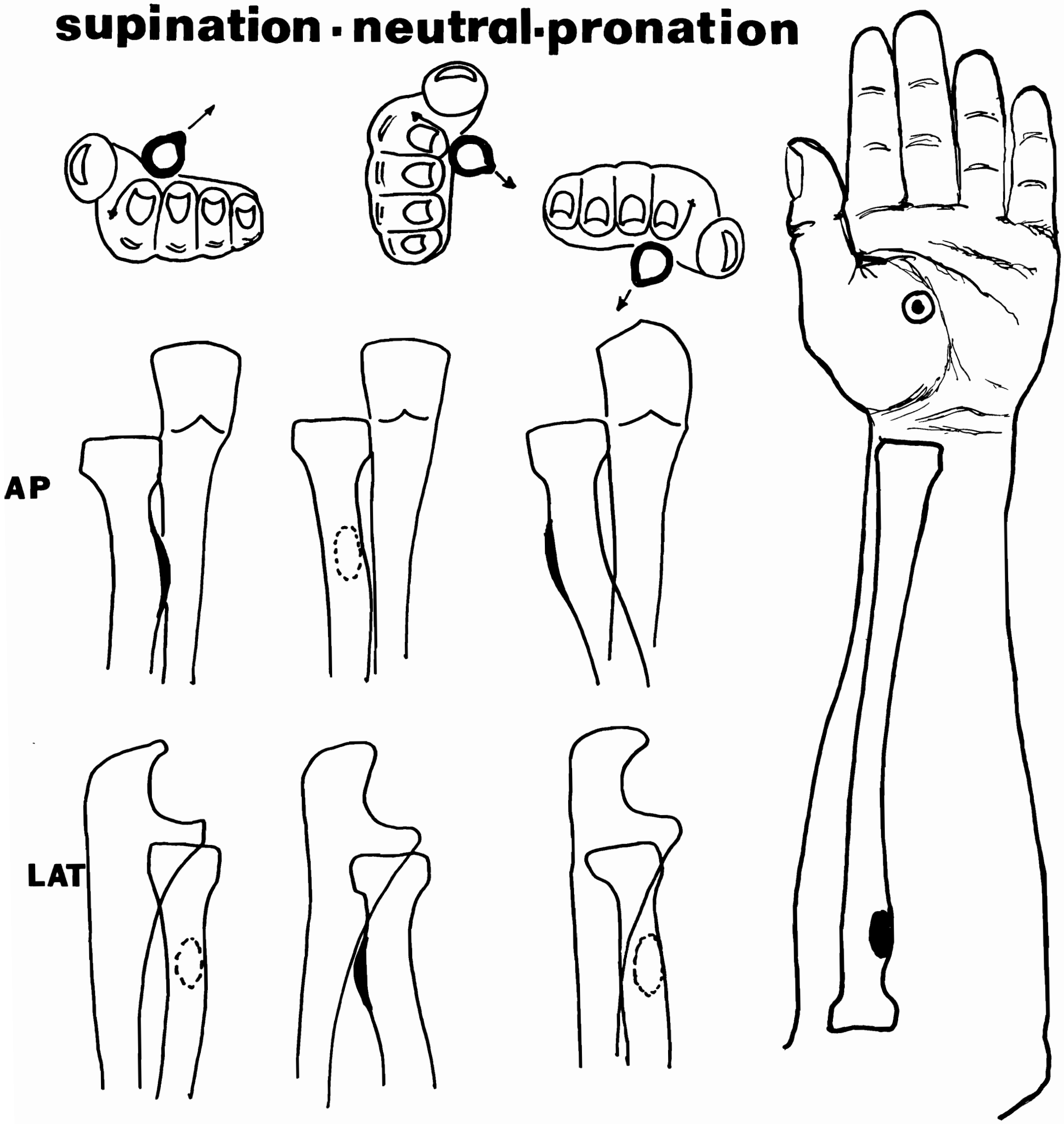
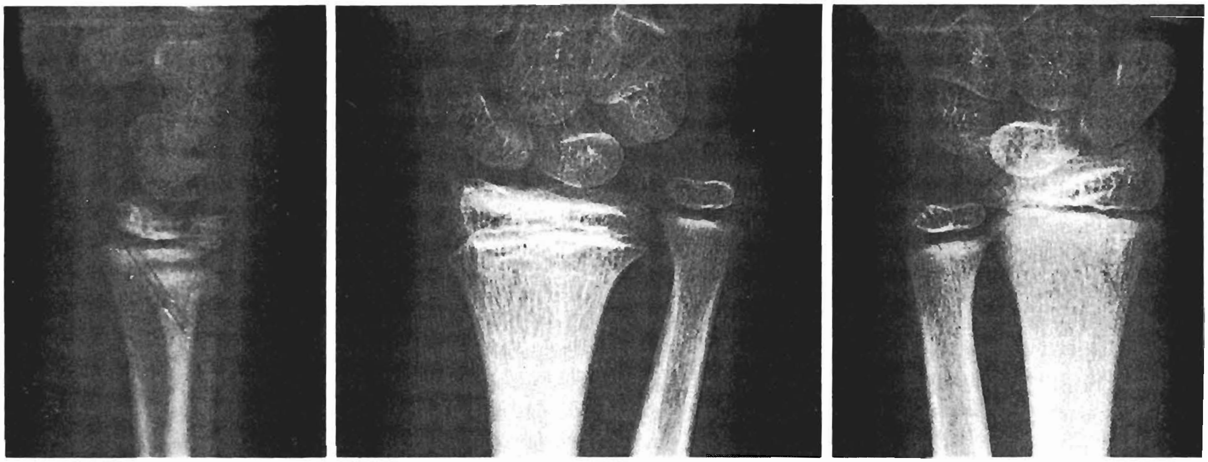


Fig. 13-7. *(Left)* The bicipital tuberosity as a guide to the rotation of the proximal radius. *(Right)* If you cannot remember where the bicipital tuberosity should be, put an ink mark on your palm at the site indicated. The prominence of the tuberosity always points in this direction.



7 YEARS **9 YEARS** **NORMAL WRIST 9 YEARS**

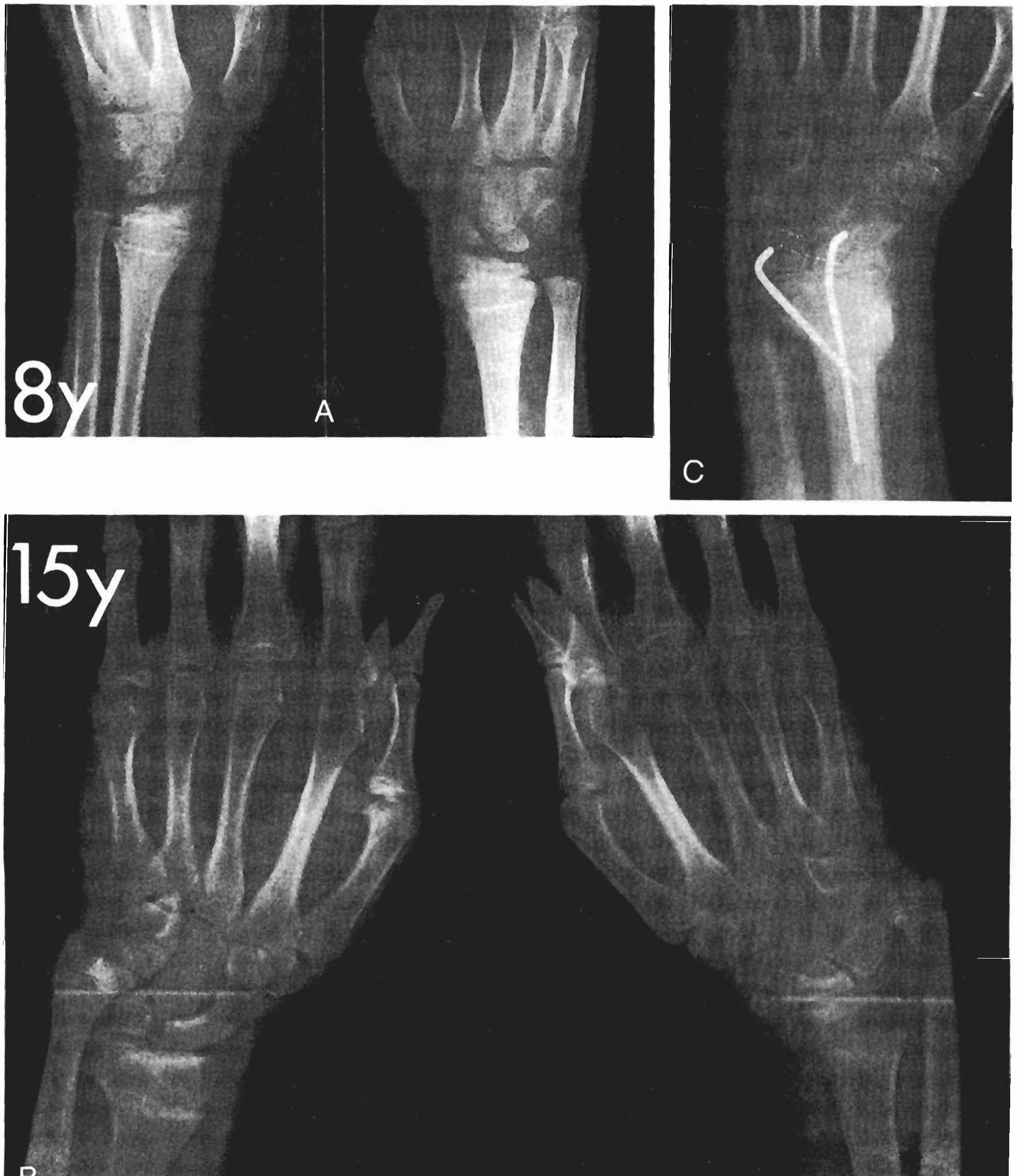


Fig. 13-8. Growth arrest due to a Type-IV injury. If this had been accurately repositioned by open reduction this complication may have been prevented. (Courtesy of Mr. Lipmann Kessel, to whom this girl was referred at the age of 9.)

Fig. 13-9. Post-traumatic Madelung's deformity. At the age of 4 years this patient had bilateral epiphyseal separations when he fell off a diving board. *(A)* The bridge can be seen. Today this would be resected. *(B)* Age 15 years. *(C)* After radial osteotomy and ulnar shortening.

13-8, 13-9). These children should be radiographed every 3 to 6 months for signs of a bony bridge so that prompt resection can be carried out.

At the upper end of the radius, complete separation of the head may cause avascular necrosis when the periosteum carrying all the blood vessels to the epiphysis is torn. Growth stops, and cubitus valgus is the result.

INDIVIDUAL FRACTURES

Displaced greenstick fractures should be slightly overcorrected by slow manipulation to take the spring out of the fracture. You will hear a crack as the bony hinge yields. If this is not done, the deformity often reappears in the succeeding weeks.

THE SLIPPER

A greenstick fracture of the radius at the junction of the metaphysis and diaphysis with supinational deformity is common and has an evil reputation, because angulation tends to recur after reduction (Fig. 13-10). It has always been our custom to hold the fracture in full pronation in an above-elbow cast. The intact periosteum locks the fracture in place, and full pronation stops a supinational deformity from developing. Pollen advances an entirely new and different approach: he considers brachioradialis the deforming force.[7] In pronation, brachioradialis displaces the fragment, whereas in supination the pull of brachioradialis holds the reduction (Fig. 13-11). Perhaps we should enliven the care of this fracture by running a controlled trial. Certainly anything less than full pronation and full supination should be avoided, because this is a troublesome injury. The fracture should be radiographed every week for 3 weeks, and the slightest suggestion of deformity should be corrected. The cast can be removed at 6 weeks. For some reason, refracture is common at this site.

MIDSHAFT GREENSTICK FRACTURES

Angulated greenstick fractures of the midshaft require slight overcorrection. The periosteal tube is intact, and reduction is easy. Supination injuries are pronated and then given a push to get rid of the anterior angulation, at which time a crack is heard. The cast should be well molded. Greenstick fractures are very much easier to manage than complete fractures (Figs. 13-12, 13-13).

Minimally displaced fractures are very common. The deformity may be corrected with pressure while the cast is setting.

COMPLETE FRACTURES OF BOTH BONES

Complete fractures of the radius and ulna can be very challenging to manage. Reduction may be difficult and unstable, particularly in children under 2 years, in older children, in high fractures, and in those that are comminuted or oblique. There are several general rules to guide you:

1. Good reductions last better than poor reductions, particularly in a well-molded cast.
2. Cortex-to-cortex apposition is adequate if rotation is correct, if the interosseous space is preserved, and if there is no angulation.
3. Immobilize the fracture in the position—any position—in which the alignment is correct and the reduction feels stable. Immobilization with the elbow extended is invaluable for fractures in the proximal one-third of the forearm and in children under 2 years.
4. Minor improvements can be made at 3 weeks when the fracture is sticky.

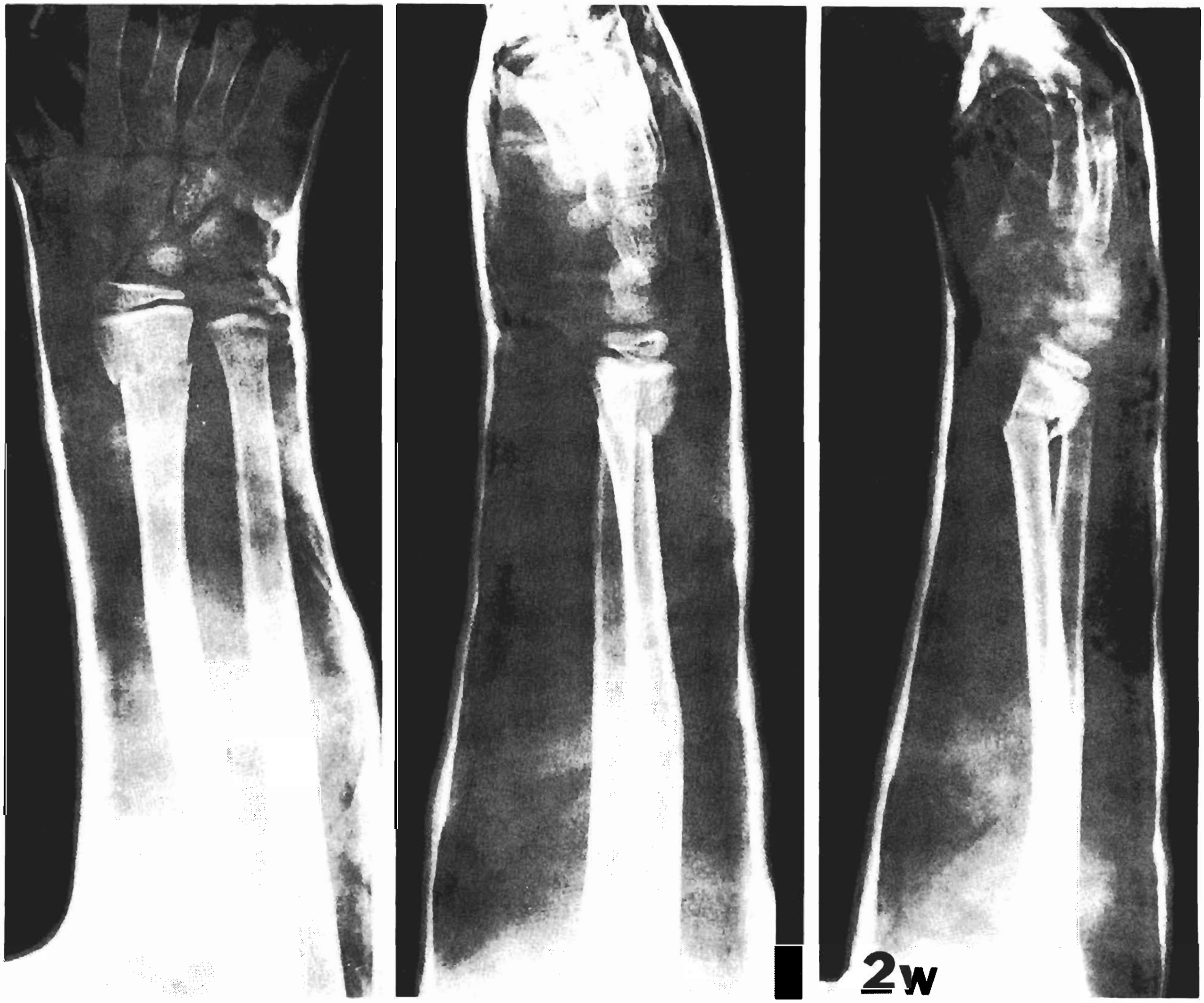


Fig. 13-10. This minimally displaced fracture should be easy to treat. The fracture slipped because of three errors. (1) The cast is round in cross-section, (it should be oval); (2) there is no moulding; and (3) the arm is not in full pronation, as it should be. All the errors are evident in the radiographs. The fracture was remanipulated.

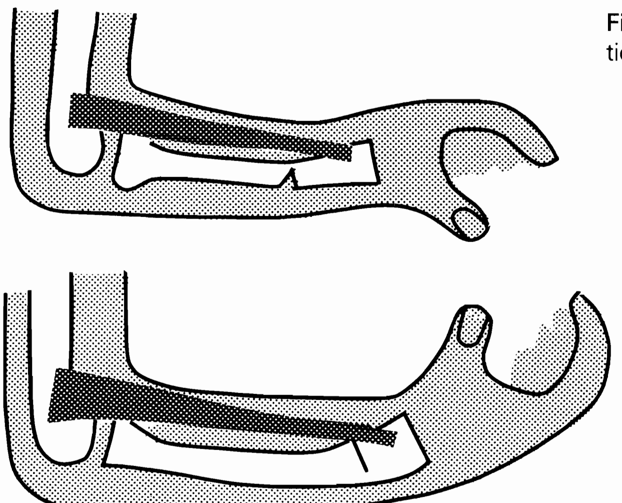


Fig. 13-11. Brachioradialis is a deforming force. In supination it holds reduction.

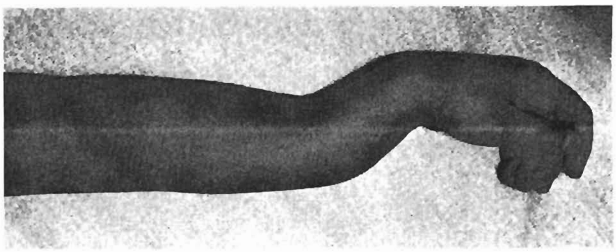


Fig. 13-12. A typical greenstick fracture in a 7-year-old boy. It is easily reduced.

5. Be prepared to carry out open reduction and internal fixation, particularly in children over the age of 10, rather than accept a poor position. Overlap of both bones in the forearm of a child under the age of 10 is probably acceptable so long as there is no malrotation or angulation. In children over 10, permanent loss of motion is the price to be paid. Skin traction is a neglected method of controlling longitudinal instability in younger children.
6. Always warn the parents before you reduce the fracture that remanipulation is often necessary later and that there will be a bump when the cast comes off.

Technique of Reduction

Examine the radiograph to determine the position of the proximal fragment. If necessary, take tuberosity views of the normal elbow in varying degrees of rotation to be sure. Reduction is best carried out by retracing the events of the fracture. Increase the deformity until the overlapping bones can be hitched together by thumb pressure. Do one at a time, then correct the deformity, and set the arm in the desired degree of rotation. Test longitudinal stability by attempting to telescope the arm. (Increasing the deformity looks repugnant to some. I can well remember trying to catch a fainting nurse and hold a reduction at the same time.)

It is always difficult to hold the limb while the cast is being applied. Having tried many different ways, the way I like best is with stockinette to maintain alignment and traction. Don't bend the elbow after applying the plaster—it will only dig in and produce a sore (Fig. 13-14).

Mold the cast well, as shown in Figure 13-15. A good cast may leave the child's grandmother complaining that the arm looks more crooked now than it did before reduction. The cast should be pear-shaped in cross section. The ulnar border should be straight, with the elbow at a perfect right angle. Close molding just above the elbow should prevent the cast from telescoping up and down the arm. If the radius is comminuted or tends to shorten, include the thumb in the cast. A bad cast looks like a loose shirt sleeve. Hold the fracture with a thin cast while radiographs are being taken. Supervise them personally in order to obtain true lateral and anteroposterior (AP) views. At this time, all should be peaceful and serene.

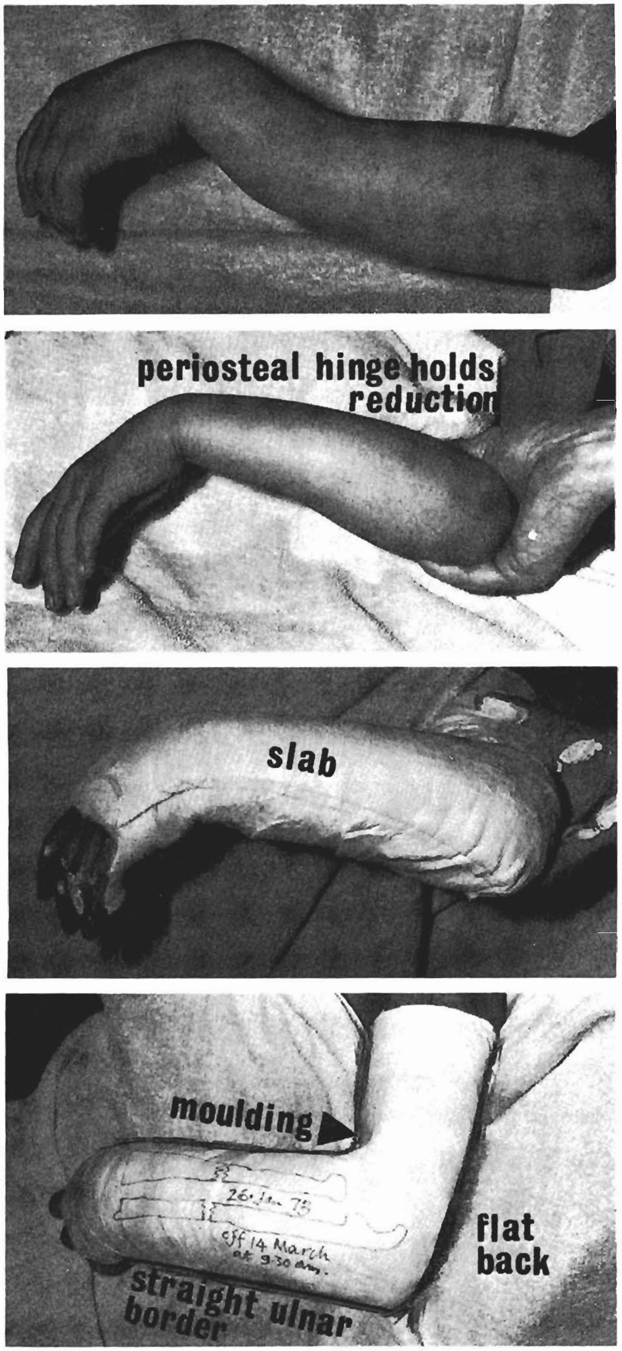


Fig. 13-13. A method of treatment for greenstick fractures. The supinational deformity is corrected, and then the fracture is held by the periosteal hinge. A slab is allowed to harden, after which the circular layers are applied and moulded (the stockinette technique shown in Fig. 13-14 is perhaps simpler). Write on the cast. It helps the radiographer provide well-centered follow-up films and it saves embarrassment if the written record is lost.

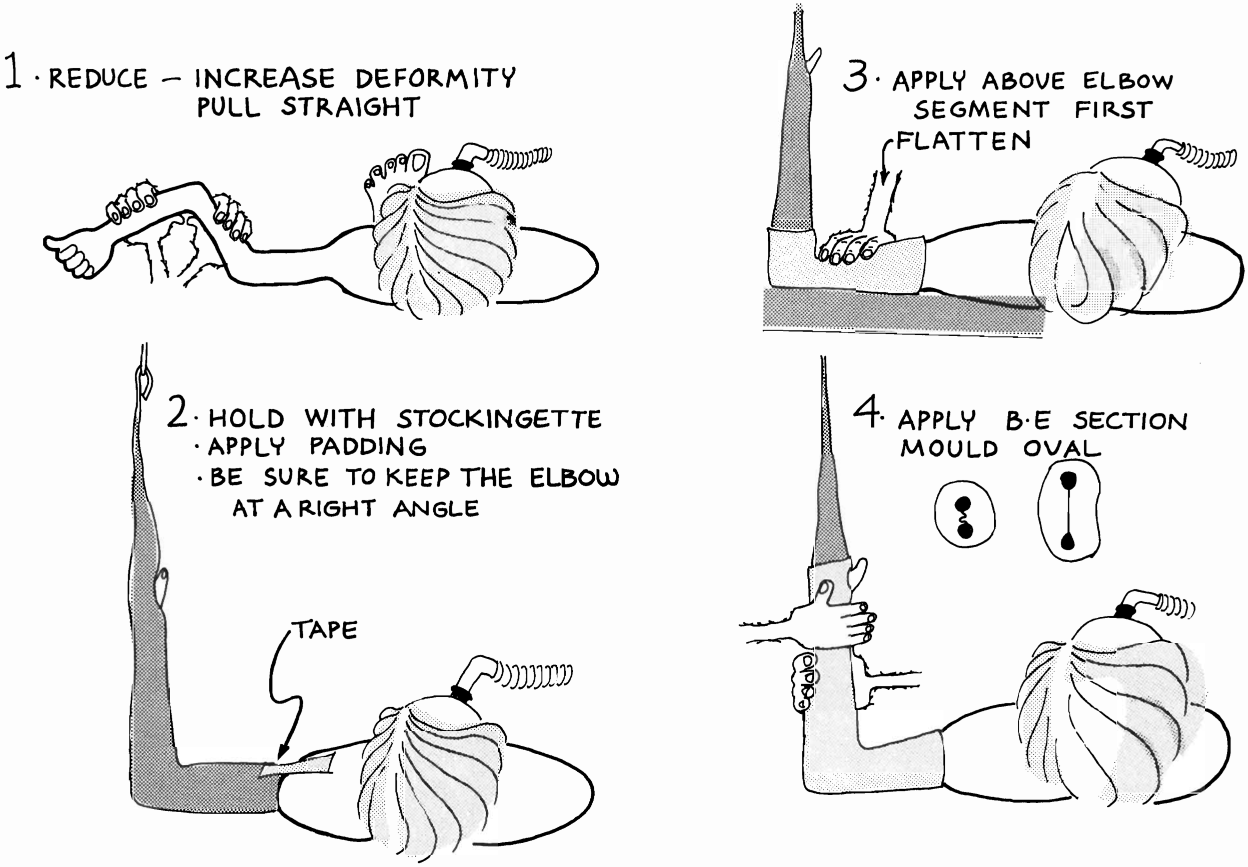
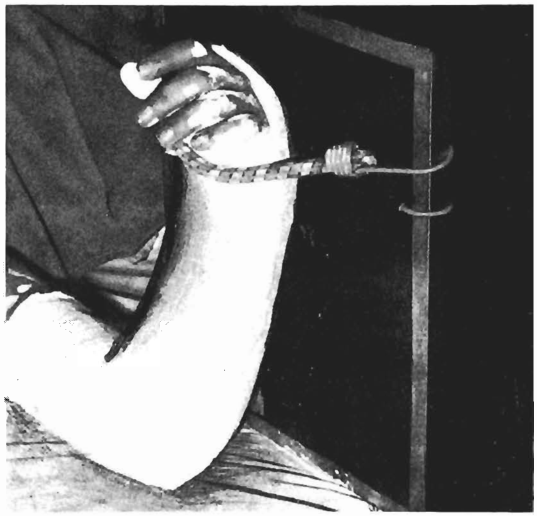


Fig. 13-14. The steps in reducing a fracture of the forearm.

Fig. 13-15. Mold the cast well around the anterior surface of the radius. The rubber straps hold the cassette and the arm very conveniently.



The room should be free of distractions, such as an anesthetist struggling with a patient, a nurse hurrying you out of the plaster room, or a radiographer serving up overexposed keyhole views of the limb. Remember that the quality of reduction that is accepted is inversely proportional to the difficulties involved in changing it. If the position is not satisfactory, try again. Look at the radiographs in order to decide if the arm should be supinated further, or pronated further, or left in the midposition. An image intensifier can be useful if the reduction is very difficult. When the position is satisfactory, put on a good, strong cast, because children are very destructive. Support the weight of the cast with a neck hoop, so that the weight of the cast will not act as a deforming force at the fracture site (Figs. 13-16 to 13-18). Include the thumb in the cast if the fracture is very unstable.

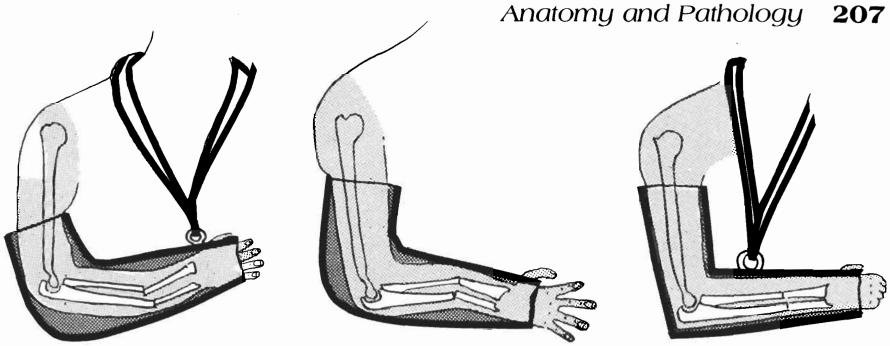


Fig. 13-16. The fracture will not support the weight of the cast. Incorporate a loop in the cast for attachment to a collar of a stuffed stockinette.

Fig. 13-17. *(A, B)* The best position that could be obtained in an open fracture in an 11-year-old boy. Both bones are hitched, the rotation is correct, and there is no angulation. The cast is well molded and incorporates a collar. *(C, D)* Nine months after the injury, the arm looks normal and has a full range of motion. Bayonet apposition is perfectly acceptable but requires a good cast to maintain position.

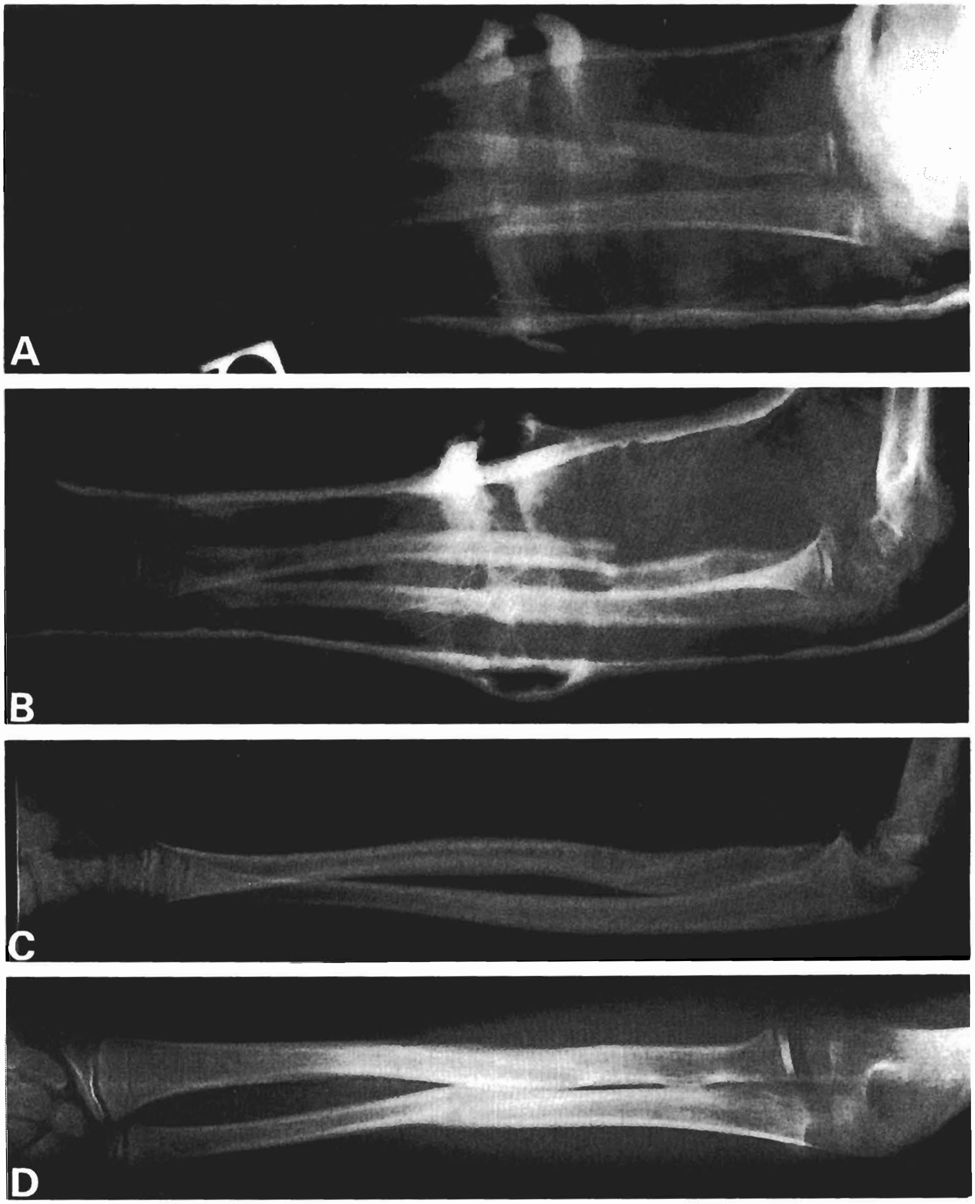


Fig. 13-18. Four weeks after the fracture was originally manipulated the bones were still end-to-end but had become angulated. The fracture was manipulated again, and the radiograph taken 6 months later shows an excellent result. The range of movement was full. Boy aged 5 years. Correction of angulation when a fracture is sticky is a useful technique.

Many authors advocate an alternative method of reduction: traction is used to reduce and hold the limb while the cast is applied. Counter traction is provided by a padded sling around the arm. The sling is fixed to a hook on the wall or to a post on the table. An assistant pulls on the hand while the surgeon manipulates the bone ends. The cast is applied, and then the sling is pulled out. I have not liked this method because the intact periosteum must be stretched to allow the overlapping ends to jump into end-to-end contact. It is like trying to force a door shut when something is in the way of the hinge. Fearsome traction is required. The hand becomes white, and the sling can produce nerve palsies. The sling gets in the way of cast application and leaves a depression in the cast.

Extension. Tradition calls for flexing the elbow in a cast. This position encourages the ulna to sag and provides poor control of proximal fractures and frac-

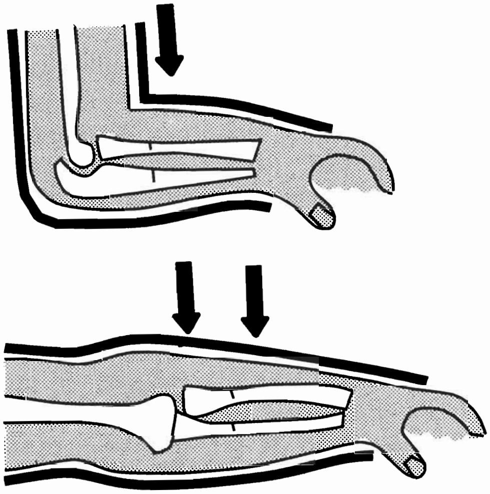


Fig. 13-19. Treat proximal fractures and fractures in small fat arms in extension. The cast hugs the fracture and prevents ulnar sag.

tures in short, fat arms (Fig. 13-19). A cast with the elbow in extension overcomes these problems and carries no disadvantages. The uninjured elbow does not become stiff. Remember to stop it slipping off by applying tincture of benzoin to the skin and by squeezing the cast above the condyles. Watson Jones, more than 40 years ago, advocated immobilizing fracture of the proximal one-third of the forearm with the elbow in extension.[10]

Open Reduction. There is the feeling around that open reduction is *"verboten"* for children, but not all fractures of both bones can be managed by closed reduction. There are bad results! Internal fixation is preferable to malunion. The only indication is failure to achieve satisfactory alignment after one or two sessions of manipulation by an experienced surgeon. Teenagers with high oblique fractures are particularly likely to require open reduction. Open reduction without internal fixation can be disastrous. Semitubular compression plates require a large exposure in small arms. An intramedullary Kirschner wire in the radius provides some fixation, but delayed union and malunion are major disadvantages. The ulna is easily rodded through the olecranon, but rodding the radius means transgressing the growth plate or drilling obliquely through the metaphysis. It seems tacky compared with plating (Fig. 13-20).

Fig. 13-20. *(Top)* Proximal fracture in a boy of 15 years. The best position that could be achieved after several attempts was not good enough. *(Bottom)* Open reduction produced an excellent result.

EPIPHYSEAL SEPARATION OF THE DISTAL RADIUS

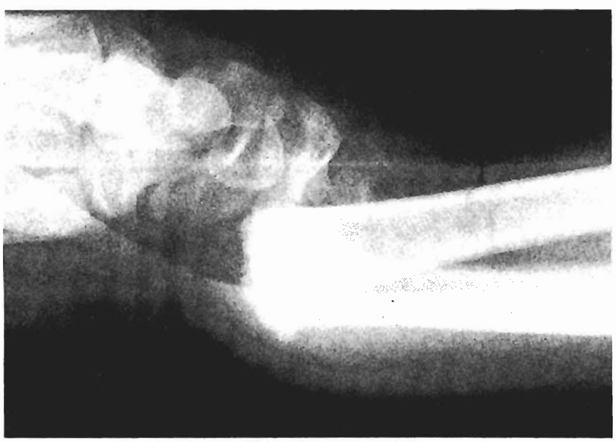
Type-I Injuries

Type-I injuries are seen in younger children, are seldom much displaced, and are diagnosed on clinical suspicion more than by radiographic findings. Swelling and tenderness at the growth plate, despite normal radiographs, are our grounds for making this diagnosis. Protection for 3 weeks in a cast is more than enough treatment. You may think this is overdiagnosis, but the entity is common, real and painful. A cast relieves the symptoms and stops the parents worrying and telephoning.

Type-II Injuries

Type-II injuries are the most common, usually associated with posterior displacement, and frequently accompanied by a chip off the ulnar styloid. They are easily reduced by direct pressure under anesthesia. Wrist flexion does not help to hold reduction, because the wrist joint flexes easily to 80 degrees before the capsule tightens enough to exert any influence on the distal fragment. In order to achieve anything with wrist flexion, more than 80 degrees of flexion will be required, and such a position is intolerable. Therefore, leave the wrist in a neutral position. Apply a below-elbow cast with scrupulous three-point molding. In 3 weeks the fracture will be united, and the cast can be removed (Fig. 13-21).

Fig. 13-21. Type-II epiphyseal separation in a boy of 15 years. This is easily and completely reduced.



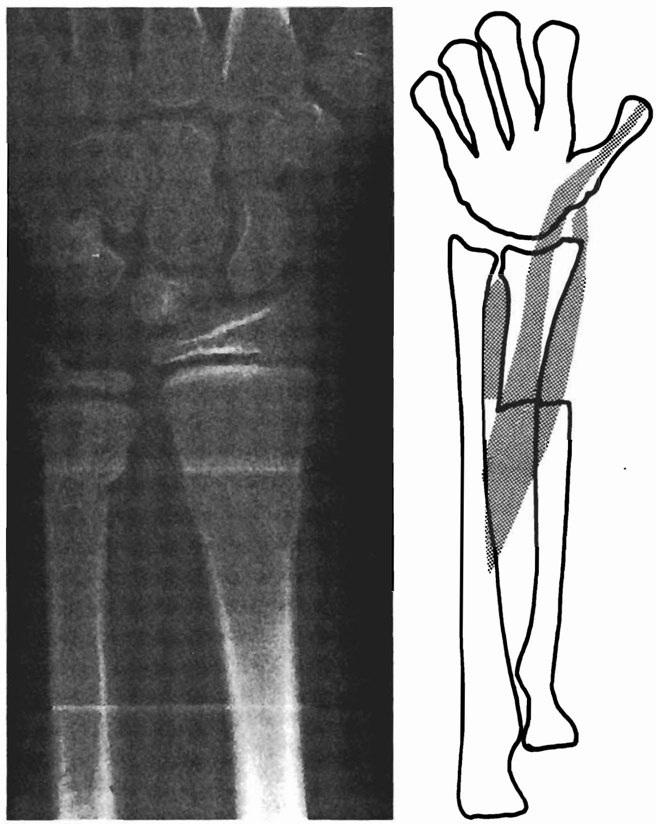
BUCKLE FRACTURES

Buckle fractures are common and usually dismissed by the family for a day or two as a sprain. The diagnosis is usually accompanied by guilty feelings on someone's part. Protect these injuries for about 3 weeks with a below-elbow cast (Fig. 13-22).

OVERLAPPING SOLITARY RADIAL FRACTURES

The ulnar styloid is usually avulsed. Armed with strong thumbs and an awareness of the periosteal hinge, you can reduce all these fractures closed, as shown in Figure 13-23. If the fragments are still in cortex-to-cortex apposition, repeat the maneuver with more thumb pressure. Be careful not to dislocate your own thumb in the process, as a surgeon in our group did. Set the arm in full pronation to hold the reduction.

Fig. 13-22. *(Left)* A buckle fracture in a girl of 10 years. *(Right)* Medially displaced fracture of the radius. The outcropping thenar muscles and pronator quadratus contribute to the deformity.



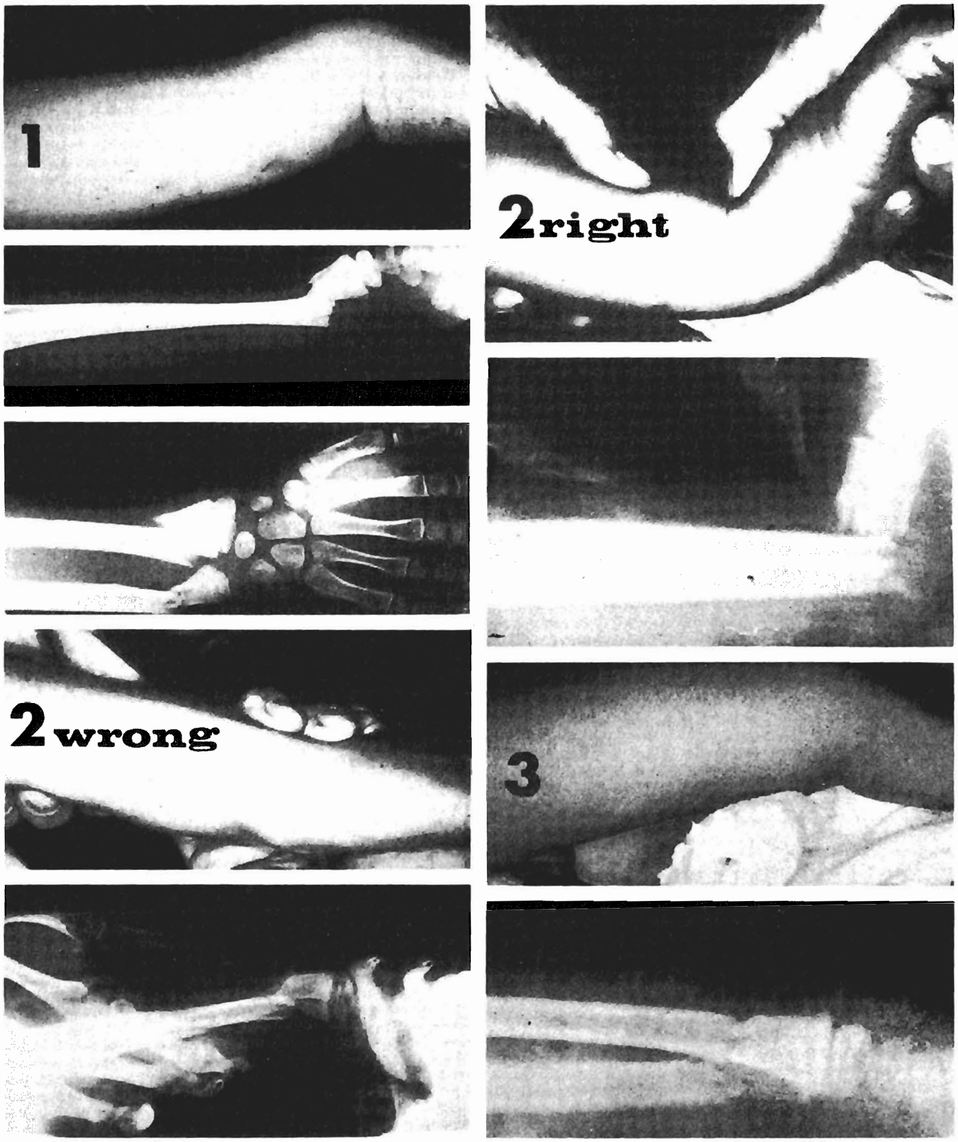


Fig. 13-23. Reduction of a forearm fracture with overlap.

MEDIALLY DISPLACED SOLITARY RADIAL FRACTURES

Outcropping thenar muscles contribute to this deformity. Reduce the fracture in supination to relax them, and include the thumb in the cast. Complete reduction is often difficult but, fortunately, slight displacement gives little or no functional disability (see Fig. 13-22, *right*).

DISPLACED FRACTURES OF THE DISTAL RADIUS AND ULNA

If both bones are overlapping, reduce them one at a time by increasing the deformity as described above. Hold the fracture in the midposition, with firm three-point molding. If the fracture is put up in either full pronation or supination, one fragment will be angulated anteriorly, while the other is posteriorly angulated (Fig. 13-24).

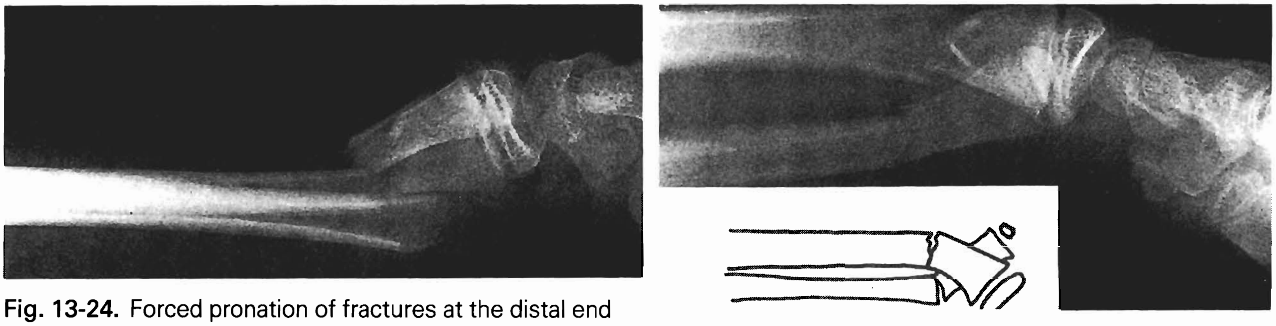


Fig. 13-24. Forced pronation of fractures at the distal end of the radius and ulna will produce angulation.

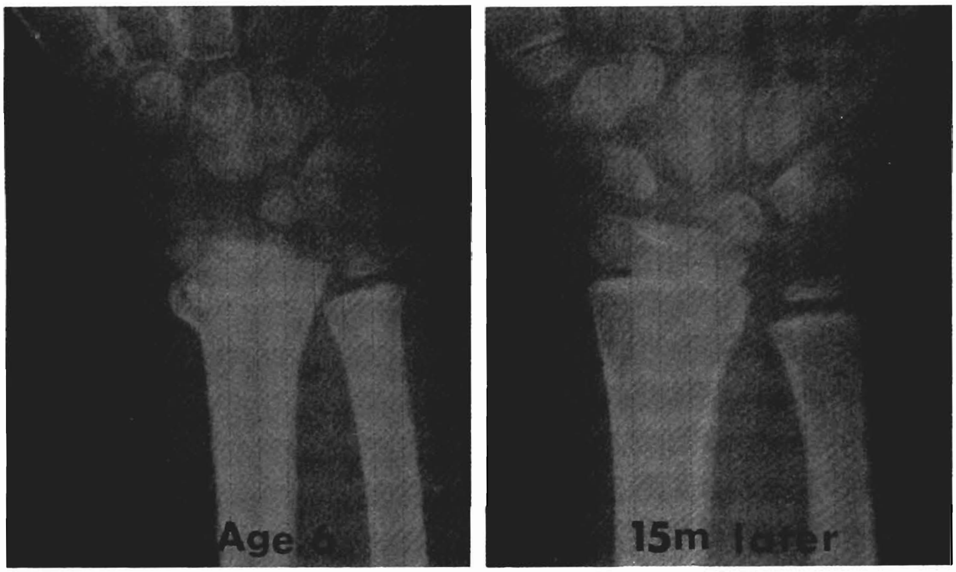


Fig. 13-25. Remodeling is effective at the ends of bones in young children.

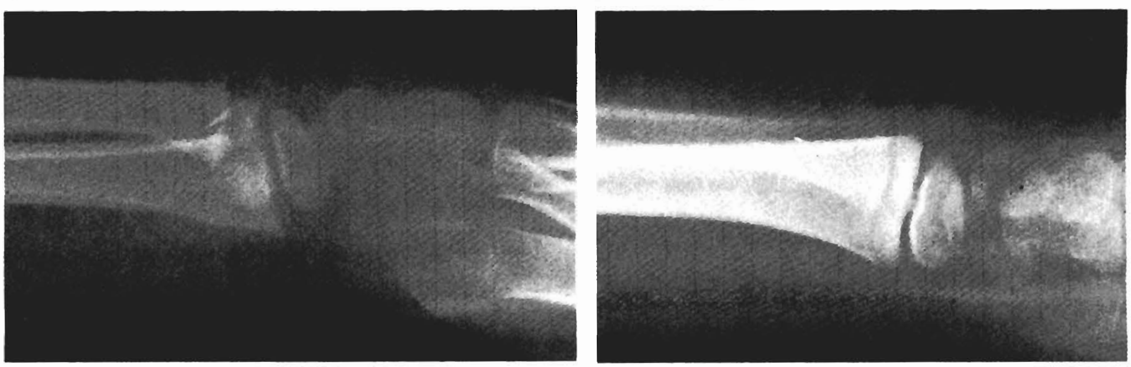


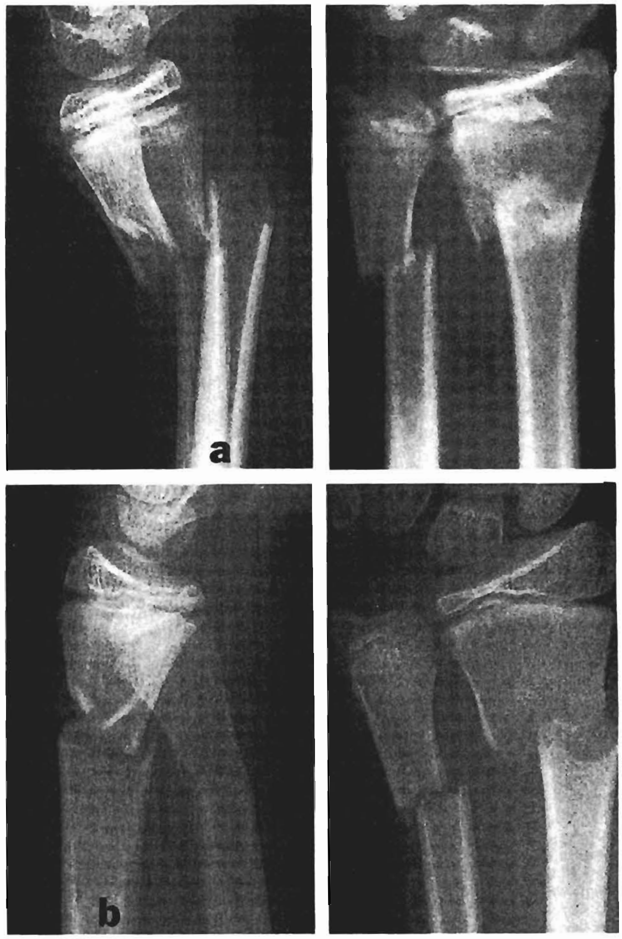
Fig. 13-26. Remodeling does not correct rotational deformity in older children: *(A)* initial injury in a 14-year-old boy. *(B)* After manipulation the distal fragment of the radius has been rotated through 90 degrees. Note the difference in the width of the bone. *(C)* When the cast is removed, the fracture has angulated. *(D)* Two years later he has only a jog of rotation. The combination of 90 degrees of deformity and angulation has prevented movement, but the ends have rounded off. Look at the position of the bicipital tuberosity; what is the position of the proximal fragment?

Remodeling

Children's forearm fractures have an amazing capacity to improve their radiological appearance with the passing of the months (Figs. 13-25 to 13-27). Friberg has shown that fractures at the distal end of the radius will correct at the rate of about 1 degree a month or 10 degrees a year as a result of epiphyseal realignment.[2–4] But diaphyseal malunion is unforgiving. The bone may round off on radiographs so that the site of the fracture disappears, but the arm looks just as crooked and lacks just as much rotation as when the cast was removed. This should be described as "rounding off" rather than "remodeling."

A few rules may help:

1. Only crude predictions can be made about remodeling.
2. Perfect function can only be promised when the fracture remains perfectly aligned.
3. Bayonet alignment or overlapping may be unstable, but it is compatible with perfect alignment.
4. Realignment of a malunited fracture occurs as a result of epiphyseal growth. The malunion does not straighten. For every 10 degrees of metaphyseal malunion a year's growth should lie ahead for correction.
5. Diaphyseal malunion that blocks more than 50% rotation and looks ugly should be treated by osteoclasis, not benign neglect (Fig. 13-28).



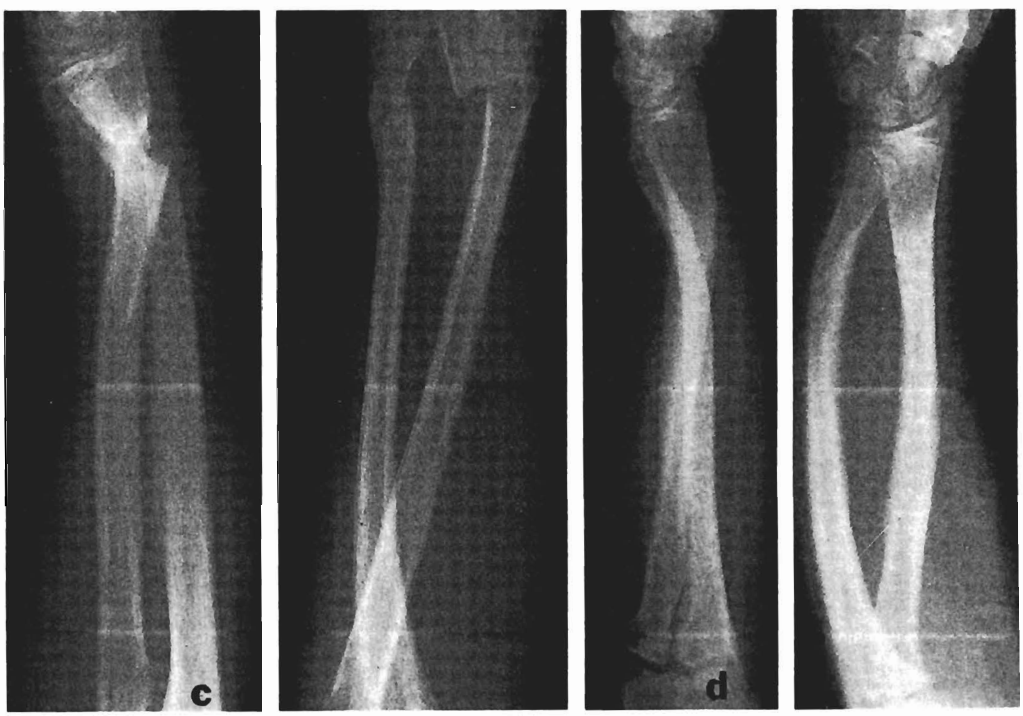
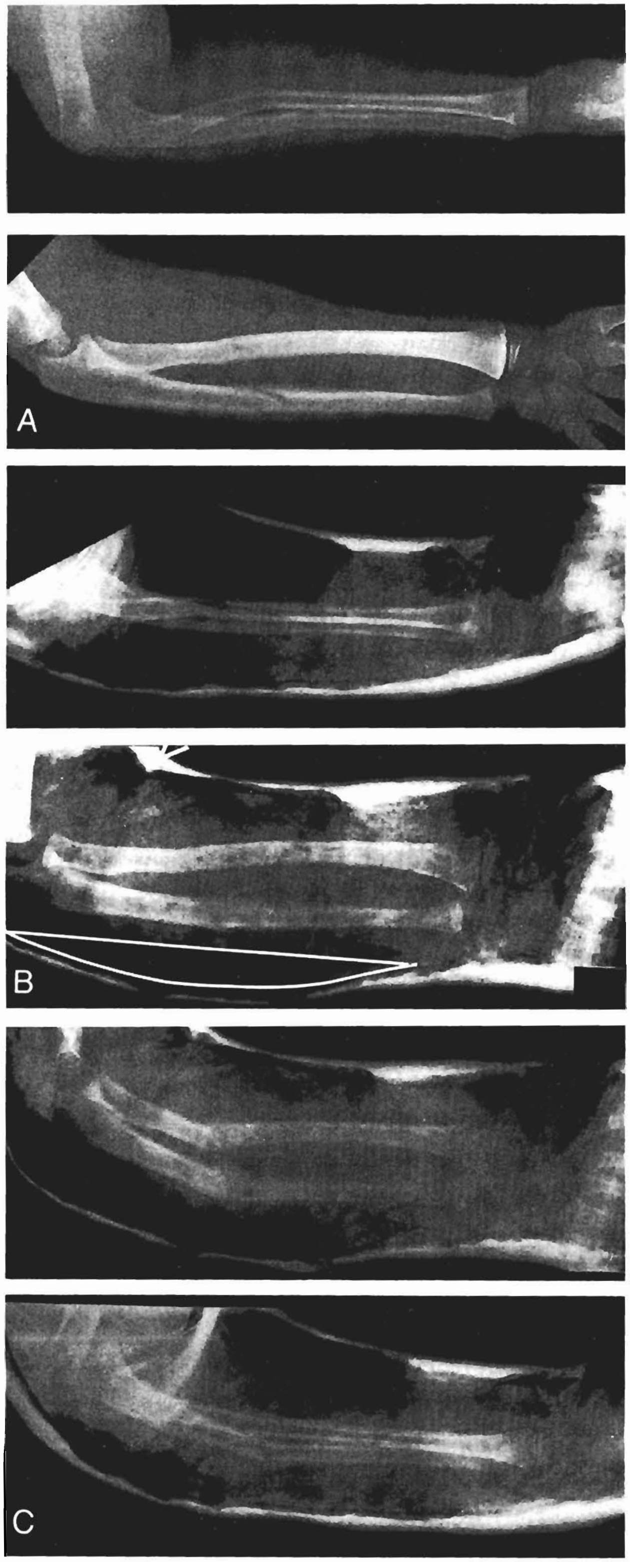


Fig. 13-27. Remodeling is effective in the young at the junction of the radial metaphysis and diaphysis. This child straightened out without treatment. This is a common problem.



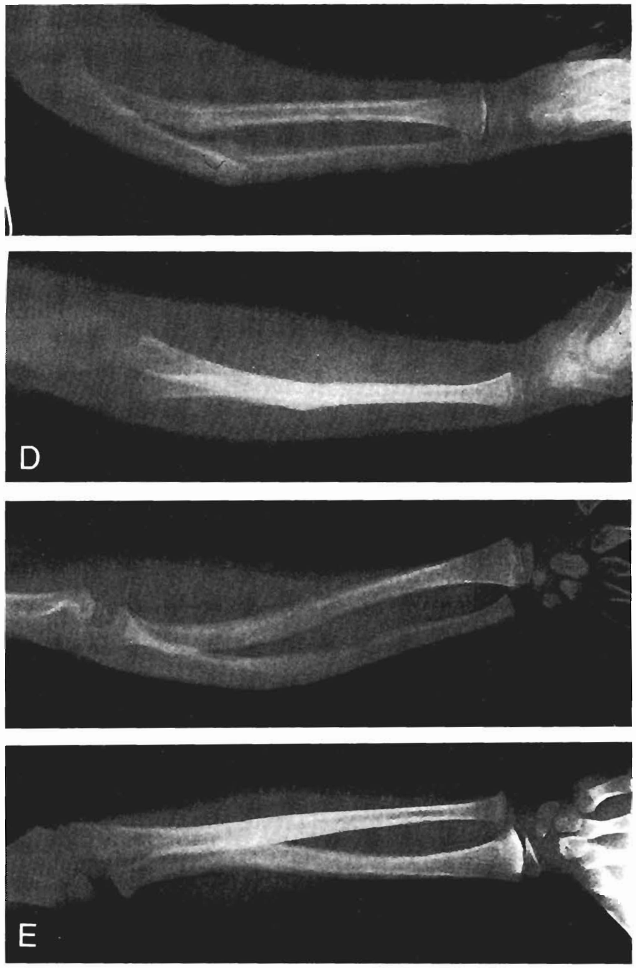


Fig. 13-28. *(A)* Was the arm immobilized when the x-ray film was taken? No. What is the displacement? Supination. What position should the fracture be placed in? Pronation, with the elbow extended, because it is a proximal fracture in a small child. *(B)* Is the cast satisfactory? No, the fracture is not reduced. The forearm should be pronated. The cast does not have a straight ulna border—it sags, inviting the ulna to fill the void. The elbow lacks moulding anteriorly, asking the cast to ship off. *(C)* Three weeks after injury. Would you accept this position? No reduction is required. *(D)* The arm looks crooked 3 months after injury. Will it remodel? No, angular deformities in the diaphysis are unforgiving. *(E)* Two years after injury the child awaits osteotomy.

FRACTURES OF THE RADIAL NECK AND OLECRANON

Fractures of the radial neck and the olecranon are discussed in Chapter 12.

FRACTURE DISLOCATIONS

MONTEGGIA'S FRACTURE DISLOCATION

For practical purposes there is no such thing as an isolated fracture of the ulna (Fig. 13-29). Giovanni Monteggia's 1814 experience is still being repeated. Here is Monteggia's original account:

> I unhappily remember the case of a girl who, after a fall, seemed to me to have sustained a fracture of the ulna in its upper third. It might have been that some commotion of the dislocated bone misled me at the beginning of treatment, or else it might have been that there really was a fracture of the ulna with a dislocation of the radius, as I undoubtedly found in another case. The fact is that at the end of the month, when the bandage was removed and all the swelling had disappeared (which, however, in simple dislocation of the radius is usually slight), I found that on extending the forearm the head of the radius jumped outwards, forming a hard ugly prominence on the anterior surface of the elbow, showing in an extremely obvious way that this was a true anterior dislocation of the head of the radius. When compressed it went back into place, but left to itself it came out again especially on extension of the forearm. I applied compresses and a new bandage to hold it in, but it would not stay in place.[8]

Monteggia did not have radiography to help him. All radiographs of the forearm should include the wrist and elbow joints (Fig. 13-30). *A line through the long axis of the radius should pass through the capitellum in all views* (Fig. 13-31). The radial head may be displaced anteriorly, laterally, or (occasionally) posteriorly. Closed reduction is usually possible in children (unlike adults)—perhaps because the orbicular ligament is avulsed from the ulna rather than torn.

There are two catches to this diagnosis. Congenital dislocation of the radial neck may masquerade as a new injury; however, the radial head is too big, eccentric, and slightly irregular, and the radius is too long to permit serious confusion. Acute radial dislocation may be accompanied by bending of the ulna,

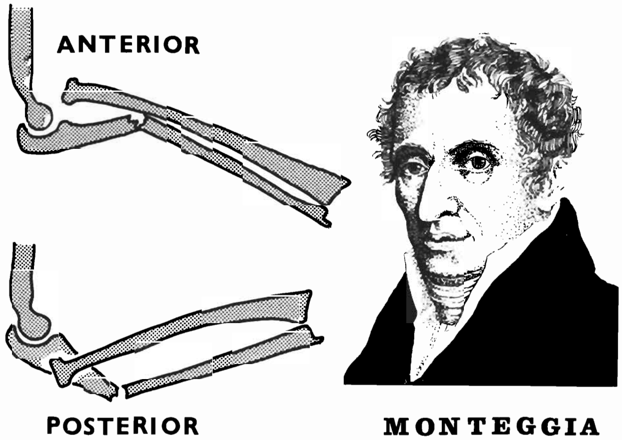


Fig. 13-29. Monteggia gave his name to this injury after he had missed the diagnosis. Today these injuries are still missed frequently.

Fig. 13-30. There is a conspiracy to prevent recognition of the dislocated radial head. Either the film does not include the elbow joint or the name goes over it.

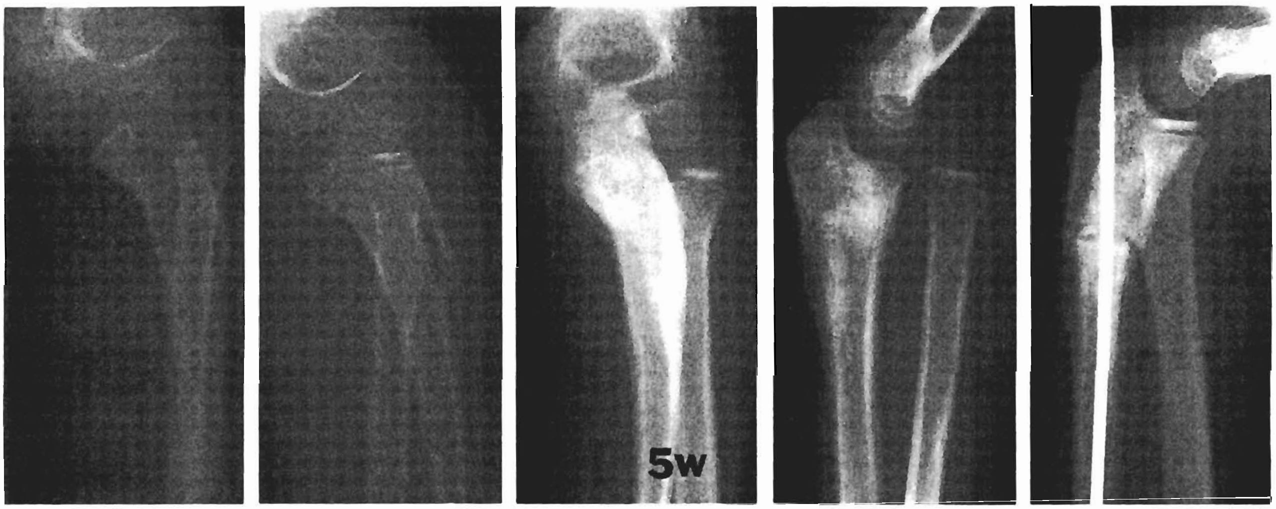


Fig. 13-31. Initial films did not include a lateral of the elbow. Anterior dislocation was missed until the cast was removed. Osteotomy of the ulna and open reduction of the radial neck was required.

which may go unrecognized until the normal ulna is radiographed (Fig. 13-32). A separated radial epiphysis is another variety of the Monteggia injury seen in children (Fig. 13-33).

Treatment

Anterior Dislocation. Apply traction with the forearm extended and supinated. Press the radial head back into position while flexing the elbow. Immobilize the elbow in full supination with as much flexion as the circulation will tolerate (Fig. 13-34).

Lateral Dislocation. Traction in extension followed by flexion to 90 degrees and supination will reduce the radial head (Fig. 13-35).

Posterior Dislocation. Apply traction to the forearm with the elbow in as much extension as the deformity will permit. Push the radial head forward, and immobilize the elbow in extension.

GALEAZZI'S FRACTURE

Fracture of the radius with dislocation of the inferior radioulnar joint is less common than Monteggia's injury and less definite. It is easily managed by reduction of the displacement of the radius (Fig. 13-36).

Fig. 13-32. The ulna may bend in young children in association with a dislocation of the radial head.

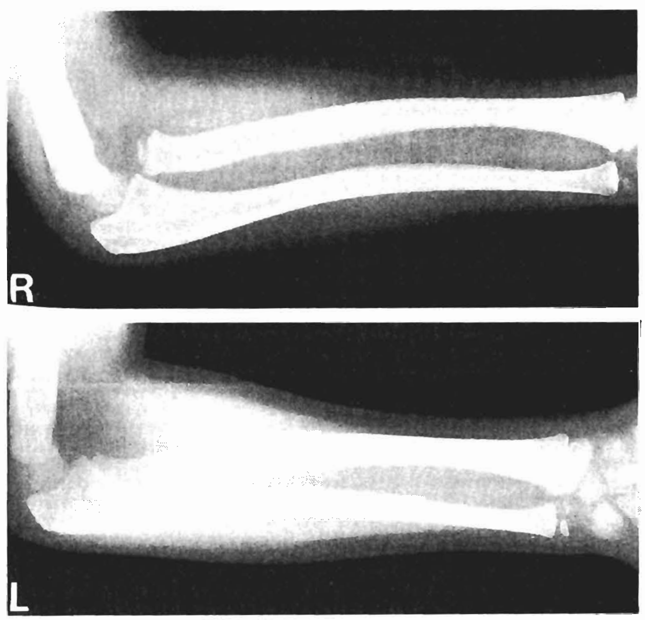


Fig. 13-33. Separation of the radial head with a fracture of the ulna in a boy of 12 years. Views before and after reduction.

FOLLOW-UP CARE

Apart from buckle fractures, all these injuries should be considered unstable. Many a good reduction has been lost. Gandhi and associates studied 1767 forearm fractures in children under the age of 12 and found that 2.5% had significant angulation when the cast came off.[5] The causes of angular deformity in these children were:

1. Children missed follow-up radiograph at 1 week.
2. Nothing was done about tilting at 1 week.
3. Fractures of the distal one-third of the forearm were immobilized in midpronation.
4. Incomplete reduction was accepted.
5. Neglected cases, which presented late, occurred.

In this group Gandhi noted that angulation at the distal end corrects well if the growth plate has 5 or more years of activity.[5] Some degree of angulation can be accepted in children under the age of 10.

In the midforearm, angulation corrects poorly and limits rotation. Every effort should be made to maintain a reduction free of angulation or rotation.

We usually radiograph forearm fractures weekly for the first 3 weeks. The cast is removed at 6 weeks. If the fracture is very unstable, we may radiograph every week. If union is poor at 6 weeks, the cast should remain in place longer.

Refracture. A small proportion refracture within a few months. The fracture is a little more difficult to manipulate. In one series 10 of 18 refractures healed with deformity or loss of movement. Obviously refractures require just a little more effort.

CONCLUSIONS

Fractures of the forearm and wrist are the most common injuries in childhood. While the majority are easily treated, the occasional case will be underestimated or the patient will miss follow-up appointments and return with poor result. Thomas and others reviewed 375 consecutive fractures treated in 1 year.[9] At discharge 65 failed to achieve a satisfactory result because of loss of movement, a cosmetic deformity or more than 10 degrees angulation on radiographs. Four years later only nine were unsatisfactory. The most common problems solve themselves.

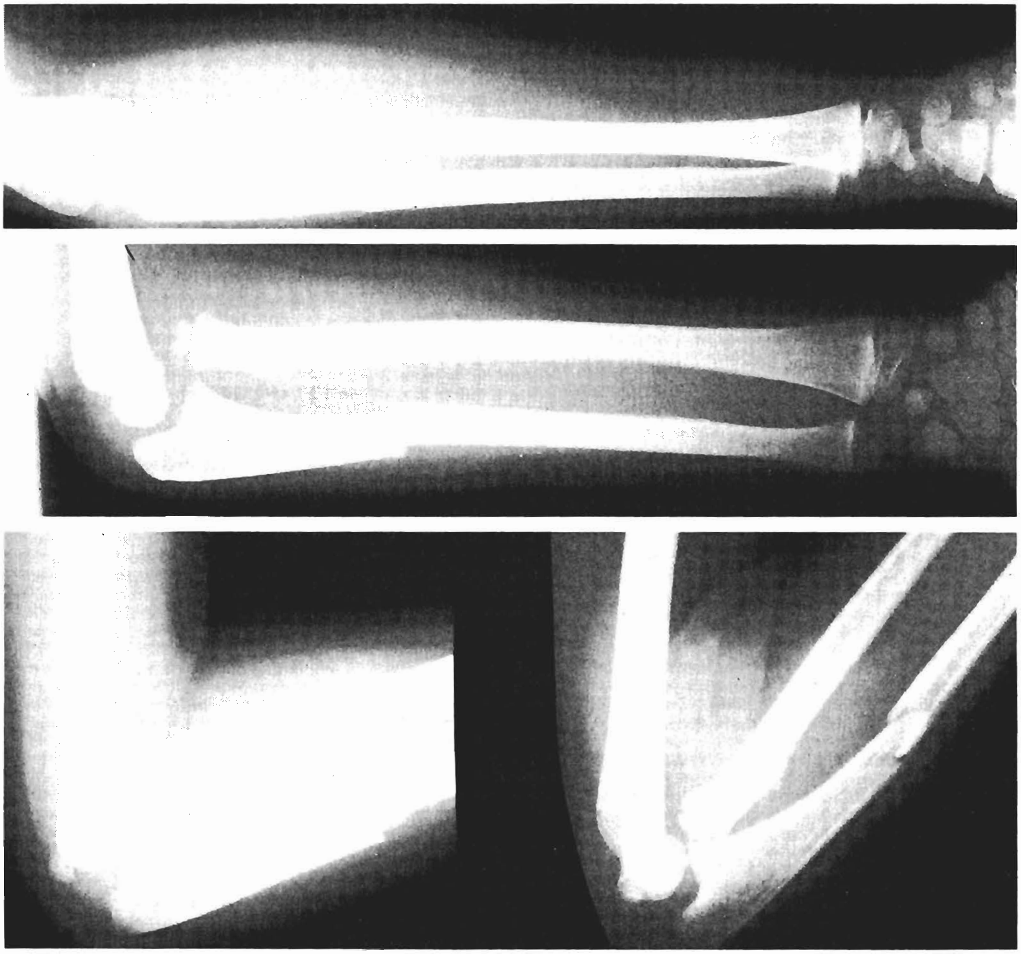
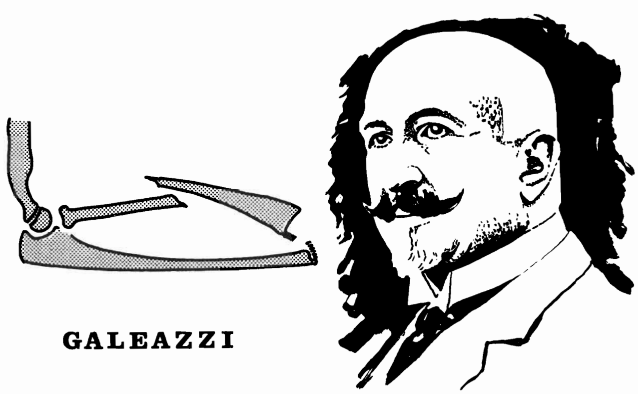


Fig. 13-34. Reduction of an anterior Monteggia fracture dislocation is by flexion and supination. *(Bottom, left)* Insufficient flexion to reduce the radial head. *(Bottom, right)* More flexion achieves reduction.

Fig. 13-35. The lateral type of Monteggia injury is difficult to reduce. The ulnar deformity has not been fully corrected. One year later pronation is restricted by 10 degrees.

Fig. 13-36.



So what should you do with the child who presents with malunion a few weeks after the cast has been removed at Elsewhere General Hospital? Angular deformity at the lower end in a young child always improves. Rotational deformity at the lower end, midshaft deformity, and deformities in teenagers do not remodel well. It does not help to send these individuals away with reassuring words. They must either accept what they have or accept correction. The parents have already been disappointed once. The choice of correction lies between:

1. **Manual Osteoclasis.** Don't try this. The bone will break at a distance from the malunion and leave you with dog-legged arm.
2. **Drill Osteoclasis.** This is the method of choice. Make a 5-mm incision over the malunion. Use a drill guide or a trochar to protect the soft tissues as you make several holes in the bone with a powered drill. Drill both radius and ulnar, keeping away from nerves. Crack the bone and immobilize it in a cast, usually with the elbow in extension. Take x-ray films frequently.
3. **Osteotomy and Plating.** Trading a scar for a deformity is a basic tenet of orthopaedics. The cosmetic disadvantage has lead us to avoid this technique, but it is the most exact method.

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14 / Hand

In our Emergency Department the hand is radiographed for possible fractures more often than any other part, yet interesting hand fractures are rare in children. Three-quarters of the injuries can be managed by a little strapping and reassurance that everything will be all right again in a few weeks. Carpal dislocations and multiple unstable fractures of the metacarpals are not seen, and challenging industrial hand injuries are missing. This leaves only a few varieties of phalangeal fractures to win an orthopaedic surgeon's interest.

PROBLEMS OF FINGER FRACTURES

Malrotation

Malrotation does not remodel. The fingers become entangled when flexed. Rotation should be checked in two ways: (1) ensure that all the fingernails are in the same plane (Fig. 14-1) and (2) ensure that the fingers remain adjacent when flexed, and do not converge or diverge. Malrotation does not show on a radiograph. Only by these simple clinical tests can the problem be recognized. When the fingers are immobilized in a flexed position, as they should be, this problem does not usually arise. Correction of malrotation in a fresh fracture is easy, but if it heals with malrotation, only osteotomy will correct the position.

Angulation

Angulation is usually apparent on radiographs and is easily detectable clinically. Straighten the finger and splint it to the adjacent finger using strapping or a cast (Fig. 14-2). Never immobilize a solitary finger. When one finger alone is immobilized, there is a great chance that angulation will develop by the time the cast is removed.

Malarticulation

Patients are very sensitive about finger stiffness because it is so easy to make comparisons with the other finger joints. Stiffness and swelling after an injury often last for several months, even when the injury does not alter a joint surface. However, these problems will certainly be permanent if you do not correct irregularities in the joint surface (Fig. 14-3).

Interposition

The volar plate of the metacarpophalangeal joint may become locked in the joint after a dislocation. The joint is swollen and stiff, and radiographs show a widened joint space.

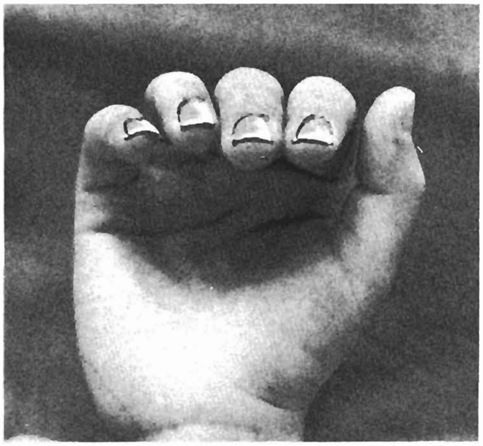


Fig. 14-1. The fingernails should be in the same plane. When there is malrotation, one finger is in a different plane.

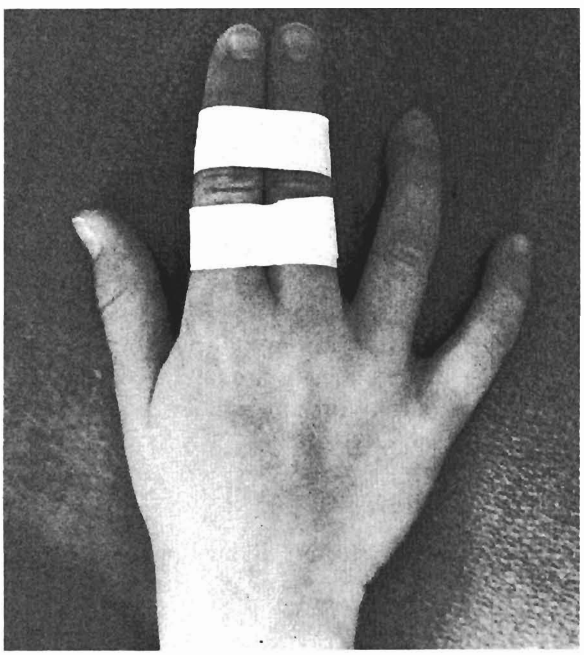


Fig. 14-2. Strap two fingers together for minor injuries.

Fig. 14-3. Type-III growth-plate injury. This girl did not come for treatment for 3 weeks, and the position was accepted. The fracture united, but she has a marked swan-neck deformity.

Interposed tendon or capsule may be recognized occasionally on radiographs. Interposition should be suspected when a fracture or dislocation cannot be reduced or when, after a dislocation has been reduced, the range of movement is incomplete. When closed reduction fails, open reduction is required.

INDIVIDUAL INJURIES

CARPAL FRACTURES AND DISLOCATIONS

Childhood scaphoid fractures are unusual but are not otherwise different from the injury in young adults. The lack of ossific nucleus until the age of six must be protective. Vahvanen and Westerlund somehow collected 108 cases: they noted many fractures of the distal third and a large number of avulsion fractures—all united.[7] But nonunion is known and may

require bone grafting.[6] Carpal dislocations are so rare that individual cases are reported. So far they have presented the same problems of recognition and treatment as in adults.

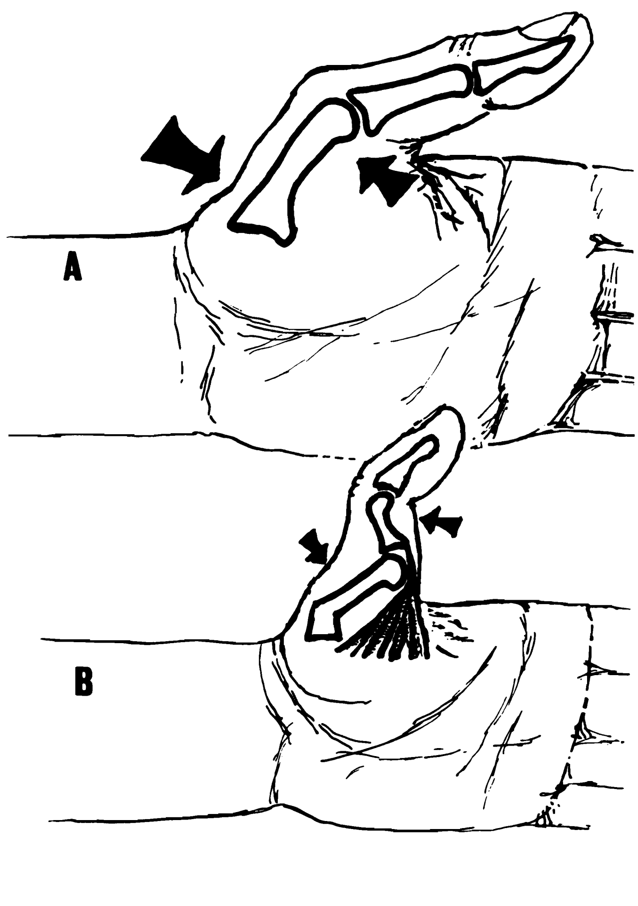
INJURIES OF THE THUMB METARCARPAL

Impacted Fracture of the Base of the Thumb

Impacted fractures of the base of the thumb are commonly the result of fighting. There is a flexion deformity (Fig. 14-4). Up to 30 degrees of angulation can be accepted; the thumb is protected in a scaphoid cast. Warn the parents that a bump will remain for a year after the cast is removed. Angulation over 30 degrees should be corrected under anesthesia. Press on the base of the thumb and apply counter pressure on the head of the metacarpal. Apply a scaphoid cast and mold it in the same way. The common error is to hyperextend the metacarpophalangeal joint by applying counterpressure too far distally, which does nothing to correct the deformity. A well-applied cast leaves the metacarpophalangeal joint slightly flexed (Fig. 14-5). It may be removed after 3 weeks.

Fig. 14-4. Buckle fracture of the thumb.

Fig. 14-5. *(A)* Three-point molding for fractures of the thumb with flexion deformity. *(B)* The common error.



Type-II Injuries

Some Type-II injuries are minimally displaced and require only protection. Occasionally there is complete displacement that buttonholes through the periosteum anteriorly. Although closed reduction is worth attempting, these injuries usually require open reduction to lever the metaphysis back into position (Fig. 14-6).

Type-III Injuries

The medial part of the growth plate closes last, and adolescents may separate the medial corner of the epiphysis. This is the same as a Bennett's fracture and requires accurate repositioning. Under anesthesia, traction usually reduces the fracture dislocation; a thin, percutaneous Kirschner wire can be inserted just proximal to the base of the metacarpal into the trapezium to maintain reduction (Fig. 14-7). A scaphoid cast completes the immobilization. Three weeks is sufficient.

Fig. 14-6. *(A)* Ulnar displacement of a Type-II fracture usually defies closed reduction. This one was left because of severe head injury. The thumb was short and bumpy, but it moved well. *(B)* Radial displacement is easily corrected by closed reduction, as indicated in the Figure 14-5.

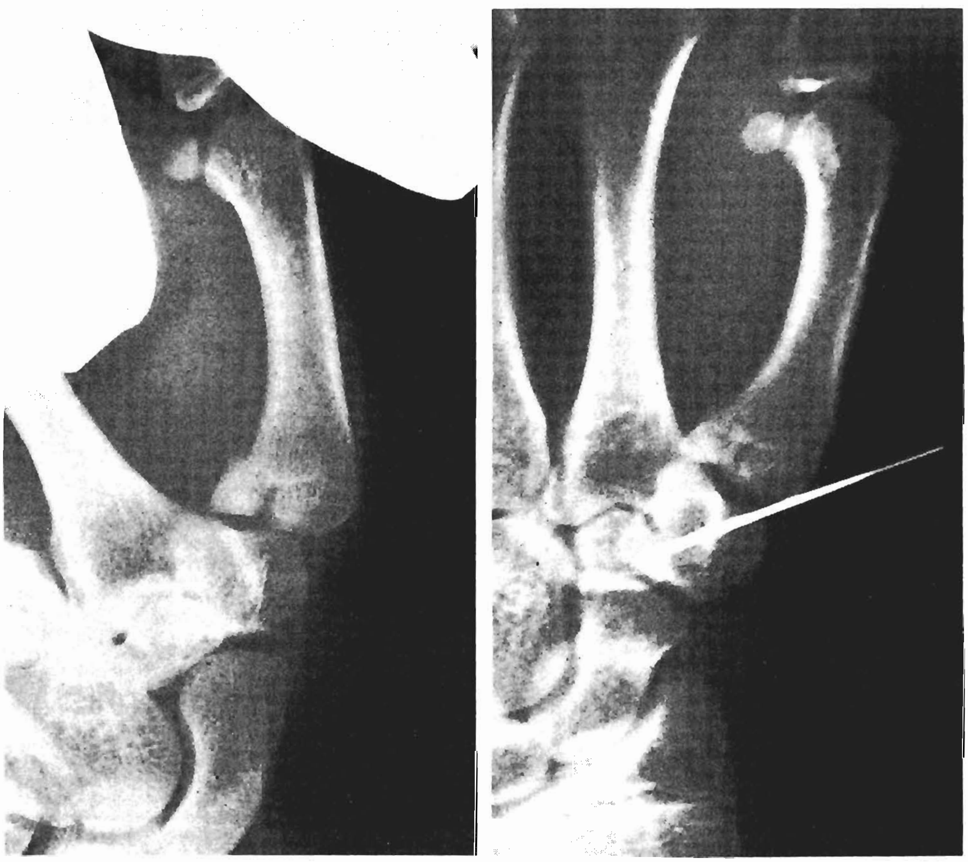


Fig. 14-7. Bennett's fracture dislocation. A pin passed percutaneously will hold the reduction. In children, the fragment is too small to be held with a screw.

FRACTURE DISLOCATION OF THE METACARPOPHALANGEAL JOINT OF THE THUMB

Skiers who hold the loop of the ski-pole strap in the palm are liable to avulse the ulnar collateral ligament. Skiers should use poles without straps or else keep the strap loosely round the wrist to avoid this injury. I believe the best results follow surgical replacement, but cast immobilization produces adequate results (Fig. 14-8).

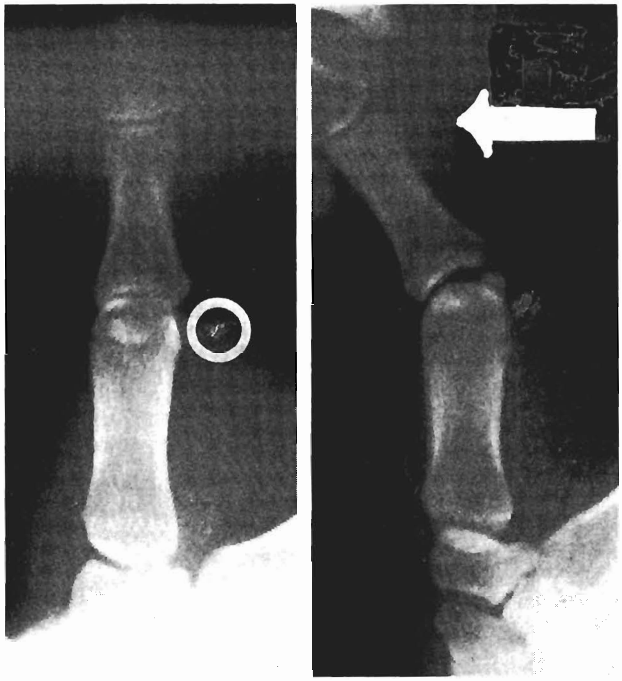


Fig. 14-8. Ski-pole thumb. The ulnar collateral ligament has been avulsed with a chip from the base of the proximal phalanx. Stress films make this clearer.

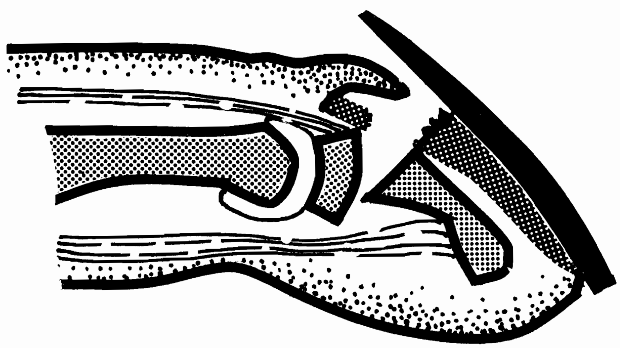
INJURIES OF THE FIFTH METACARPAL

Impacted fractures of the neck of the fifth metacarpal are very common after fights. There is no satisfactory method of holding the fracture reduced without hazard. Cleverly molded casts produce stiffness and sores. For this reason, I usually put a bandage around the palm for comfort, and warn the parents that the knuckle will be less prominent for a year or two. The functional results are excellent. Tell the child in the future to fight only with a tightly clenched fist, like a real fighter. Strongly contracted muscles protect the hand from injury.

OTHER METACARPAL FRACTURES

Fractures of the metacarpal shaft are much less common in children than in adults. Marked swelling appears on the dorsum of the hand. Elevate the arm, apply a front slab of plaster, and apply a well-padded, yielding bandage around the palm and forearm. Encourage finger movements, and remove the cast after 2 to 3 weeks.

Fig. 14-9. The Seymour injury.



PHALANGEAL FRACTURES

Children's former friends step on fingers, bend them back, and damage them with baseballs.

Injuries of the Proximal End of the Phalanx

The Seymour Injury. A mallet finger with much deformity, owing to an epiphyseal separation, may avulse the base of the nail and lacerate the nail bed (Fig. 14-9). The nail overlies the nail fold. Seymour observed the temptation to remove part of the nail, which rendered the fracture unstable.[5] The best results came from replacing the nail and using a mallet finger splint. Engber and Clancy note that infection will damage the nail bed and the growth plate.[4] When there is infection, remove the detached portion of the nail, debride and irrigate the wound, splint the fracture, and administer antibiotics effective against resistant staphylococci.

Type-I Injuries. In the infant, the proximal epiphysis is unossified, a fact that may lead to diagnosistic difficulties. I recall an infant of 9 months whose little finger was caught in a car door. When the swelling went down after a couple of weeks, the finger was crooked at the level of the proximal interphalangeal joint. Radiographs suggested a dislocation. At operation, the proximal epiphysis was found rotated through 180 degrees. After reduction, the appearance was improved, but the joint had only half the normal range of movement and the epiphysis did not grow well (Fig. 14-10).

A more typical Type-I injury produces a mallet deformity of the distal interphalangeal joint. This is easily held with a splint or strapping until union is solid at 3 weeks (Fig. 14-11).

Type-II Injuries. Type-II injuries are most common in the proximal phalanges. A minor degree of displacement is usual and almost impossible to correct. The extra octave fracture of the little finger is the most common and usually requires nothing more than strapping to the ring finger (Figs. 14-12, 14-13). Greater degrees of displacement may be associated with gross swelling. Such a case requires admission, elevation, and reduction later (Fig. 14-14).

Type-III Injuries. In the adolescent, a mallet deformity is most commonly the result of a Type-III fracture–dislocation. It requires open reduction and fixation with two fine Kirschner wires (Fig. 14-15).

Corner fractures of the epiphysis are the equivalent of collateral ligament injuries in adults. If the articular surface is involved, these should be accurately replaced (Fig. 14-16).

Kirner's Deformity. This growth-plate abnormality mimics a mallet deformity of the little finger in children of about 9 to 12 years of age (Fig. 14-17). The fingertip is bent and there may be pain and tenderness. The x-ray film is characteristic, and bilateral

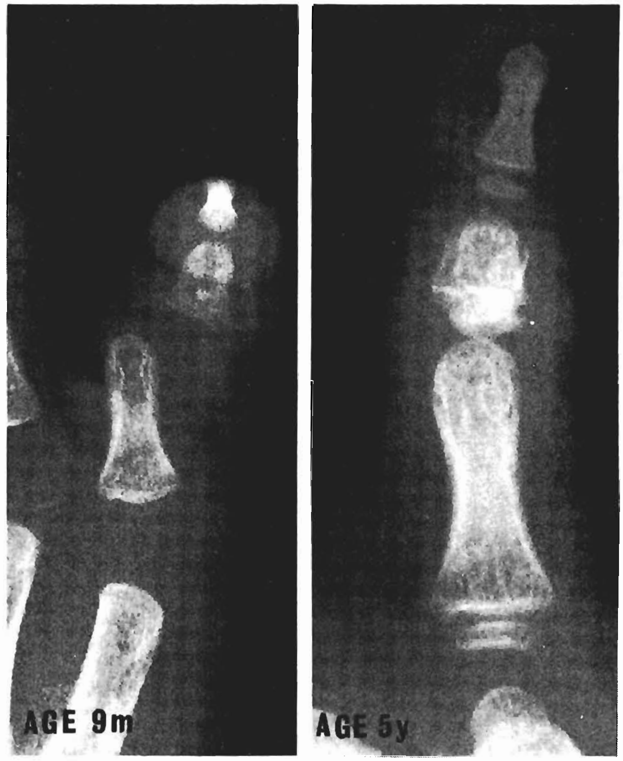


Fig. 14-10. An irreducible dislocation is always an indication for surgery. The proximal plate of the middle phalanx had been rotated through 180 degrees. After open reduction the finger was straighter, but growth was affected.

Fig. 14-11. Mallet finger.

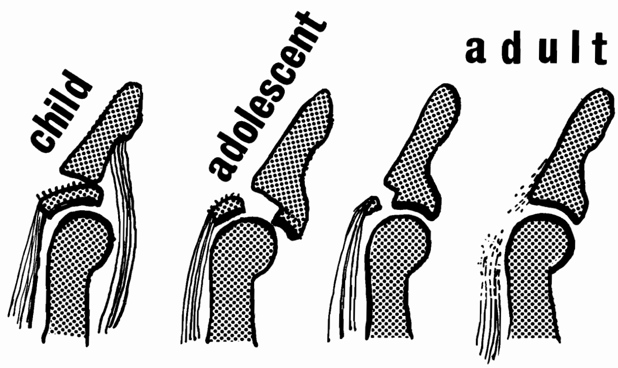
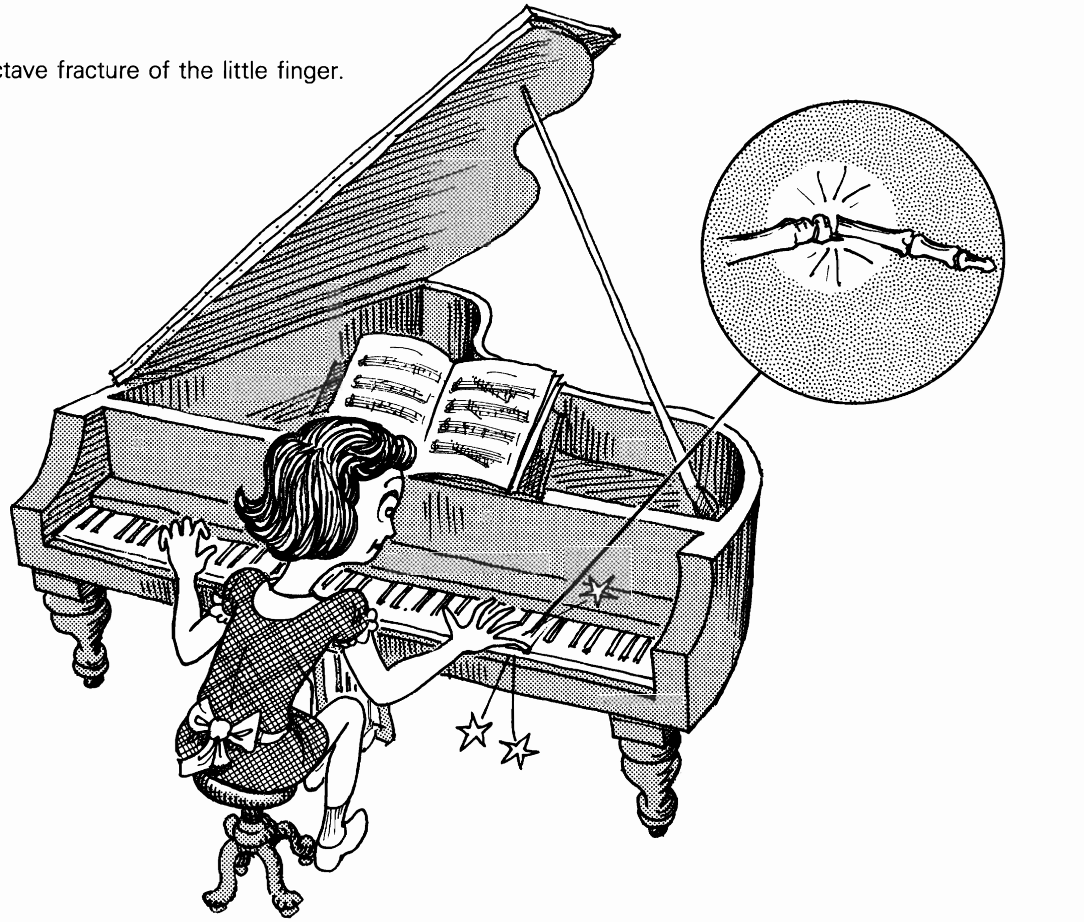


Fig. 14-12. The extra-octave fracture of the little finger.



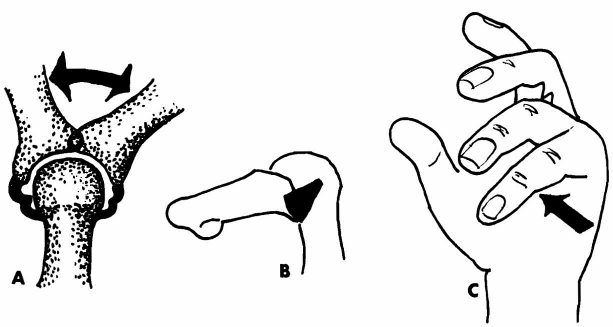


Fig. 14-13. *(A)* An extra-octave fracture cannot be reduced in extension because the metacarpophalangeal ligaments are lax. *(B)* The ligament becomes tight in flexion. Test this on yourself. *(C)* Reduce the fracture with the metacarpophalangeal joint flexed to 90 degrees. It is better than the pencil trick.

Fig. 14-14. When skating, this girl hyperextended her fingers. Gross soft-tissue swelling is evident on radiographs, and there are Type-II injuries of the middle and ring fingers. The hand required elevation, but reduction was not necessary.

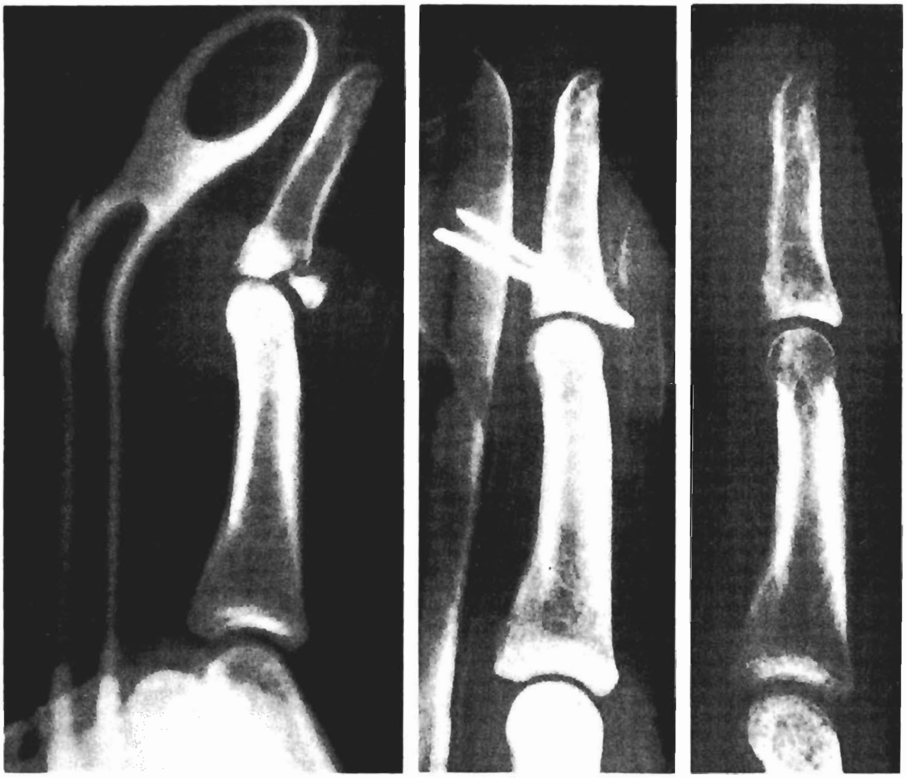


Fig. 14-15. Closed reduction did nothing for this 15-year-old. Open reduction was performed. The pins were left protruding anteriorly to facilitate skin closure. The length is easily adjusted. They are removed from the front.

Fig. 14-16. A corner fracture of the epiphysis of the index finger and a Type-III injury of the middle finger. The fingers were strapped together.

changes are frequent. It is sometimes familial. It may be a stress fracture owing to attachment of the tendons. The main reason for recognizing the condition is that deformity will be unaffected by splinting, and the parents should be warned. Splinting may be helpful for pain.

Fractures of the Shaft of the Phalanx

The majority of phalangeal shaft fractures are undisplaced injuries that require only protection. When displacement is minimal, strap two fingers together for about 3 weeks. If there is much swelling and there is a risk of displacement, use a slab of plaster in front of the fingers, and strap them down to it. The fingers should be well flexed in order to ensure that alignment and rotation remain correct.

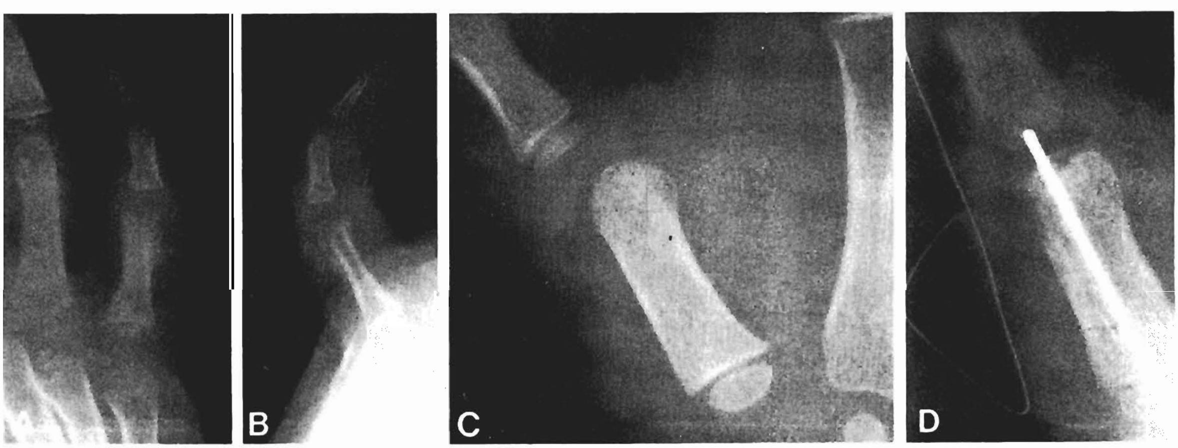
Injuries of the Distal End of the Phalanx

Cartilaginous Injuries. The cartilage cap of the phalanx has no epiphysis and is occasionally separated. This is not immediately obvious, but the passage of time reveals subperiosteal new bone formation and explains the cause of prolonged stiffness (Fig. 14-18).

Unicondylar Fractures. Undisplaced unicondylar fractures are almost unknown. Minimally displaced ones are easily overlooked (Fig. 14-19). They can be reduced by closed manipulation and held with a fine percutaneous Kirschner wire (Fig. 14-20). Grossly displaced fractures that cannot be reduced should be opened; loose fragments may have to be removed before the fracture is held reduced with two fine Kirschner wires. The wires and the cast should be removed at 3 weeks. These injuries are *commonly undertreated* and result in angulation and stiffness in the finger.

Fig. 14-17. Kirner's deformity. At first it was called a fracture. But there had been no injury and an x-ray film of the contralateral little finger was identical.

Fig. 14-18. *(A, B)* Three weeks after a crushing injury of the cartilaginous cap of a phalanx. No injury was recognized on the initial films. *(C)* A fresh osteochondral fracture of the metacarpal of the thumb. Closed reduction was impossible. At operation the fragment was found to be flipped over. *(D)* After open reduction and fixation with a fine wire.



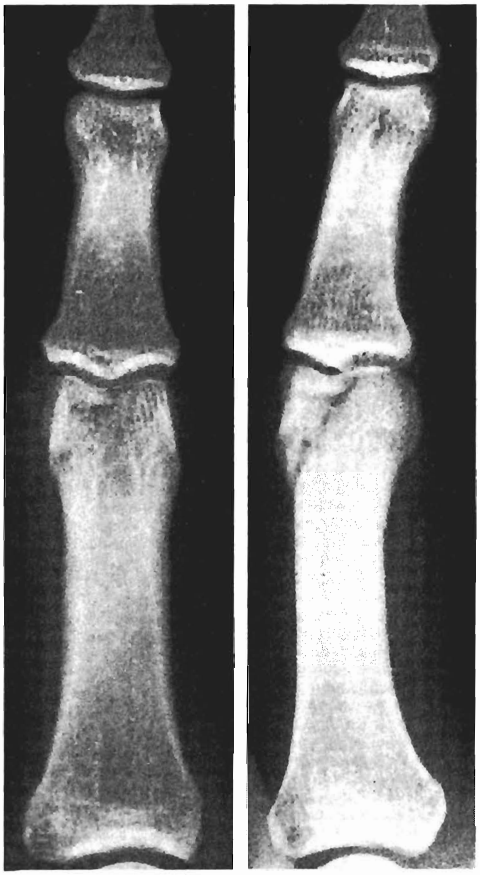


Fig. 14-19. Different projections are needed to show some condylar fractures. The fracture could not be seen on an anteroposterior (AP) film *(left)* but would have been visible on an oblique view *(right)*. This was "held" in a cast, slipped, and the patient now has a slightly crooked finger. It should have been pinned percutaneously.

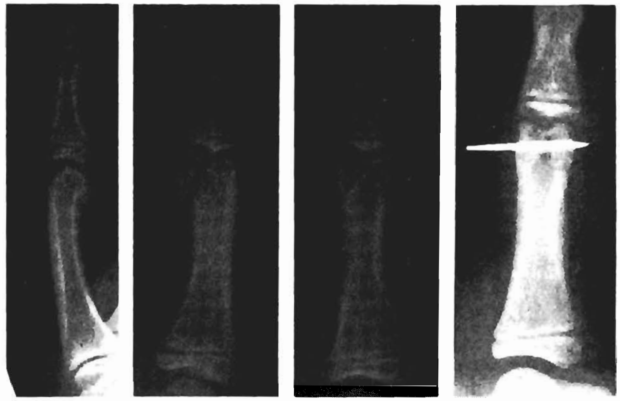
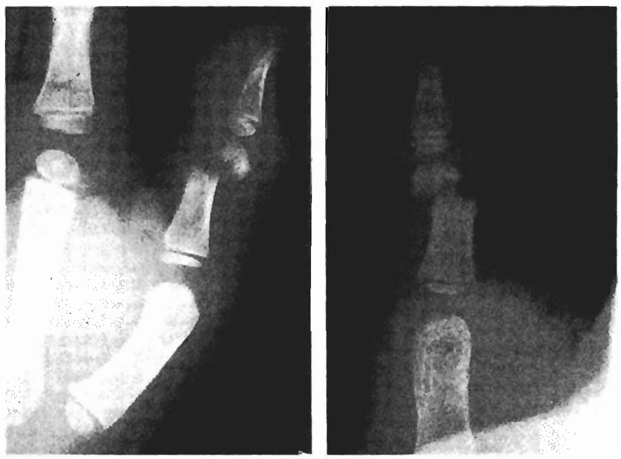


Fig. 14-20. Percutaneous pinning of a unicondylar fracture.

Fig. 14-21. This car-door injury healed well with cast immobilization.



Bicondylar Fractures. Some bicondylar fractures are little cracks, but others are widely displaced (Fig. 14-21). Dixon and Moon described fractures with 180 degrees of displacement.[3] You might think that this degree of displacement would be obvious, but unless you look for it, it will pass unnoticed. This degree of wide displacement denotes complete periosteal severance, and open reduction is required. Leave the pins in place for 6 weeks, because healing may be slow. Avascular necrosis, surprisingly, has not been described.

Stiffness after an injury, which is such a nuisance in adults, is not a great problem with finger fractures in children. Barton reviewed 203 children with phalangeal fractures and concluded:

1. Epiphyseal separations at the base of the proximal phalanx remodel in both planes; at the middle phalanx they remodel only flexion and extension, and at the distal phalanx commonly leave a mallet deformity.
2. Fractures of the neck do not remodel, and deformity must be corrected completely.[1]

DISLOCATIONS

Dislocation of the metacarpophalangeal joint of the thumb is common and can usually be reduced with traction under anesthesia. Cast immobilization with the thumb flexed is advisable for 3 to 6 weeks, to allow healing of the volar plate and to prevent repeated dislocation (Fig. 14-22).

Trigger thumb may present as a dislocation, but the signs are obvious and the radiographs are normal.

Posterior dislocations of the metacarpophalangeal joint of the finger usually requires open reduction. The metacarpal head may become trapped by the flexor tendons and the palmar fascia, or the capsule may become interposed.

Becton and associates advocate a posterior longitudinal incision; this is safer than the traditional volar approach and permits replacement of any osteochondral fragments.[2]

MISCELLANEOUS INJURIES

FROSTBITE

The growth cartilage is much more sensitive to cold than either skin or vessels. Permanent growth arrest may result from children riding bicycles in extremely cold weather. In the months that follow this, parents realize that the tips of the fingers are not growing. Radiographs disclose premature closure of the epiphyseal plates (Fig. 14-23).

WRINGER INJURIES

Crushing may damage growth cartilage and produce growth arrest (Fig. 14-24). Wringer injuries are discussed in greater detail on page 81.

Fig. 14-22. Dislocation of the metacarpophalangeal joint of the thumb.

Fig. 14-23. Frostbite injury. The fingers of one hand are short.

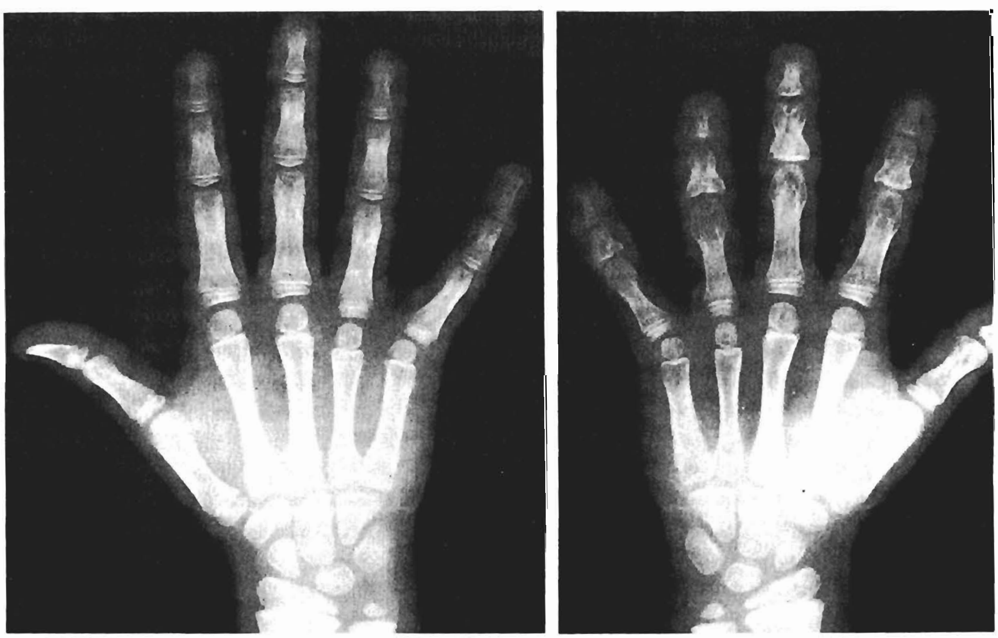


Fig. 14-24. Growth arrest in the left hand owing to an old wringer injury.

NERVE AND TENDON INJURIES

There is much to be said for primary repair of injured nerves and tendons. Children with these injuries should be referred immediately to a surgeon who specializes in hand surgery. Because there are several excellent works on tendon and nerve injuries, the subject will not be discussed further.

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15/ Pelvis

The pelvis is like a suit of armor: when it is damaged there is much more concern about its contents than about the structure itself. The problems for the orthopaedic surgeon are different at each age. Osteoporotic old people sustain minor fractures in falls that pose neither visceral nor orthopaedic problems; young adults involved in road accidents suffer fractures that may be difficult to reduce in addition to life-threatening visceral injuries; childrens' fractures are seldom displaced much and can usually be treated by bed rest, but their other injuries may require much treatment.

A review of 100 cases of fracture of the pelvis in children between the ages of 1 and 18 years who were treated at our hospital during the past 10 years was carried out by Dr. Bernard Nolan.* The greatest incidence was in children between 1 and 8 years old, who have little road sense. Ninety percent were the result of automobiles striking child pedestrians. Associated injuries were seen in 87% and the mortality rate was 8%. Blood transfusion was necessary in 30%, but that was mostly because there were multiple injuries: only 2% required transfusion for the pelvic fracture alone.

*Bernard Nolan, personal communication

ASSOCIATED INJURIES IN 100 CHILDREN WITH PELVIC FRACTURE

Remote

- Head injury—61% (caused most deaths)
- Chest injury—9%
- Fractures of the upper extremity—17%
- Fractures of the lower extremity—17% (15 fractures, 2 hip dislocations)

Local

- Hematuria—30%
- Urologic injury requiring surgery—10% (3 renal, 3 urethral ruptures, 4 bladder ruptures)
- Abdominal injury—11% (6 required surgery for spleen, GI tract, and mesentery)
- Perineal/gluteal lacerations—7%

These statistics are similar to those for adults. The incidence of hematuria is the same as reported by Levine and Crampton.[5] A similar proportion of patients required surgery, as reported by Hawkins and associates.[3] The visceral problems are not different in children.

CLASSIFICATION

A useful classification of pelvic fractures in children is based on the most serious aspect of the injury.[9]

Group I: Uncomplicated. A minor fracture is undisplaced. Shock is absent and transfusion is not required. Signs of abdominal and urologic injury are absent or settle quickly with nonoperative treatment.

Group II: Fracture with visceral injuries requiring exploration. These are more severe, and the child is in shock and requires immediate transfusion.

Group III: Fracture with immediate massive hemorrhage. The sacroiliac joint is separated, and the pulses in one leg are absent. A major branch of the internal iliac artery is torn. The child is admitted in profound shock and requires rapid transfusion of blood in massive quantities—up to 8 liters. Visceral injuries are also present. Despite energetic treatment, most of these children die.

The importance of concealed hemorrhage from fractures of the pelvis cannot be overstated. An autopsy study of 200 fatally injured pedestrians revealed that about half had sustained a fracture of the pelvis. In 21 the injuries were restricted to the pelvis; 10 had visceral injuries and 11, or 5%, had no visceral injuries and died of hemorrhage alone. (Many died while their doctors were obtaining sheaves of x-ray films without starting fluid replacement.)

INITIAL MANAGEMENT

The possibility of a fracture of the pelvis is great in any child who has been hit by a car. The initial care is that of any patient with multiple injuries. Life-threatening injuries are treated, an IV infusion is started, blood is ordered for immediate use, and a nasogastric tube is passed if there is abdominal distension. The number of physicians quickly increases, and the areas of injury are mapped out and investigated as thoroughly as time permits.

Pelvic fractures may be accompanied by visceral, vascular, or neurologic injuries, so look for blood at the urethlal meatus, vagina, and anus. Perform abdominal and rectal examinations. Feel the pulses, and test active movements in both legs. Test sacral sensation. The site and size of any swelling should be noted. Stability of the pelvis should be judged by compression.

The session in the radiography department may be long if urologic injury is suggested by either clinical signs or by the location of the fracture. Disruption of the symphysis or displaced fractures of the pubic ramus are most likely to cause injury to the bladder and urethra. Urethrogram, cystogram, and intravenous pyelogram may be required. The radiography department is usually the venue for a consultation among all specialists involved. While this goes on, the general condition of the child should be the first priority: in the twilight of an x-ray department the temptation is to take more and more films. But don't let the patient bleed to death.

A plan of definitive treatment is worked out for each aspect of the injury.

Visceral Injury

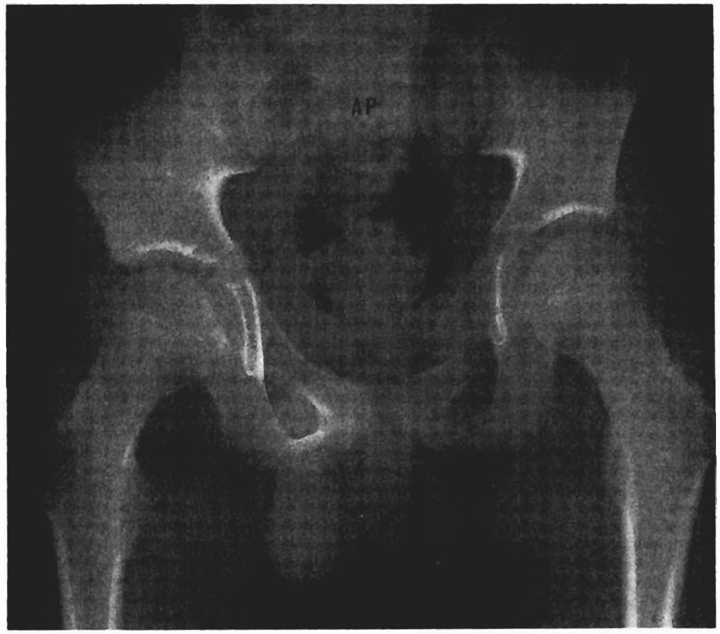
The investigation and treatment of urologic injury is described on page 124 and of intraperitoneal injury on page 109.

Hemorrhage

Hemorrhage may be intraperitoneal or extraperitoneal. Intraperitoneal hemorrhage is comparatively easily controlled at laparotomy: extraperitoneal may be massive around the sacroiliac joint, and (at operation) has terrified and defeated many surgeons (including me). Slow hemorrhage will tamponade and stop, but rapid hemorrhage requires control. Exposure of the bleeding vessels is often difficult; if packing does not control hemorrhage, it may be helpful to enlist the assistance of a radiologist. Ring and associates[10] have used arteriography to reveal the site of hemorrhage. An arterial catheter is inserted through the femoral artery of the least injured side. The catheter is then manipulated into the vessel leading to the leak, usually the hypogastric artery. Autologous clot is injected, which is carried to the leak by preferential flow. Successful arrest of hemorrhage is recognized by a fall in the blood requirements and by a repeat arteriogram.

Nerve Injury

Many of these injuries are missed because detailed neurologic examination is neglected, and weeks later



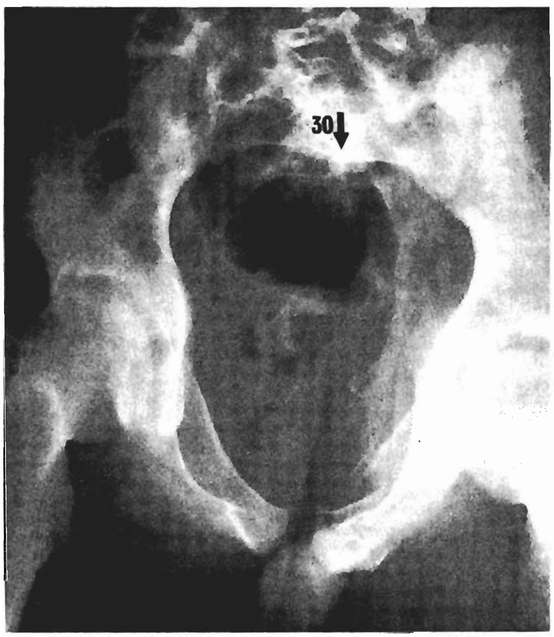


Fig. 15-1. Three views of the pelvis are the minimum required to identify the degree of displacement. The fracture through the right sacral foramen is seen only in the 30-degree, down-shot view.

a slight limp is easily attributed to other factors. The lumbosacral plexus is closely related to the sacroiliac joint. When the sacroiliac joint is dislocated and widely separated, the lumbosacral trunk, the superior gluteal nerve, and the obturator nerve may be stretched or ruptured as they cross the joint. Intradural rupture of the roots of the cauda equina may be produced by traction, particularly by transverse fractures of the sacrum. Fractures of the sacral ala can narrow the foramina and compress sacral nerves.

Huittinen, who studied this subject in patients and in the autopsy room, found nerve injuries in 20 of 42 dissections of fractures of the pelvis.[4] He noted that these injuries could only be recognized by careful neurologic examination. Exploration is not required. The chances of recovery are remote.

Fracture Patterns

The site and displacement of the fracture is best defined by upshot and downshot views in addition to the standard anteroposterior view (Fig. 15-1). On

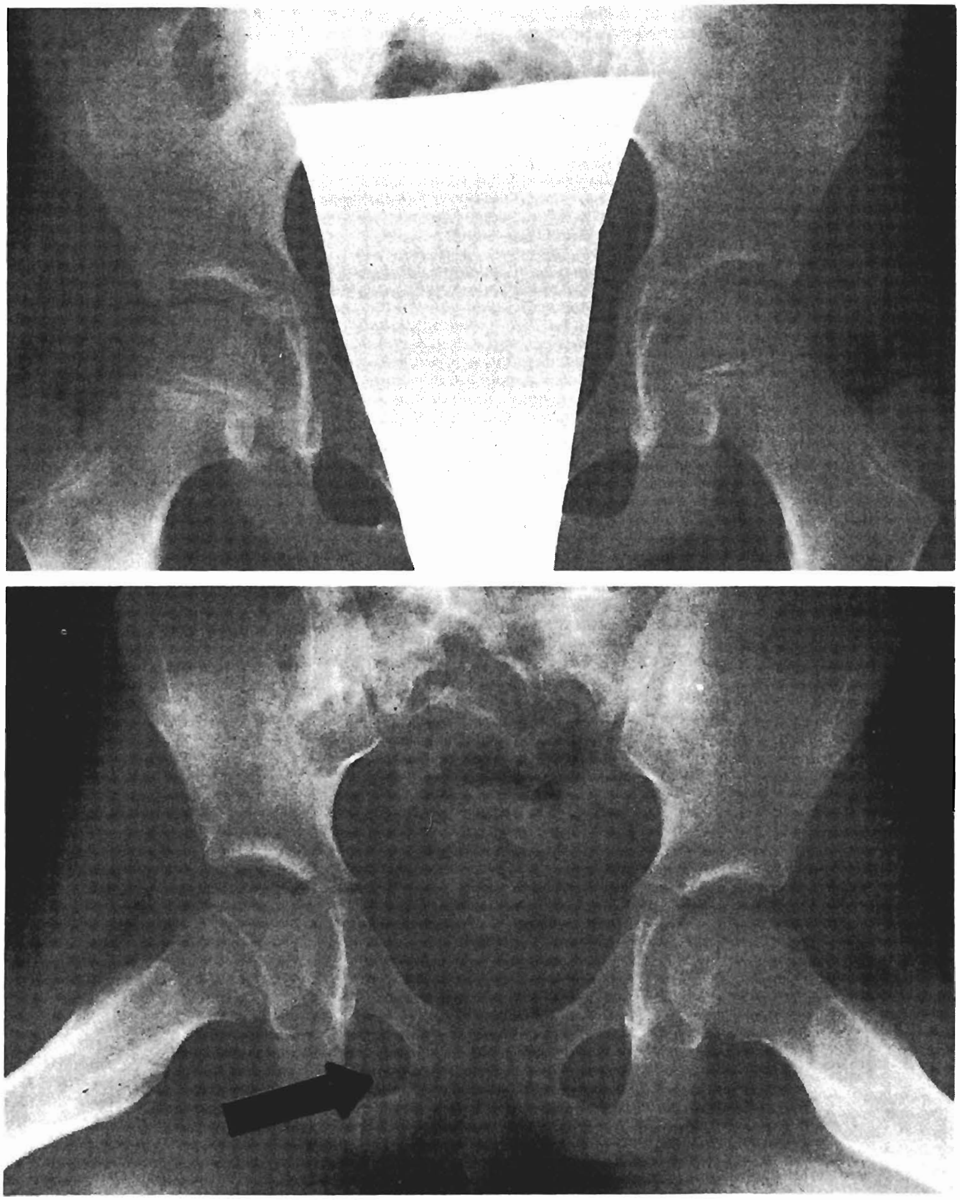


Fig. 15-2. This boy complained of pain in the right hip after a fall. The guard hid the fracture of the pubic ramus on the first film.

occasion, lateral and oblique films are required. Obviously a gonadal shield should not be used; we have missed a few minor fractures of the pubic rami in children who were having x-ray films taken for a painful hip with a shield in place (Fig. 15-2). A CT scan shows displacement clearly and will soon be mandatory for acetabular fractures.

The classification of children's pelvic fractures is essentially the same as that in adults: double fractures of the ring (Fig. 15-3); single fractures of the ring; fractures involving the acetabulum; and fractures not involving the ring (Fig. 15-4).

However children's fractures, unlike fractures owing to extreme violence in adults, are seldom displaced enough to require reduction.

In our series, 80% of fractures involved the pubic rami; 19%, the ilium, and 2%, the acetabulum. The majority were stable; only 13% showed radiologic evidence of disruption of the sacroiliac joint.

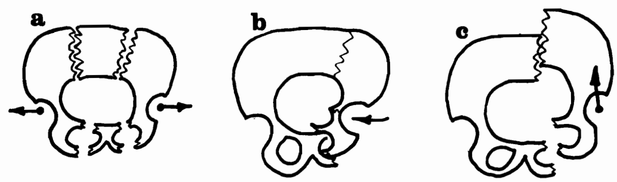
Fig. 15-3. Crushed by a car, this 8-year-old girl was admitted with hypotension, a large laceration, a left obturator, sciatic nerve palsy, and vaginal bleeding. Radiographs disclosed fracture of the left pubic ramus and disruption of the sacroiliac joint. She received 4 litres of blood, and extraperitoneal hemorrhage was controlled with packs.

Double Fractures of the Pelvic Ring. These can be classified by the direction of force. The classification serves as a guide to reduction. (Fig. 15-5).[7,8]

1. **Anteroposterior compression.** This springs the front of the pelvis open. In the adult the symphysis separates, but in the child the rami fracture. The sacroiliac joints may open. In one child the ureter was trapped and squashed in a sacroiliac joint. The pelvic disruption had reduced spontaneously so that no bony injury was recognized.

Fig. 15-4. Hit by a car, this 4-year-old sustained an isolated fracture of the left ilium that posed no problems.

Fig. 15-5. Double fractures of the pelvis. Which way has the acetabulum moved? This is a useful guide to the classification of the fracture.



The problem was noticed on intravenous pyelogram and confirmed at operation. These fractures are reduced by lateral compression.

2. **Lateral Compression.** The side of the pelvis is driven in so that the acetabulum is closer to the midline. In the adult the whole hemipelvis shifts medially, but in the child the triradiate cartilage forms a weak point. The hemipelvis may bend through the triradiate cartilage, or the ischium and pubis alone may be driven medially. Reduction is difficult because the fragment needs pushing out.
3. **Vertical Shear.** One hemipelvis moves upward. Reduction can be achieved by traction.

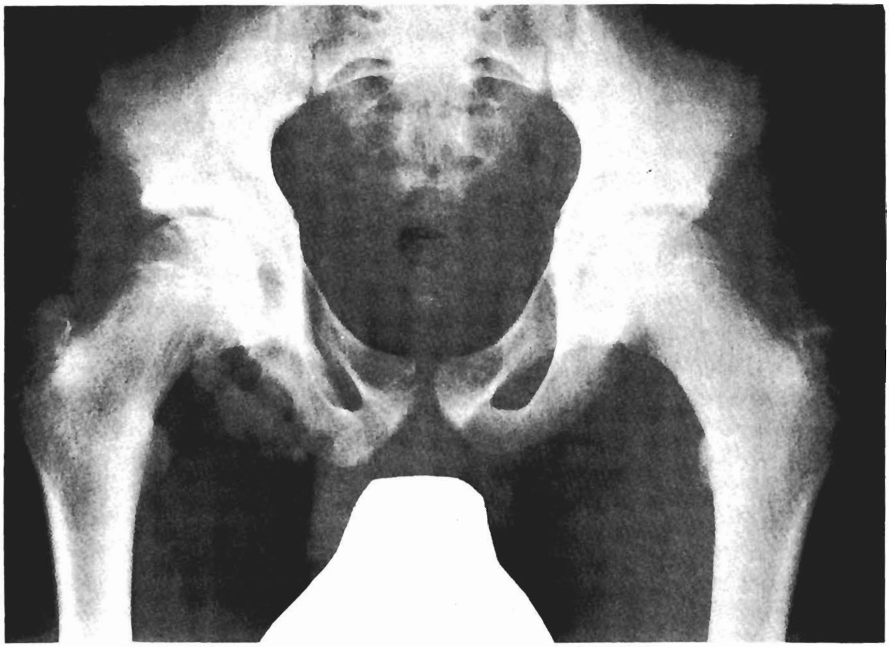
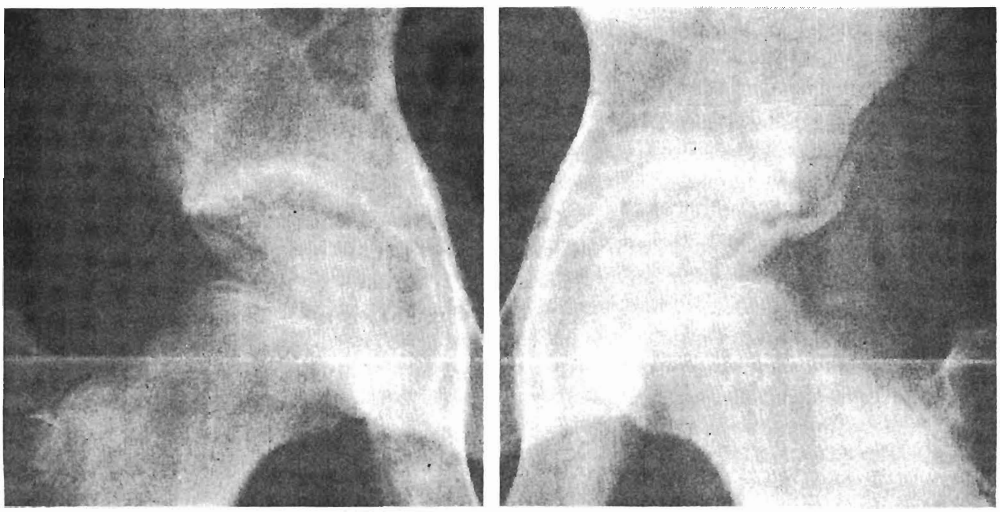


Fig. 15-6. Avulsion of the ischial tuberosity 1 year ago. If you have not seen this before, you may mistake if for an osteosarcoma.

Fig. 15-7. Avulsion of the anterior inferior iliac spine, the result of a 12-year-old kicking a ball. This appearance can be confused with an accessory center of ossification.



Sacral fractures are difficult to see on radiographs and are usually missed. Compression fractures through the foramina of the ala are overlain by gas shadows; transverse fractures are in the wrong plane to be seen on anteroposterior films; laterals or upshots are needed. Both types of fracture may be associated with neurologic lesions.

Injury through growth cartilage may occur in major and minor trauma. Everett has described avulsion of an unossified iliac apophysis resulting in intestinal obstruction owing to a lumbar hernia.[1] Rodrigues noted growth arrest following injury to the triradiate cartilage; this caused a mini-acetabulum and subluxation of the hip.[11] Hallel and Salvati described another case and reproduced the condition in rabbits.[2] Perhaps all children with a pelvic fracture should have a radiograph every 2 to 3 years until maturity to detect this early.

Muscles spanning the hip and knee joints may pull off an apophysis during moments of extreme athletic effort. The hamstrings avulse the ischial tuberosity (Fig. 15-6); the rectus femoris, the anterior inferior iliac spine (Fig. 15-7); and the sartorius, the superior spine.

The classic picture is represented by an athlete collapsing on the field. Radiographs confirm the diagnosis and usually show marked displacement. An apophysis is held in position by periosteum more firmly than by growth cartilage. Any displacement signifies a periosteal tear. Unlike most other Type-I injuries, these are usually widely displaced.

Muscle function does not suffer as a result of fibrous union in the displaced position. However, the ischial apophysis is a weight-bearing area for sitting: an ununited apophysis leads to discomfort. Spontaneous reduction has been reported by Martin and Pipkin, but most reported cases have required reposition with a screw using Milch's approach.[6] Excision may be required for neglected cases.

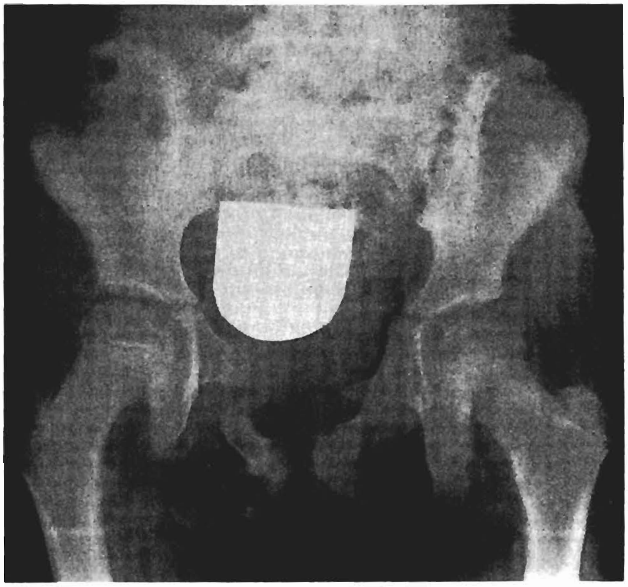
Apophyseolysis—slight displacement owing to repeated sprains—has been described as a source of local pain. Rest is suggested to prevent massive displacement.

TREATMENT

Although the same general principles apply in children as in adults, the majority of children require only symptomatic treatment. Most anteroposterior compression fractures reduce with bed rest. Lateral compression fractures are generally stable, and the position can be accepted. When there is marked asymmetry and instability, the fracture should be reduced and held with an external fixator. Vertical shear fractures are best treated with longitudinal traction using a supracondylar pin. Open fractures usually require external fixation.

In our series 97% were treated by bedrest until the pain subsided and then by mobilization on crutches. Reduction was attempted in 3%. (An open fracture of the ilium with overlapping fragments was treated by open reduction. Manipulation improved another, and traction made no difference to a third.) The associated injuries require much more treatment than the fracture itself.

Fig. 15-8. Nonunion 2 years after bilateral fracture of the pubic rami in a 7-year-old girl. Disruption of the vagina and bladder had required repair.



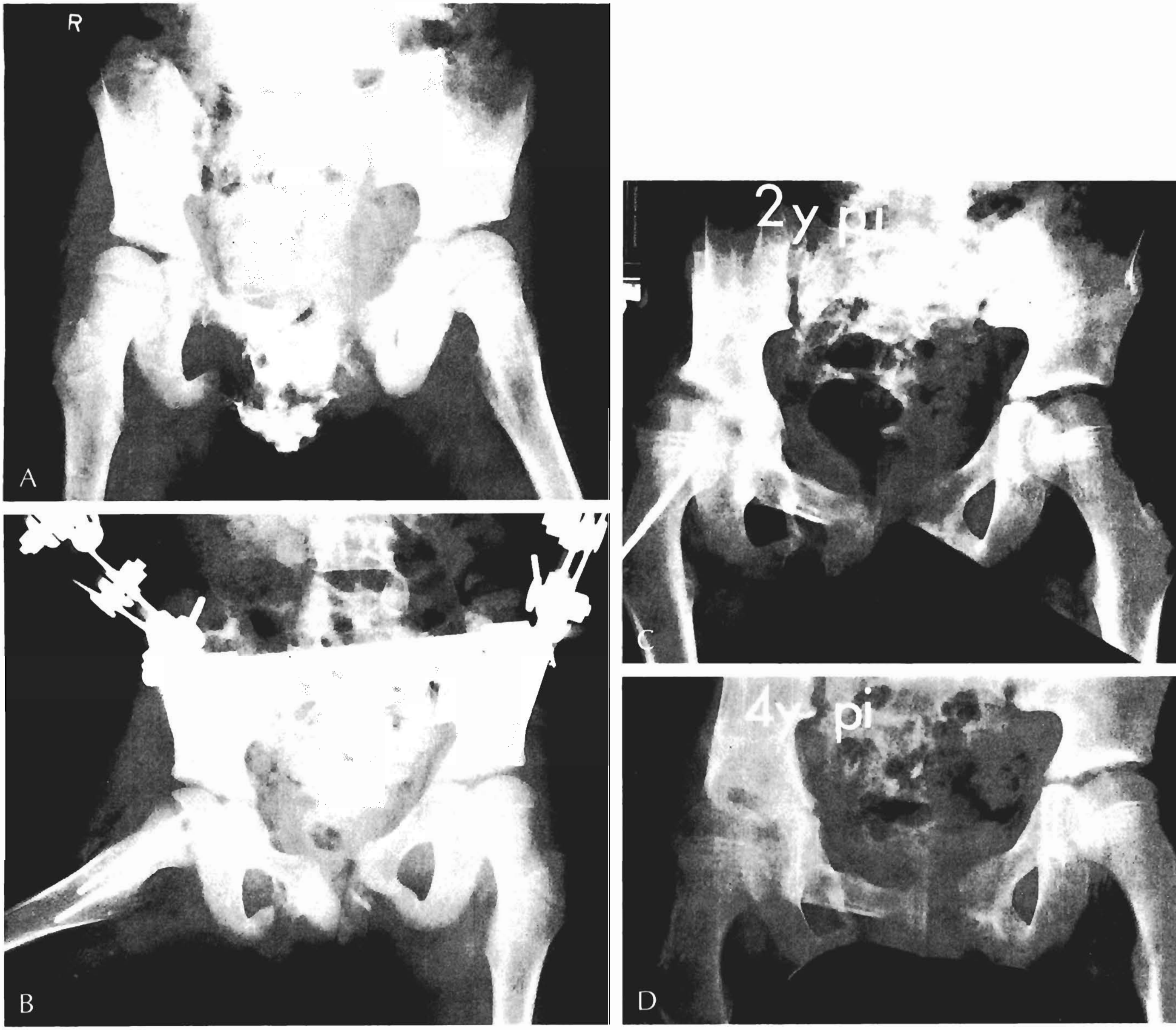


Fig. 15-9. Malunion of a pelvic fracture may leave the femoral head uncovered. This boy also had an open epiphyseal separation of the right upper femoral epiphysis, a degloving injury, and a ruptured urethra. *(A)* Initial film—note extravasation. *(B)* Fracture control with Roger Anderson apparatus. *(C)* Two years after injury. *(D)* A modest innominate osteotomy has improved acetabular direction.

The long-term results have not been systematically studied, but a few minor problems have come to light. A few girls complain of assymetry of the pelvis owing to malunion or to fat fracture (see p. 71). One girl has asymptomatic nonunion of an open fracture of the pubic rami (Fig. 15-8). Remodeling usually makes recognition of the fracture difficult after a year or two. In girls it is wise to obtain obstetric views of the pelvis a year after injury (though I am not aware of any girl being left with a narrowed birth canal). More serious problems have been reported.

1. **Growth disturbance.** McDonald noted undergrowth of a hemipelvis following a lateral compression injury that caused fusion of a sacroiliac joint.[7]
2. **Leg-length discrepancy.** This may be a sequel to an unreduced vertical shear injury. This may be corrected by innominate osteotomy with insertion of a rectangular graft.
3. **Subluxation of the hip.** This may be a sequel to a mini-acetabulum or due to pelvic obliquity. Both may be helped by innominate osteotomy (Fig. 15-9).

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16 / Hip

The osteoporotic bone of an old lady is very different from the tough, growing bone of a child. Great violence is required to produce a fracture in a child. For example, most trochanteric fractures are bumper injuries in children of 6 or 7 years, the age when the greater trochanter is at the level of a car bumper (Fig. 16-1).

Fractures of the hip are rare in children; we have treated only two or three patients a year during the past 20 years. Ratliff estimated that the incidence of fractures of the femoral neck in children is 0.8% of that in adults.[11,12,13] Most orthopaedic surgeons will not treat more than four or five in a professional lifetime. If this were a more common injury, perhaps we would all know a lot more about the best methods of treatment and thus be able to achieve better results.

There are several important differences between hip fractures in adults and in children:

1. The periosteal tube in a child is much stronger than that in an adult, so that perhaps half of these fractures are undisplaced.
2. The blood supply of the head is different. Avascular necrosis in a child may affect the epiphysis, the epiphysis *and* the metaphysis, or the metaphysis alone.[12] The violence of the initial injury is commonly blamed for the high incidence of avascular necrosis in children—about 40% in most series.

   It is not clear whether avascular necrosis results from complete division of all vessels, kinking of those vessels that remain intact, or tamponade by a high-pressure hemarthrosis within the hip capsule.
3. Avascular necrosis is commonly accompanied by premature closure of the growth plate, which leaves the child with a short femoral neck.
4. The hyperemia of fracture repair may produce coxa magna and a slightly long leg.
5. Children will tolerate cast immobilization. The chance of union is excellent in a young child with an *undisplaced* fracture. In a cast he will not develop bed sores or deep vein thrombosis or lose the will to live, but malunion is a real hazard. When a *displaced* fracture of the neck is reduced and held in a cast, coxa vara is almost a certainty.
6. The hardness of a child's bone and the small size of the femoral neck are not suited to fixation with a standard Smith–Petersen nail (Fig. 16-2). Threaded pins or screws should be used.
7. When problems arise in a child, prosthetic replacement is not available as a solution, although one good hemiarthroplasty has been reported.

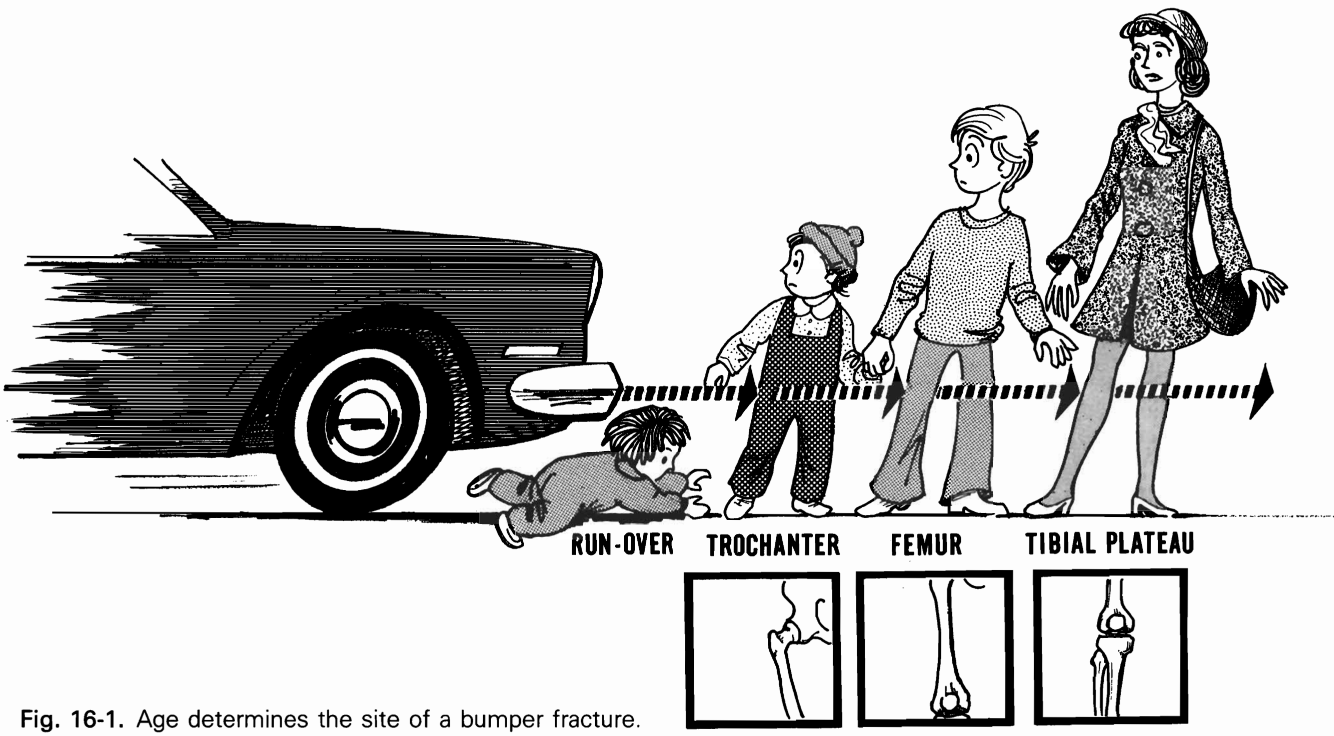


Fig. 16-1. Age determines the site of a bumper fracture.

Fig. 16-2. Triffin nails should not be used. The pin has displaced the epiphysis.

TYPE-I INJURIES

The femoral head separates from the neck through the growth plate. The various degrees of severity are shown in Figure 16-3.

In *infants,* this injury is most likely to occur when the child has been run over. It may also be seen in an abused infant. In *children,* great violence is required, and there are usually other injuries as well (Fig. 16-4). In *adolescents,* an acute Type-I injury is seen, which represents one end of the spectrum of slipped upper femoral epiphysis. *Pathologic* slip occurs in many diseases, including renal osteodystrophy, hypothyroidism (Fig. 16-5), and neglected septic arthritis. The outcome is determined by the degree of damage to the blood supply.

Traumatic Separation

Ratliff has analyzed 13 traumatic separations in children aged 9 years or under and found complications in 11: premature fusion, avascular necrosis, and nonunion.[14,15] He recommends traction for those with no displacement. In displaced fractures, closed reduc-

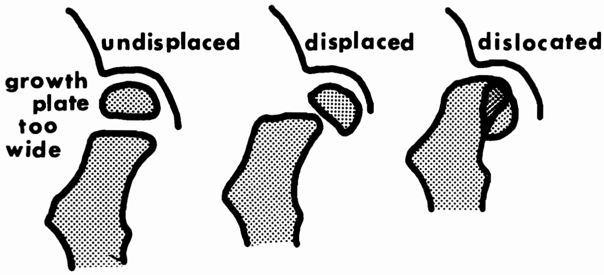


Fig. 16-3. Classification of Type-I injuries.

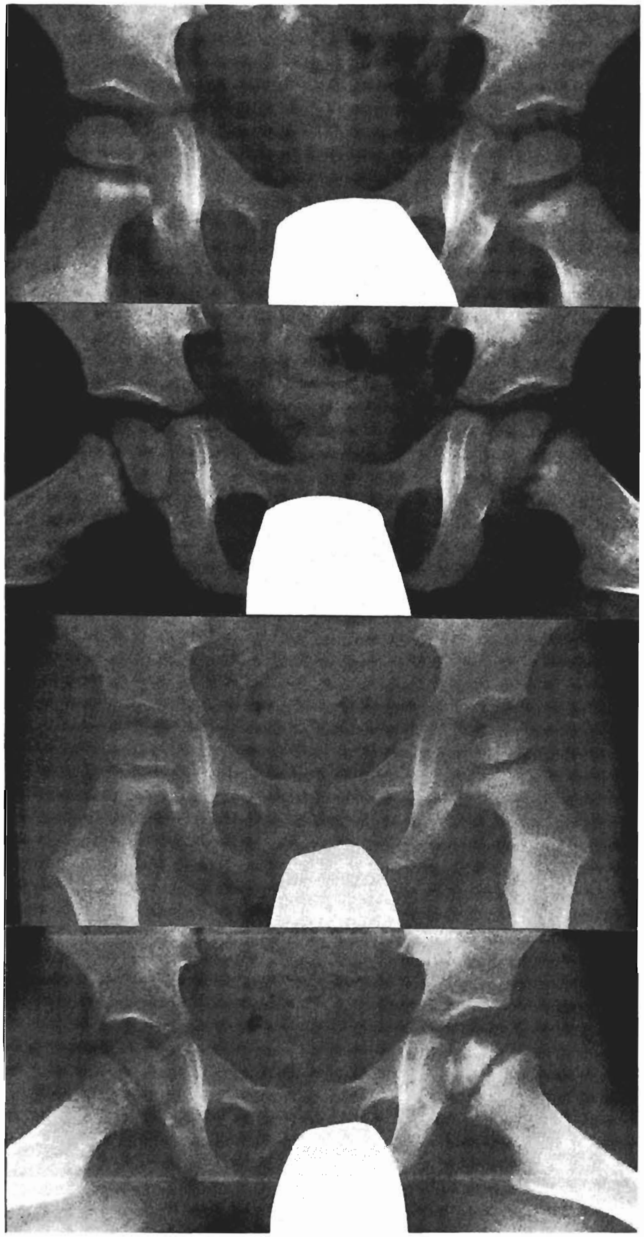


Fig. 16-4. Type-I separation of left upper femoral epiphysis of a boy of 3 years. The growth plate is too wide. Later, avascular necrosis can be recognized.

Fig. 16-5. *(A, B)* Acute slipped upper femoral epiphysis; girl aged 12. *(C, D)* Three months later, after pinning, the other epiphysis is displaced. *(E)* After further pinning. The girl was found to be hypothyroid and was placed on medication.

tion is commonly easy, and the reduction should be held in a one-and-a-half hip spica. Displacement does occur occasionally in the cast, and frequent radiographs should be taken to detect this. Pin fixation is unnecessary and may aggravate the tendency to premature fusion. If the head is dislocated, open reduction will be required (Fig. 16-6). Canale and Bourland describe five cases of traumatic separation accompanied by dislocation; all developed avascular necrosis, and four out of five developed degenerative arthritis.[4] The young patients required leg-length equalization. Milgram and Lyle describe 11 cases, many in battered babies.[8] Traumatic separation of the proximal femoral epiphysis is a severe injury, and the parents should be warned that problems are more likely than not.

Slipped Epiphysis

Bobechko, at The Hospital for Sick Children, has reviewed acute slipped upper femoral epiphysis in adolescents, and concludes that immediate but slow reduction using skin traction with internal rotation is safer than immediate manipulative reduction under general anesthesia.[5] Avascular necrosis occurred in 5 of 35 children, and all these had had manipulative reduction under anesthesia. Therefore, immediate institution of gradual correction is recommended over 3 to 4 days before internal fixation is carried out (Fig. 16-7).

In conclusion, use a cast for the younger child with a traumatic separation and use internal fixation for older children and when the slip is pathologic.

TRANSCERVICAL AND BASAL FRACTURES

Transcervical and basal fractures are common hip fractures; the midcervical level is the most common level. The perils of this injury may be very great. Avascular necrosis has been reported in 17% to 45%. Obviously much more common in displaced fractures, avascular necrosis also occurs in undisplaced, even basal, fractures (Fig. 16-8). A sequel to avascular necrosis is premature closure of the growth plate, which leads to a short neck and a weak lever arm for the abductor muscles; a short leg; and limitation of abduction owing to overgrowth of the greater trochanter (Fig. 16-9). Delayed union, nonunion, and slipping into coxa vara while in a cast carry similar penalties.

It is difficult to write much about this fracture from personal experience. It is misleading to apply the mass of information about adult fractures to children, and the small number of papers that relate specifically to children present widely varying statistics that are almost impossible to compare. But the following general observations emerge.

Fixation of the Fracture

Muscular forces across the hip joint tend to produce coxa vara in *displaced* fractures (*i.e.*, fractures in which the periosteum has been torn). Cast fixation after reduction does not neutralize these muscular forces, and slip is almost certain. For displaced fractures the conservative approach is internal fixation. *Undisplaced* fractures in young children have some inherent stability, and the safe way to supplement it is by hip spica (safe because pinning may increase the risk of avascular necrosis and carries the chance of infection and refracture at the site of pin entry). In older children pinning is technically easier and reduces the chances of displacement.

Type of Internal Fixation

One of the difficulties is that no series has been reported that used sound methods of internal fixation. Most authors condemn nails, particularly large nails, because the bone is so hard that driving nails in is difficult, and distraction is common. All the bone displaced by the nail must go somewhere; my belief is that it fills vital vascular spaces (Fig. 16-10). From the literature, it is not possible to determine the best method of internal fixation; most authors express a preference for threaded pin fixation. If multiple threaded pins are used, they should lie parallel to avoid distraction. The metaphysis is composed of hard bone, unlike the adult metaphysis, and provides a good hold. It is usually unnecessary to cross the plate, but in high fractures do not hesitate to put a pin temporarily across the plate. But when the plate is transfixed, pins should be removed as soon as possible to avoid interfering with growth. A lag screw inserted through a predrilled and tapped hole, and avoiding the growth plate wherever possible, would

Fig. 16-6. Type-I injury with dislocation. After anatomic reduction and Knowles pinning the hip is good. (Courtesy of Dr. John Wedge.)

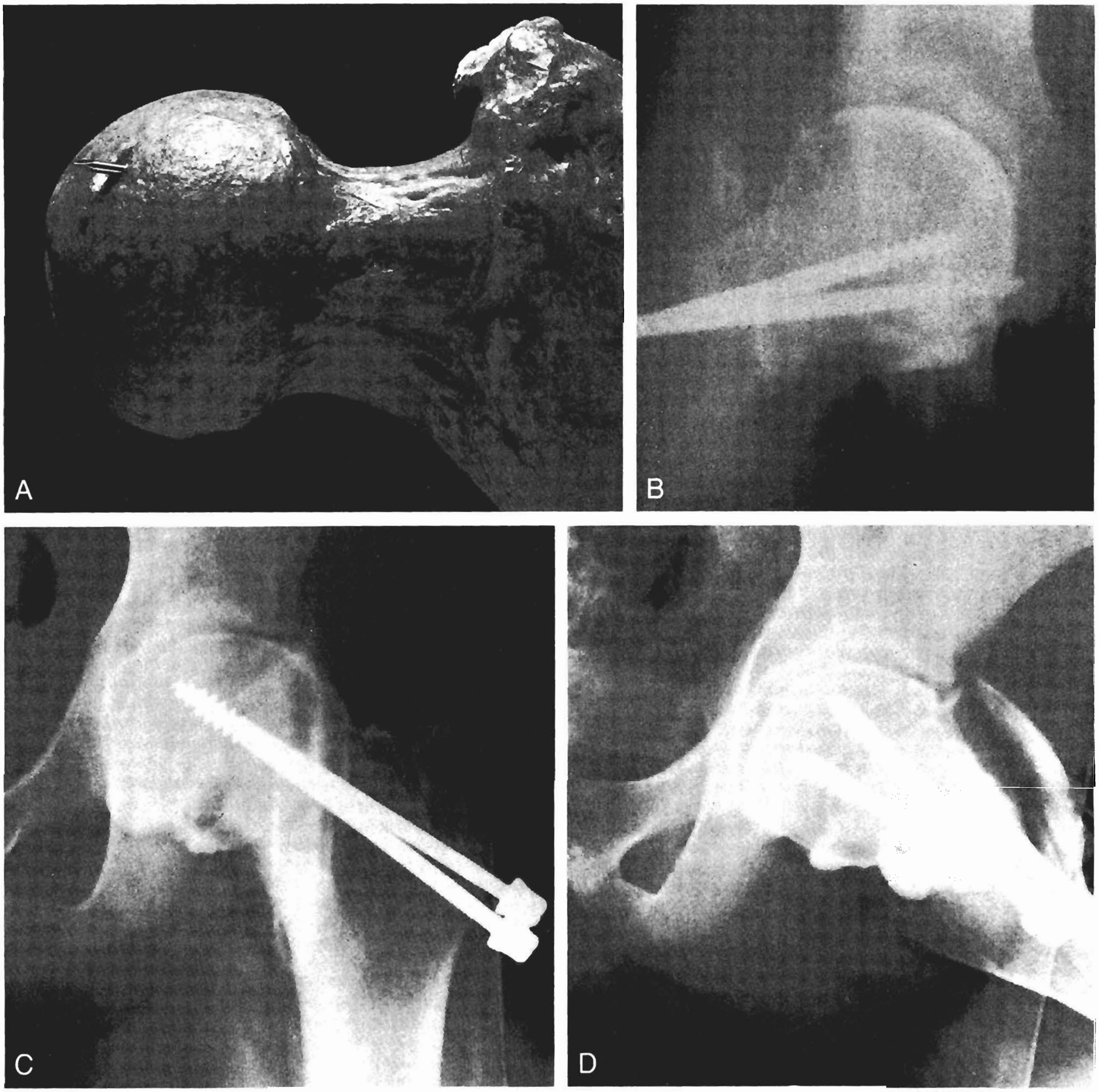


Fig. 16-7. Beware of protruding pins. *(A)* The pin may protrude without showing on the femoral horizon. *(B)* Arthrography during pinning shows pin protrusion clearly. *(C, D)* Arthrography and screening of multiple horizons makes it clear that the pins are safe before the drapes are removed.

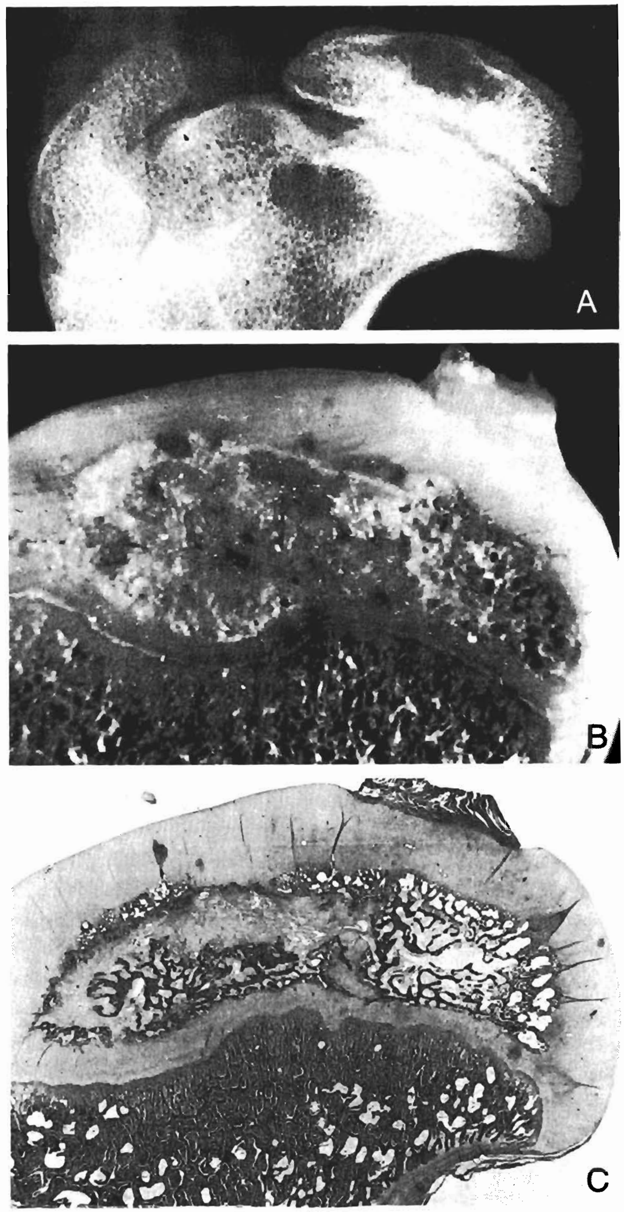
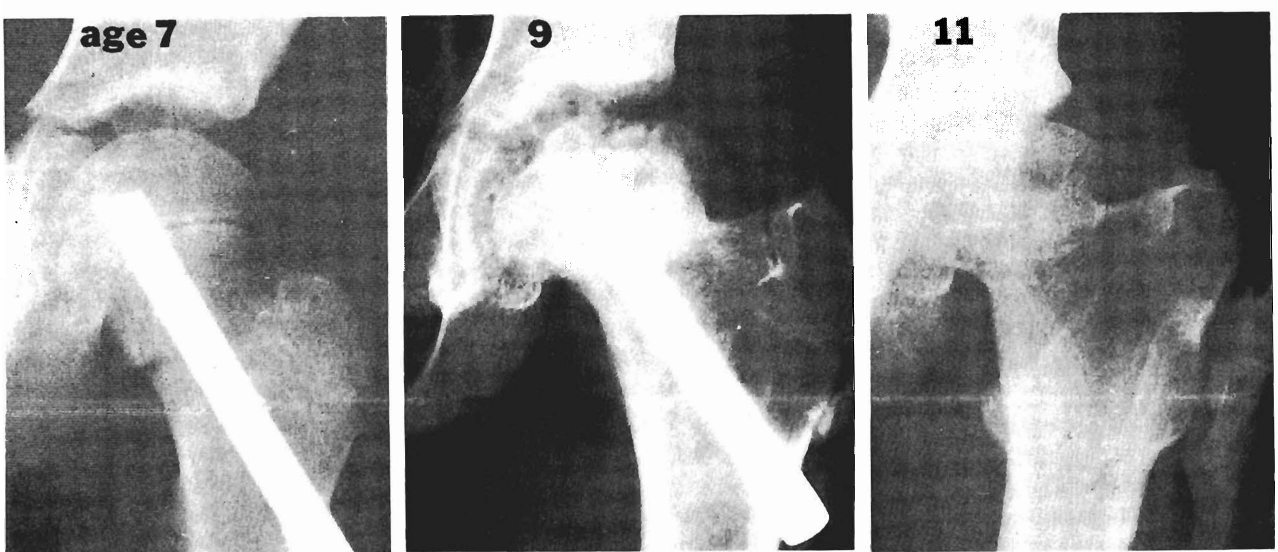


Fig. 16-8. Experimental avascular necrosis. A tight noose was placed around the femoral neck of a piglet 50 days earlier. At sacrifice the superior surface was soft and could be pushed in like a ping-pong ball. *(A)* Radiograph of whole head. *(B)* Cut section. The vessels, injected with dark vinyl, can be seen, demonstrating that the head is revascularized. *(C)* Histologic section. The head contains fibrous tissue and sclerotic bone, resembling a pseudarthrosis. New subchondral bone is forming.

Fig. 16-9. Displaced basal fracture. Total avascular necrosis leads to failure of the capital growth plate. The neck is short. Unexpectedly, the growth of the greater trochanter stops early (probably due to a Type-IV injury). Overgrowth is more common.



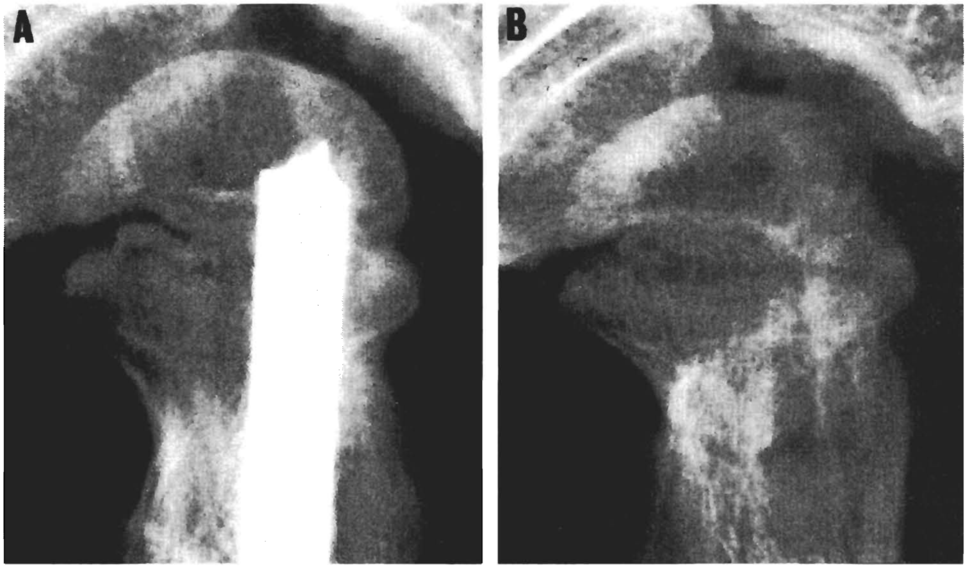
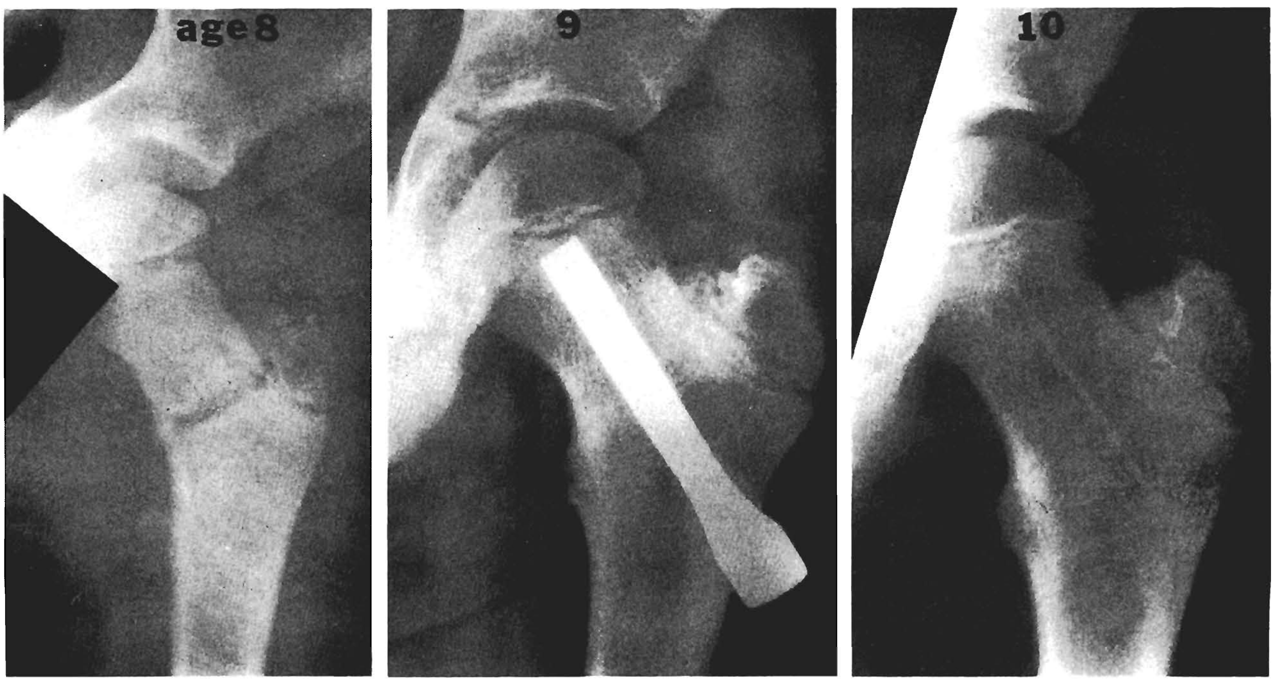


Fig. 16-10. Avascular necrosis following internal fixation in a 7-year-old boy. *(A)* On the day of hip pinning, a wedge of increased bone density extends from the top of the pin. *(B)* One year later the boy was asymptomatic.

Fig. 16-11. Basal fracture in a girl aged 8 years. A short pin does not damage the head.



appear to be the strongest and least traumatic form of fixation. There are several lag screwplate systems available now in children's sizes.

TREATMENT

Undisplaced Fractures

Experience indicates that excellent results are generally, though not universally, achieved however these are treated. A one-and-one-half tip spica with the leg held in internal rotation and abduction for 8 to 12 weeks is sufficient. The fracture should be checked for slip. In the past we have often used short pins with good results, but that is probably overtreatment (Fig. 16-11).

Displaced Fractures

The risk of coxa vara and avascular necrosis are very high (Fig. 16-12). Kay and Hall have argued that the hip should be aspirated to prevent tamponade of the vessels; this has not been evaluated. Manipulation under anesthesia will generally correct displacement (Fig. 16-13). But if a perfect reduction cannot be achieved in the older child, do not hesitate to carry out an open reduction using an anterolateral approach. There is no sense in wrestling the fracture into position nor in fixing a fracture in malposition. A hip spica alone will not hold reduction; on this all agree. Internal fixation is needed (Fig. 16-14).

A child does not need rapid rehabilitation. Apply a hip spica for 8 to 12 weeks to protect the hip. Remember the load on the hip imposed by straight leg raising is just the same as that imposed by walking. A belt-and-suspenders approach is needed to prevent coxa vara (Fig. 16-15).

Avascular necrosis is best detected with a scan early but is usually apparent radiographically within the first few months, and probably always within a year. Radiographs should be obtained every 2 months during the first year. The first signs of avascular necrosis are as follows: the head does not become osteoporotic; it does not grow; and the cartilage space becomes wider (Fig. 16-16). These signs are present long before signs of gross density, fragmentation, and deformity of the head. Slight disturbance of circulation produces coxa magna luxans (Fig. 16-17). The large head is poorly covered by the acetabulum. Both these conditions may be treated by innominate osteotomy.

Fig. 16-12. Displaced basal fracture. In addition, this 12-year-old boy sustained a complete traumatic paraplegia. The pins were not well suited to withstand his flexor spasms, and he slipped into varus. A nail plate should have been used. Growth arrest was due to threaded pins left across the plate. His paraplegia improved, and he is able to walk with crutches without trouble from the hip fracture.

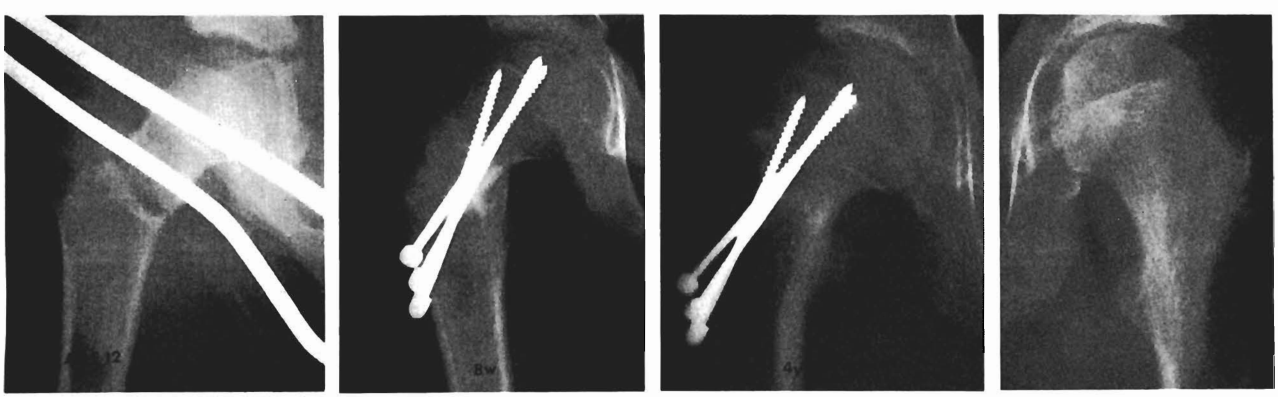


Fig. 16-13. Displaced cervical fracture. The threaded bolts could have been shorter but were removed as soon as the fracture united.

Fig. 16-14. A typical result of cast immobilization for a displaced fracture.

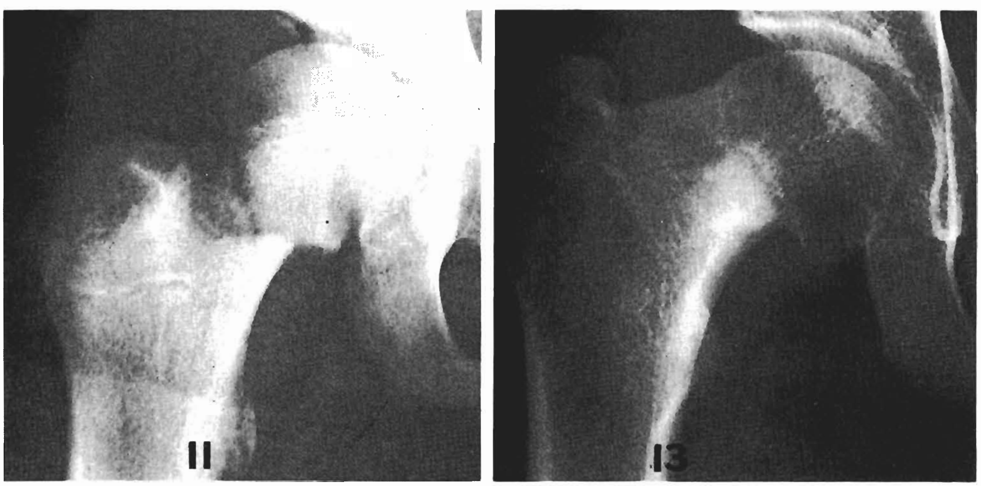


Fig. 16-15. Perhaps a cast may have prevented the pins cutting out. This girl had a severe head injury and was in a coma for 6 months. The pin displacement was not recognized. At exploration the acetabulum was scoured and the head lay free. A trochanteric arthroplasty was performed, but the hip joint became completely stiff. She is now at school and walks with a shoe raise. Leg-length equalization was required.

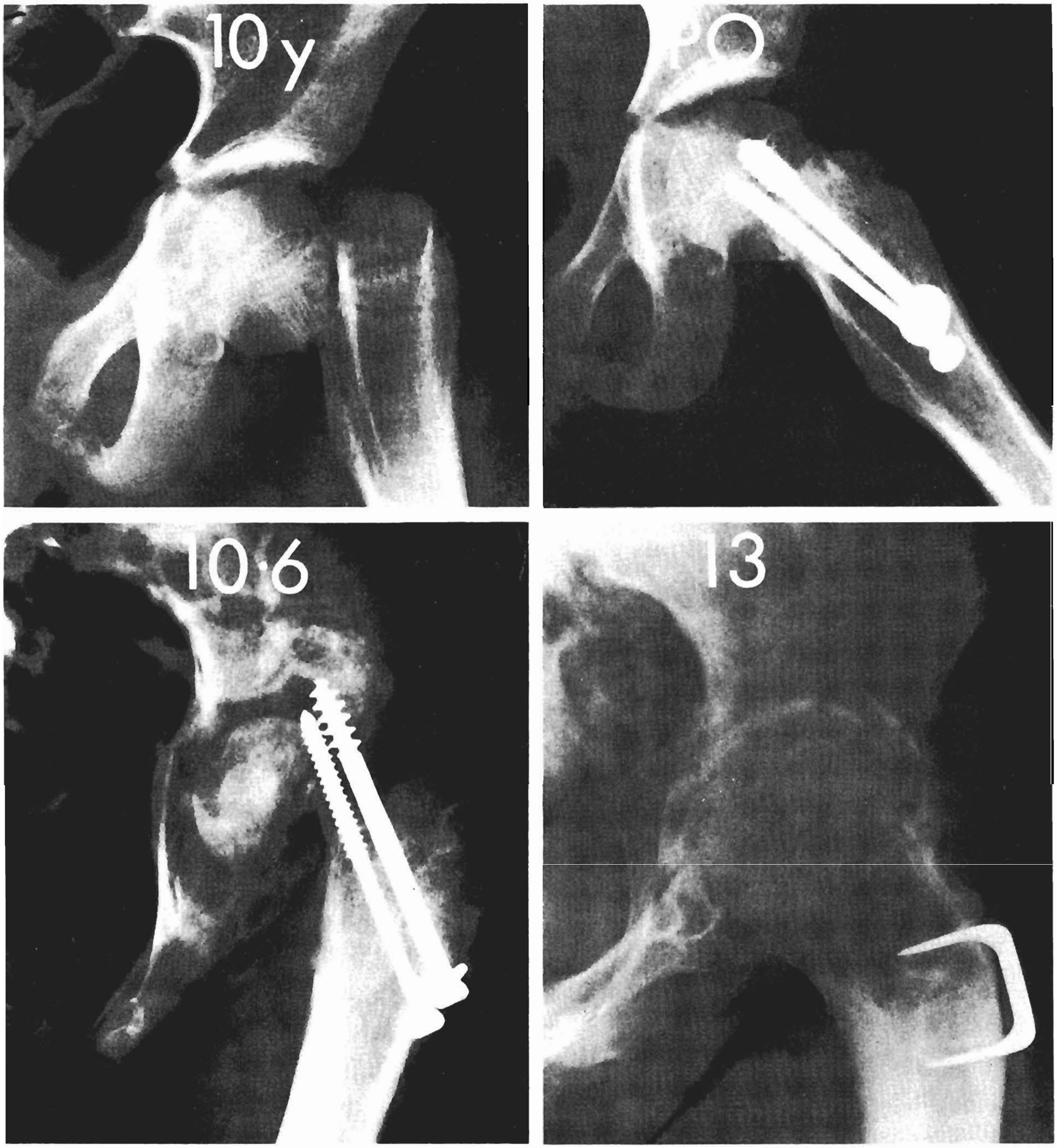


Fig. 16-15.

Fig. 16-16. *(Left)* Early avascular necrosis in the left hip of a pig. A month earlier a ligature was tied around the left femoral neck to occlude circulation of the head. *(Right)* The right hip was untouched. The left ossific nucleus has not grown, and the surface cartilage is thicker because it has not ossified.

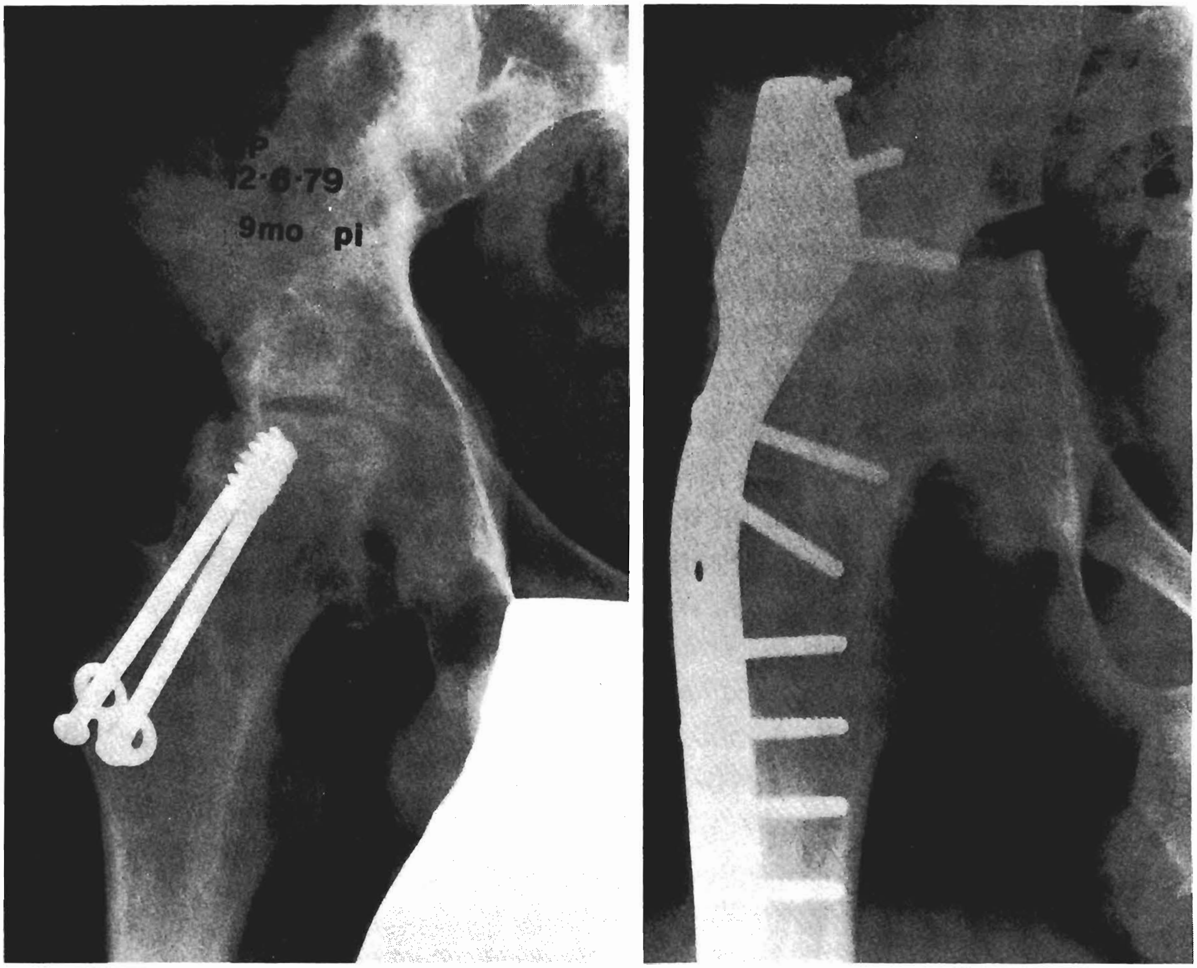


Fig. 16-17. Avascular necrosis following a transcervical fracture dislocation of the hip in a 16-year-old boy. Due to contracture and pain, he could not put the foot to the ground. Arthrodesis restored mobility; so well, in fact, that the patient skied a few weeks later and pulled the plate off.

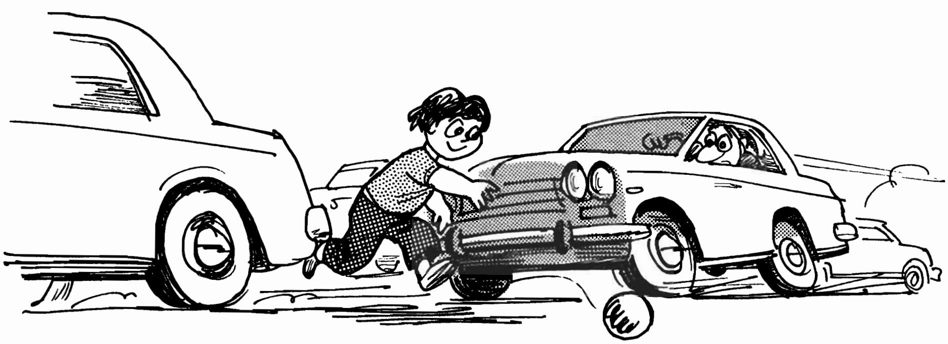


Fig. 16-18. When a child runs across the road, he is more likely to be hit by cars in the nearside lane. The cars in the opposite lane have more warning. In countries that drive on the right there is a preponderance of left-sided injuries.

TROCHANTERIC FRACTURES*

Between 1962 and 1972, 20 nonpathologic fractures of the trochanteric region of the femur were treated at The Hospital for Sick Children. All fractures between the base of the neck and a line 1 cm below the lesser trochanter of the femur were included.

The average age at time of injury was 7 years; 80% were produced by motor vehicle accidents, the remainder by falls and toboggan accidents. The majority of fractures were left-sided (Fig. 16-18). Associated soft-tissue injuries were noted in all patients, 65% sustained other fractures (*e.g.*, skull, pelvis, clavicle), and 55% had significant craniocerebral injuries, leaving four of these patients with residual post-traumatic hemiplegia or other neurologic deficit.

Treatment of Intertrochanteric Fractures

See Figures 16-19 through 16-21.

Most intertrochanteric fractures can be reduced and held in skin traction. When callus is present at 3 to 4 weeks, a one-and-one-half hip spica should be applied. The chief indication for internal fixation is irreducibility or inability to hold the fracture in traction because of other injuries. Operative treatment can be extremely difficult, because considerable comminution or separation of the greater trochanter may be present without being obvious on radiographs. Always obtain first-quality films before starting surgery.

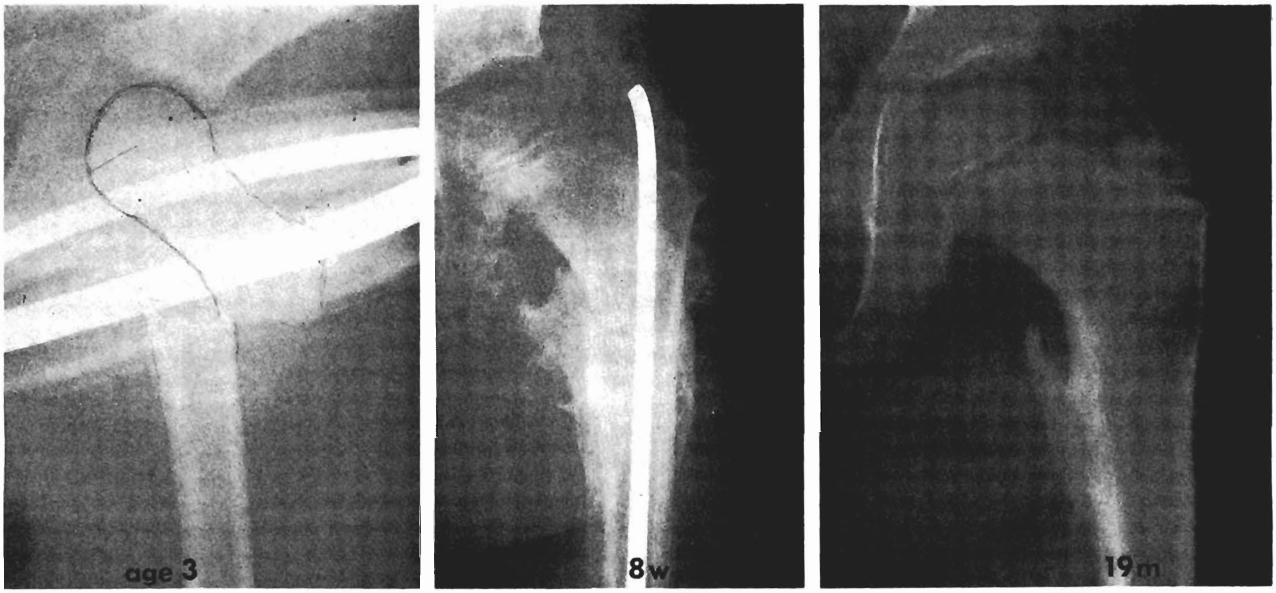
Avascular necrosis is not a hazard, and the tendency to varus deformity is more easily overcome than in more proximal fractures. The only consistent late finding in five cases we reviewed was overgrowth—an average of 1.2 cm.

Subtrochanteric fractures will be considered in the next chapter.

Literature on Hip Fractures

Canale and Bourland reviewed 61 fractures with an average follow-up of 17 years.[5] The best results occurred in undisplaced fractures, basal fractures, and younger patients, because they obtained better results from avascular necrosis—the main cause of poor results. Fixation with Knowles pins reduced the inci-

Fig. 16-19. Intertrochanteric fracture. A severe head injury made this patient very restless, and the fracture could not be controlled. A vertical pin provided simple and effective fixation.



*Based on a review by Dr. Barry Malcolm.

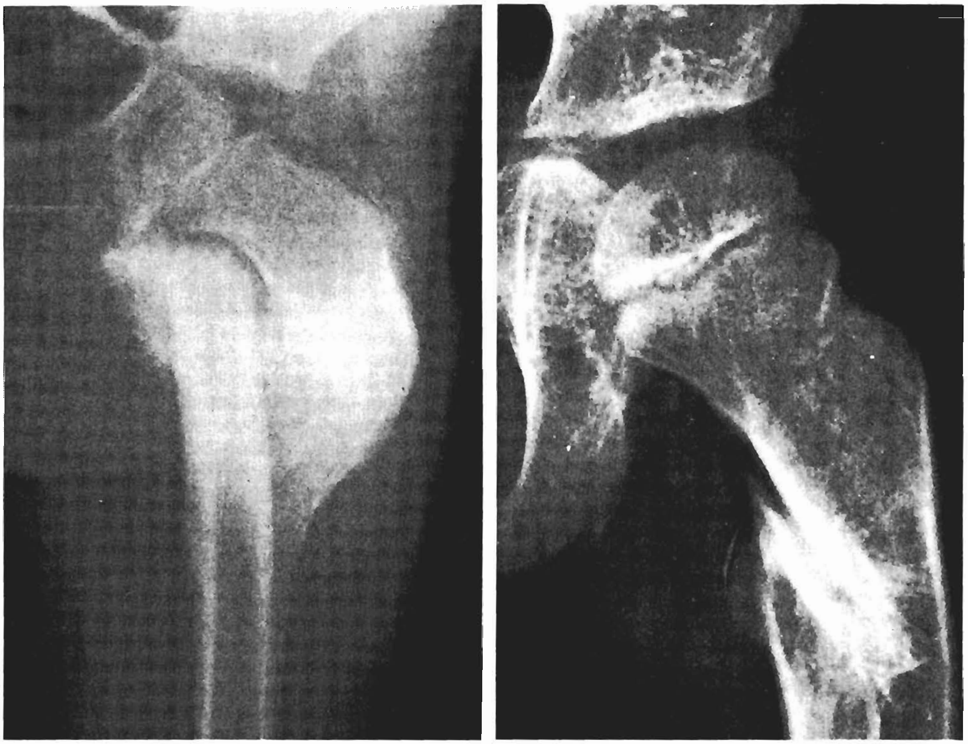
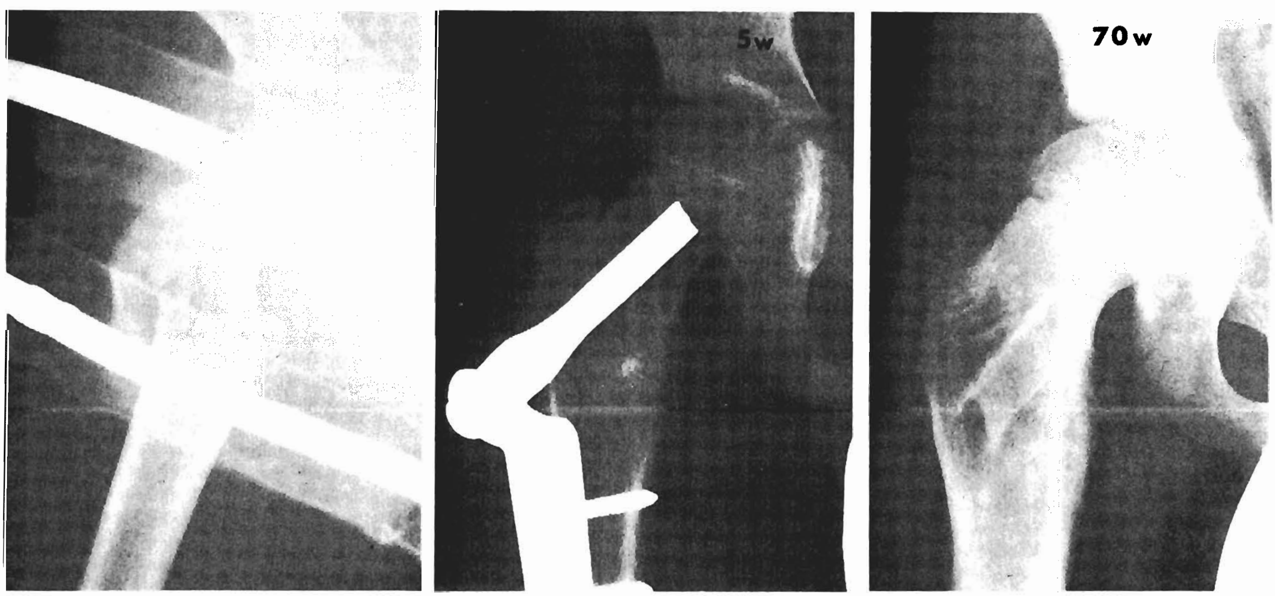


Fig. 16-20. Intertrochanteric fracture in a girl of 2½ years. She had concomitant severe injuries, and this fracture was maintained in traction without much expectation that she would survive. Four years later she has a left spastic hemiplegia; the leg is 1 inch short. There is excellent remodeling, but bone has not crossed the site of capsular interposition.

Fig. 16-21. Intertrochanteric fracture in a boy aged 7. Even a child-sized nail plate is very bulky. Though this is a good result, a similar result could probably have been obtained with traction.



dence of nonunion and coxa vara. The illustrations of patients over many years are striking.

Chong, Chacha, and Lee reviewed 20 patients and added chondrolysis as a complication.[6]

Pförringer and Rosemyer reviewed 52 fractures. They noted that the results were better in children than in adolescents. With Quinlan and associates, they concluded that immediate internal fixation was best protection against complications.[9,10]

Ratliff emphasizes that the vascular necrosis is the main cause of poor results. He describes three types: Type I—avascular necrosis of the head and neck proximal to the fracture (60%); Type II—avascular necrosis of the head alone (22%); and Type III—avascular necrosis of the head alone (18%).[11,12,13]

Type I yielded no good results, but many children have a tolerable hip for many years. Subtrochanteric osteotomy was not helpful. When symptoms are severe and there is subluxation, arthrodesis is the only treatment of value. No conclusions have been made regarding Type II. Premature closure of the plate occurred in six of ten patients with Type-III avascular necrosis. They did not require treatment for the necrosis but may require correction of leg length inequality later in life.

> The most important single cause of nonunion was the acceptance of a displaced position of the fragments and immobilization in a hip spica. . . . Nonunion did not occur after adequate primary internal fixation.[13]

But when nonunion occurs, bone grafting is advocated with abduction osteotomy if there is coxa vara.

DISLOCATION OF THE HIP

Dislocation is more common than fracture of the femoral neck, and it carries fewer problems. (The hip, metacarpophalangeal joint, and patellofemoral joint are the only sites at which dislocation occurs with any frequency in children).

The hip of a child under the age of 5 is usually dislocated by a fall. Trauma is minimal. At this age the acetabulum is largely cartilaginous and therefore soft; joint laxity is common. If all the muscles around the hip are relaxed, little force is required to dislocate the hip. As age increases, so the degree of violence escalates to athletic injuries between the age of 6 and 10, and to automobile accidents thereafter. Greater violence is more likely to be associated with fracture of the acetabulum or femur and sciatic nerve damage.

Posterior dislocation, the most common sort, produces a flexed, adducted, internally rotated leg. Anterior dislocation produces the reverse deformity (Fig. 16-22).

A recent traumatic dislocation can hardly be confused with a long-standing paralytic dislocation for which the treatment is entirely different. But recurrent dislocation of the hip in Down's syndrome may be confusing (Fig. 16-23). The bone looks normal, and only the appearance of the facies makes the diagnosis. In a survey, I found that 2% of patients with Down's syndrome (in all age groups) have dislocatable hips. Innominate osteotomy may be required.

Treatment

It is not merely kind to reduce a dislocated hip as soon as possible. Early closed reduction will almost always succeed, but each passing day makes the need for open reduction more likely. Prompt reduction will reduce the incidence of avascular necrosis. At our hospital avascular necrosis has only been seen when reduction was delayed beyond 12 hours (Fig. 16-24).

Reduction is easy if you ask the anesthetist to use relaxants. A posterior dislocation is reduced by flexing the hip and the knee to 90 degrees and applying traction while the leg is internally rotated. Anterior dislocation is best reduced by pulling the leg in extension, abduction, and internal rotation. After reduction, the hip should move freely without crepitus. A radiograph should be obtained to check that the hip is concentrically reduced.

After reduction, we nurse the child in Buck's traction with a pillow under the knee for a few days and then apply a hip spica, in which the child should remain for 4 to 6 weeks to allow capsular healing. Movement usually returns quickly, and myositis ossificans is rare. A scan should be obtained to assess the vascularity of the head. Radiographic review should continue for a year to detect avascular necrosis.

Complications

Problems are unusual (Fig. 16-25). During reduction an unrecognized epiphyseal separation may become manifest. The neck, not the head, reduces into the

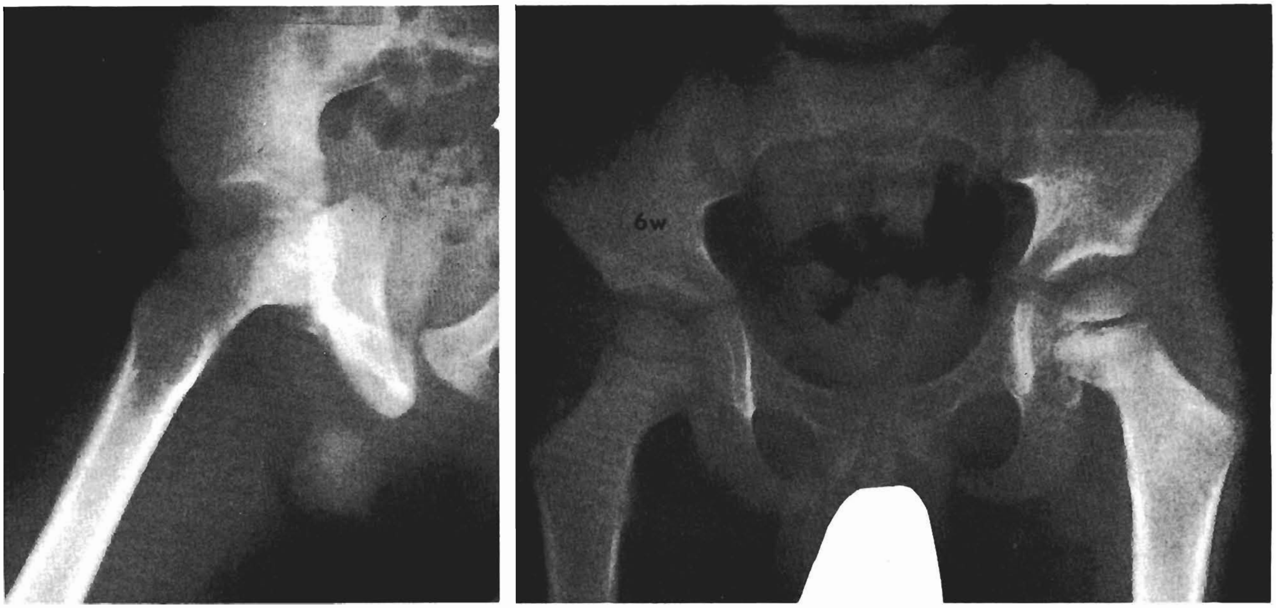
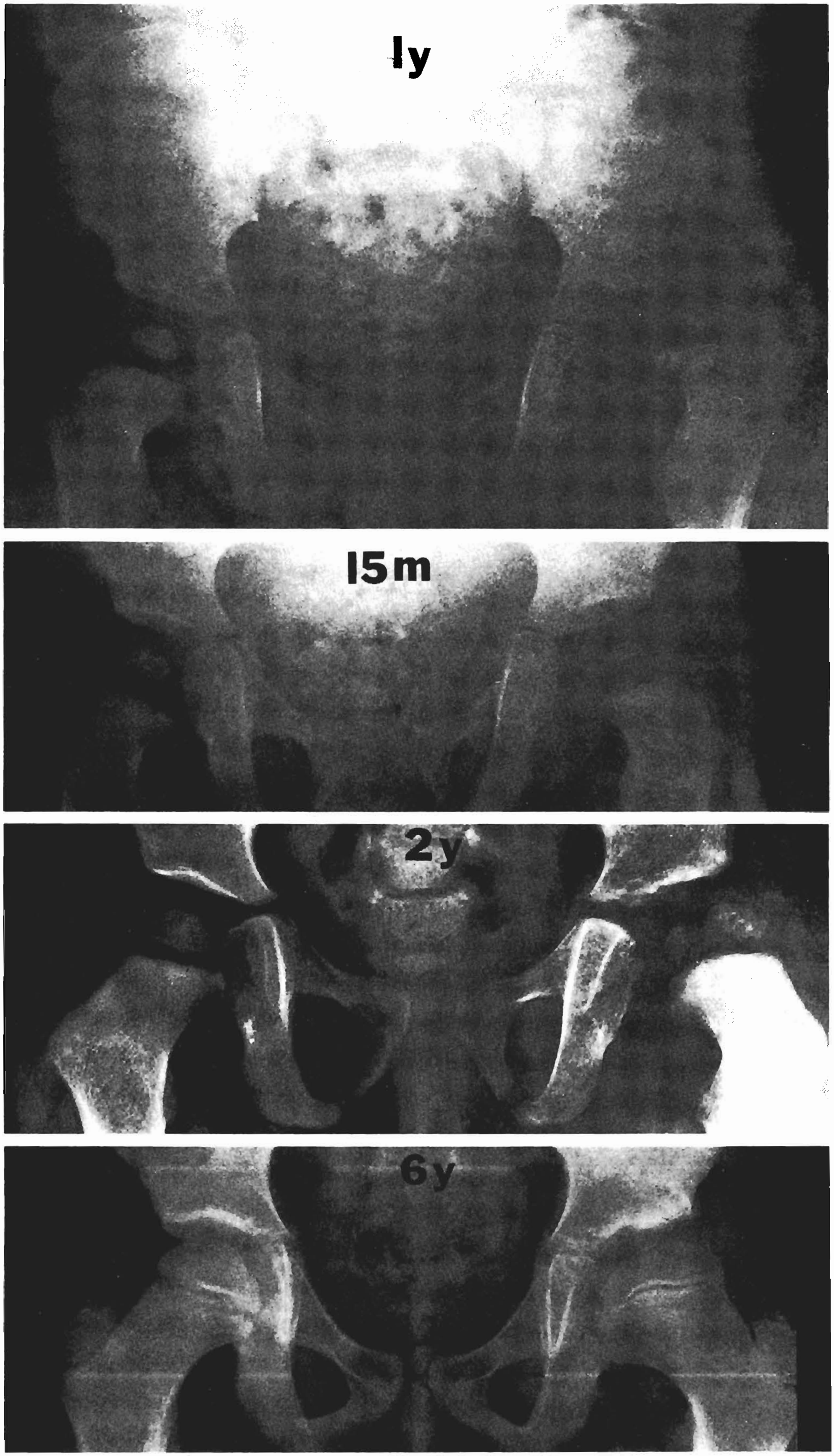


Fig. 16-22. Anterior dislocation of the hip. Six weeks after reduction the right hip is osteoporotic by comparison with the left. The circulation must be intact to permit this; avascular necrosis is most unlikely. Even in this boy, aged 6 years, the anterior and posterior lips of the acetabulum are cartilaginous.

Fig. 16-23. Dislocation in Down's syndrome.

Fig. 16-24. Traumatic dislocation of the left hip in a baby of 9 months. This dislocation was not recognized for several months. An open reduction was performed, and avascular necrosis followed. The result at the age of 6 years was good.


1y
15m
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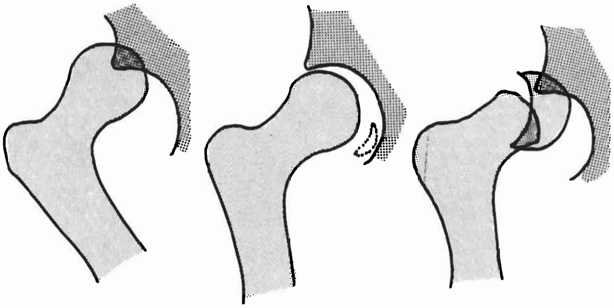

Fig. 16-25. Complications recognized after reduction. An acetabular fragment may block complete reduction. A Type-I injury may become evident.

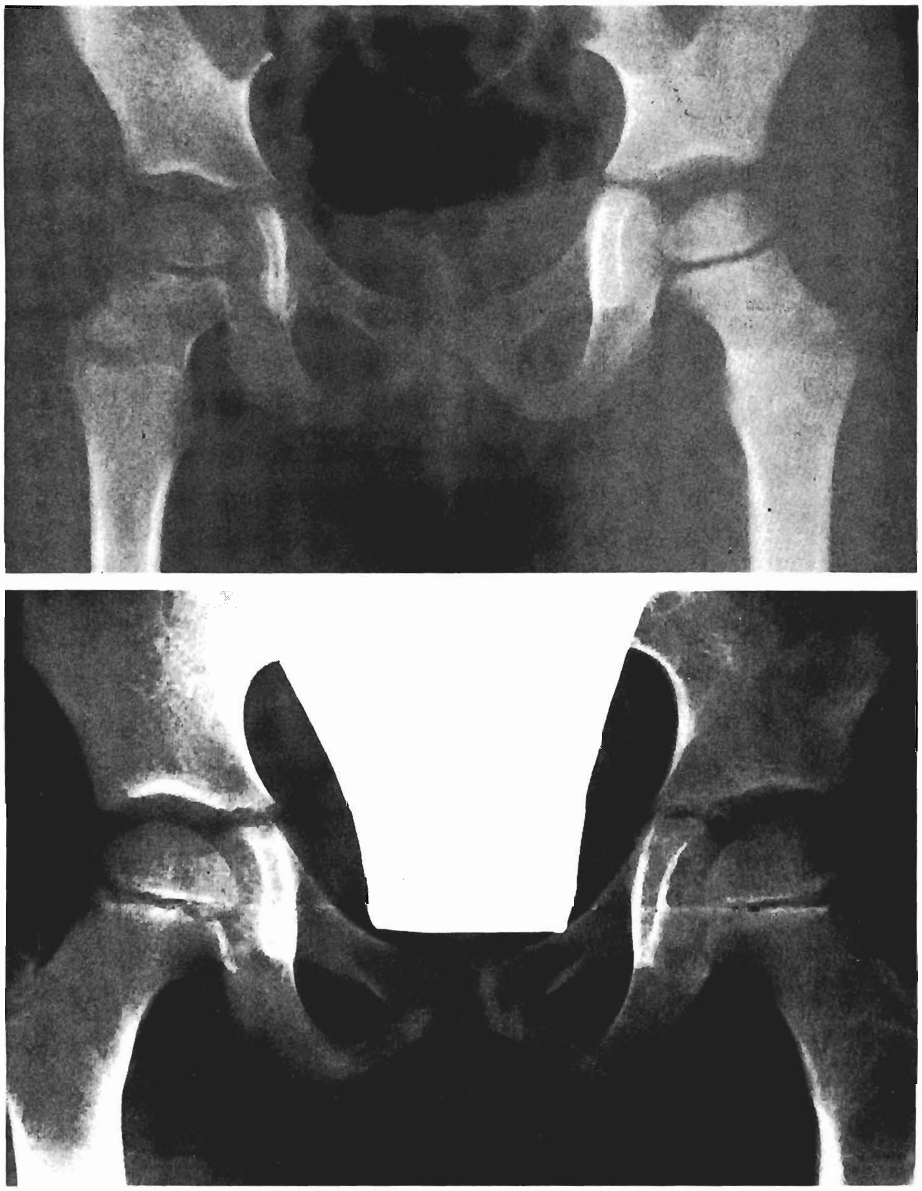

Fig. 16-26. A year after reduction of a traumatic dislocation, the right hip was stiff and painful. The distance between the teardrop and the femoral head is increased. The femoral head is displaced laterally. At arthrotomy a fibrocartilaginous body was removed from the floor of the acetabulum. A year later the hip was excellent clinically. Hyperemia has increased the size of the right head compared with the left.

acetabulum. Open reduction and pinning will be required.

Trapped Intra-articular Fragment. A trapped intra-articular fragment is easily overlooked at the time of reduction (Fig. 16-26). When the cast is removed, the hip is painful and never regains very much movement. Retrospective examination of the radiographs reveals that the head was never completely reduced. An arthrogram or CT scan will show the reason—commonly a radiolucent cartilaginous fragment from the acetabulum, which can only be removed by arthrotomy (Fig. 16-27). If this complication is borne in mind at the time when the hip is reduced, it should be possible to make the diagnosis and remove the loose fragment immediately. The incidence was 2 in 26 in Barquet's series.[2]

Recurrent Dislocation. Recurrent dislocation of the hip is a rare sequel to traumatic dislocation except in Down's syndrome.[1] Arthography or CT scan may show a defect or pouch posteriorly that requires repair. Recurrent dislocation is common in Down's syndrome. Capsulorrhaphy and innominate osteotomy, undertaken before arthrosis shows, is the best answer in Down's syndrome.

Avascular Necrosis. The overall incidence of avascular necrosis in the literature is 10% or less (see Fig. 16-24). Delayed reduction and severe injury are the most important causes. Prolonged avoidance of weight-bearing after dislocation does not influence the incidence.

RESULTS

In each of two series that reported the results in children followed to maturity, about one-third were found to have some abnormality of the hip. Simple dislocations of the hip in children under the age of 6 years almost always had a good result. A poor result was most common when treatment was delayed beyond 24 hours, when severe trauma produced associated injuries, and when the situation necessitated open reduction. The results are better than those in adults.

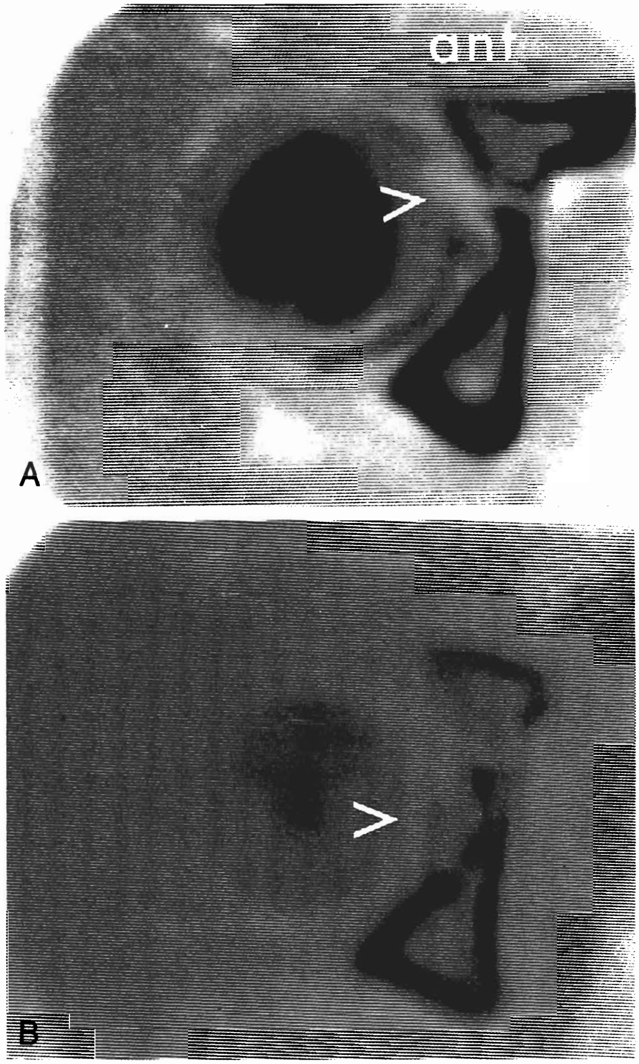

Fig. 16-27. CT scan of a trapped intra-articular fragment following dislocation of the hip. *(A)* A filling defect in the arthrogram. *(B)* The fragment. At operation the ligamentum teres had been avulsed from the femoral head, and there was a second loose fragment, which came from the posterior acetabulum. (Courtesy of W. P. Bobechko.)

VOLUNTARY DISLOCATION OF THE HIP

Some teenaged girls complain that they can feel the hip dislocating. The usual cause is a *snapping hip,* in which the tensor fascia lata jumps across the greater trochanter as the girl does the bumps and grinds. A rare cause is a *true voluntary dislocation* (Fig. 16-28). The patient I diagnosed was otherwise normal and dislocated the hip to entertain her friends at a party. This condition was described by Broudy and Scott.[3] Haddad and Drez described a case requiring surgery.[7]

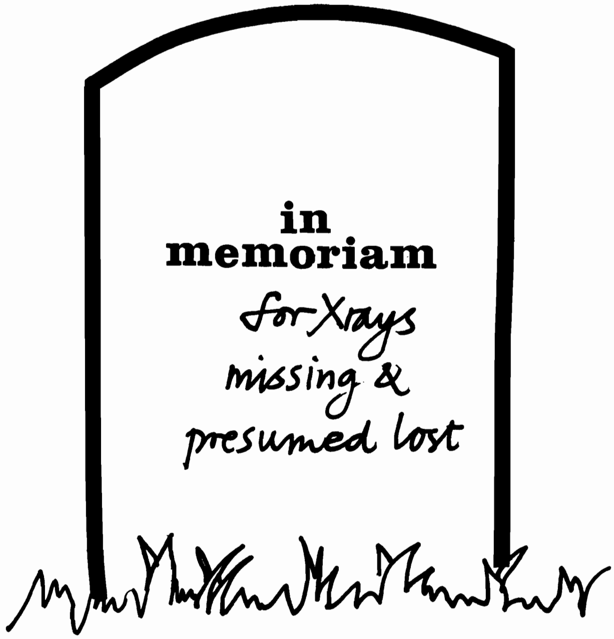

Fig. 16-28.

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17 / Femoral Shaft

As it is easily aligned on a splint, without much need to demonstrate skill in manipulation or surgical technique, femoral fracture has generally good results. Slight shortening is made up by overgrowth. Bayonet apposition is very common; in other bones, it produces an ugly lump, but in the femur, the covering muscle hides the lump from parent's probing fingers. A fracture of the femur is generally a low-key injury, but problems can arise. The most common difficulties are aligning high fractures, managing fractures when there are other major injuries, and ischemia.

INITIAL EXAMINATION

It does not require a physician to diagnose a fractured femur. The patient can do this. It does require a physician to appreciate that, after the pedal pulses have been palpated, the leg should be splinted before radiographs are taken. Look for other injuries. Determine the blood pressure. Shock is never the result of a fractured femoral shaft in children; it is always due to internal hemorrhage (*e.g.,* a ruptured spleen). The radiograph should include the hip and knee joints, otherwise the patient may be lying with a uniting fracture and an unrecognized dislocation of the hip or fracture of the femoral neck, which will cause a lot of red faces next week and white faces later.

CLASSIFICATION

See Figure 17-1.

Classical Midshaft Fractures

Whether oblique or transverse, a midshaft fracture shortens owing to the pull of the thigh muscles and to ballooning of the investing fascia of the thigh by swelling. The distal fragment displaces posteriorly owing to gravity and to the pull of gastrocnemius (Fig. 17-2). The aim of treatment is union with about a centimeter of shortening and with correct rotation and no angulation (Fig. 17-3).

Children Under 2 Year of Age. For 100 years Gallows traction has been the standard. But this may be the last edition to illustrate the technique because a steady trickle of catastrophes favor a complete ban on Gallows traction (Fig. 17-4). Ischemia and gangrene leading to amputation have occurred even in unaffected legs of tiny babies. I believe that the danger comes from the use of fixed traction. Balanced traction—using pulleys and weights—is safer. At our hospital we produced Volkmann's contracture using Bryant's traction only in children over the age of 2 years; this was many years ago. Some of my colleagues continue to use balanced Gallows traction for 10 to 14 days until the fracture becomes sticky; for toddlers, a short time in a hip spica afterwards is needed.

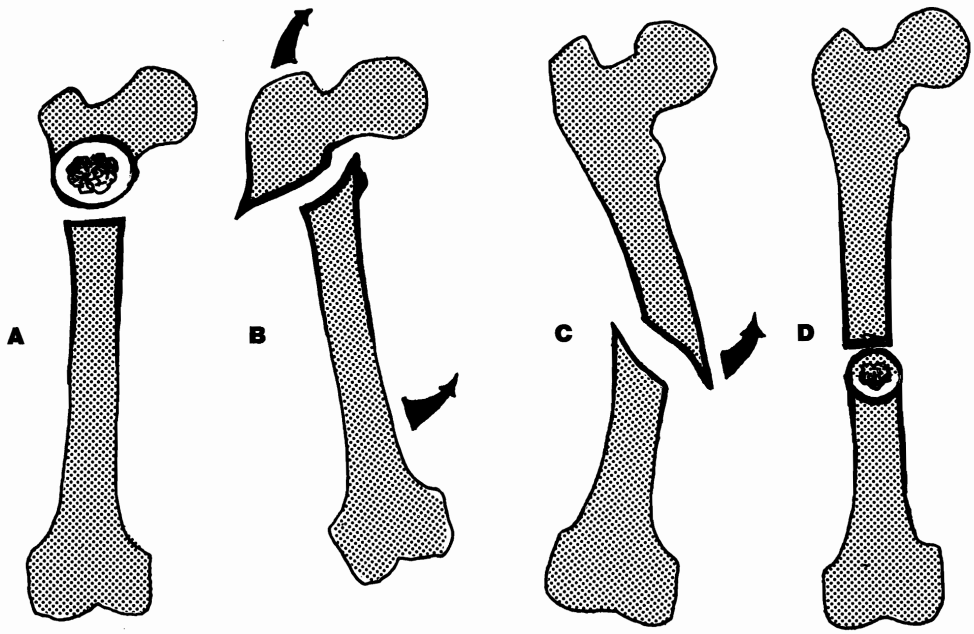
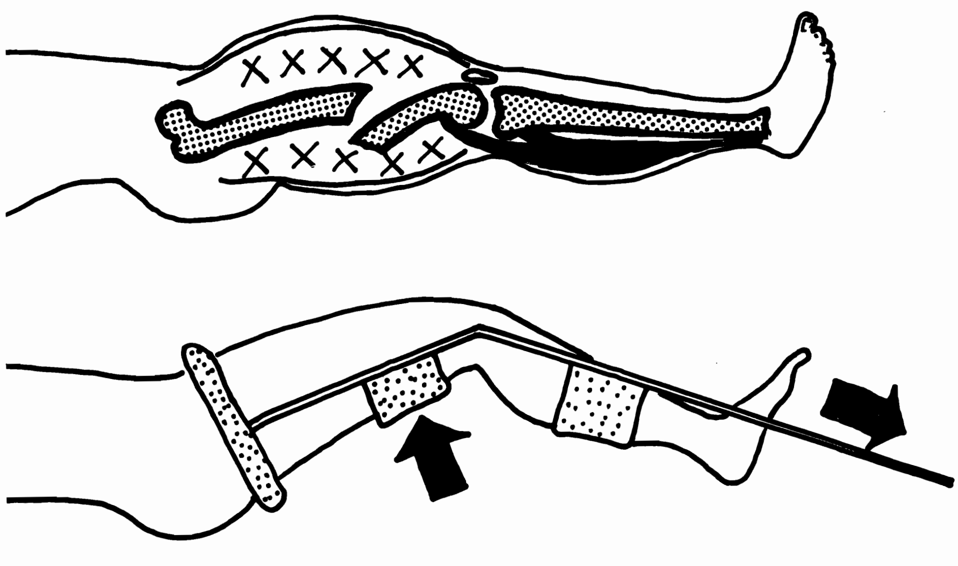


Fig. 17-1. Classification of femoral-shaft fractures: *(A)* subtrochanteric, *(B)* adduction, *(C)* abduction, *(D)* classical.

Fig. 17-2. Ballooning of the fascia and the pull of the thigh muscles cause shortening. Angulation is produced by gastrocnemius. A Thomas splint opposes these influences.



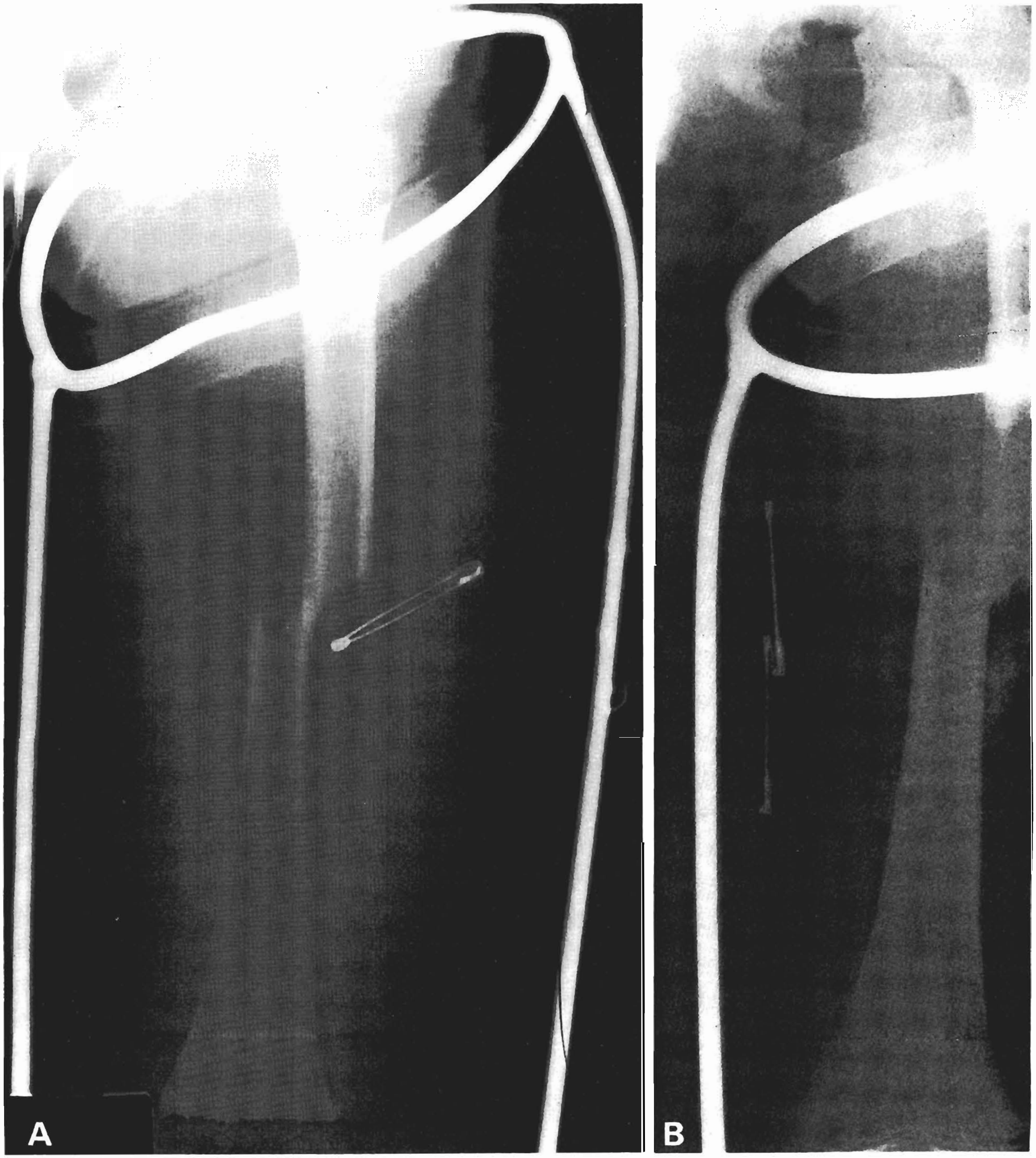
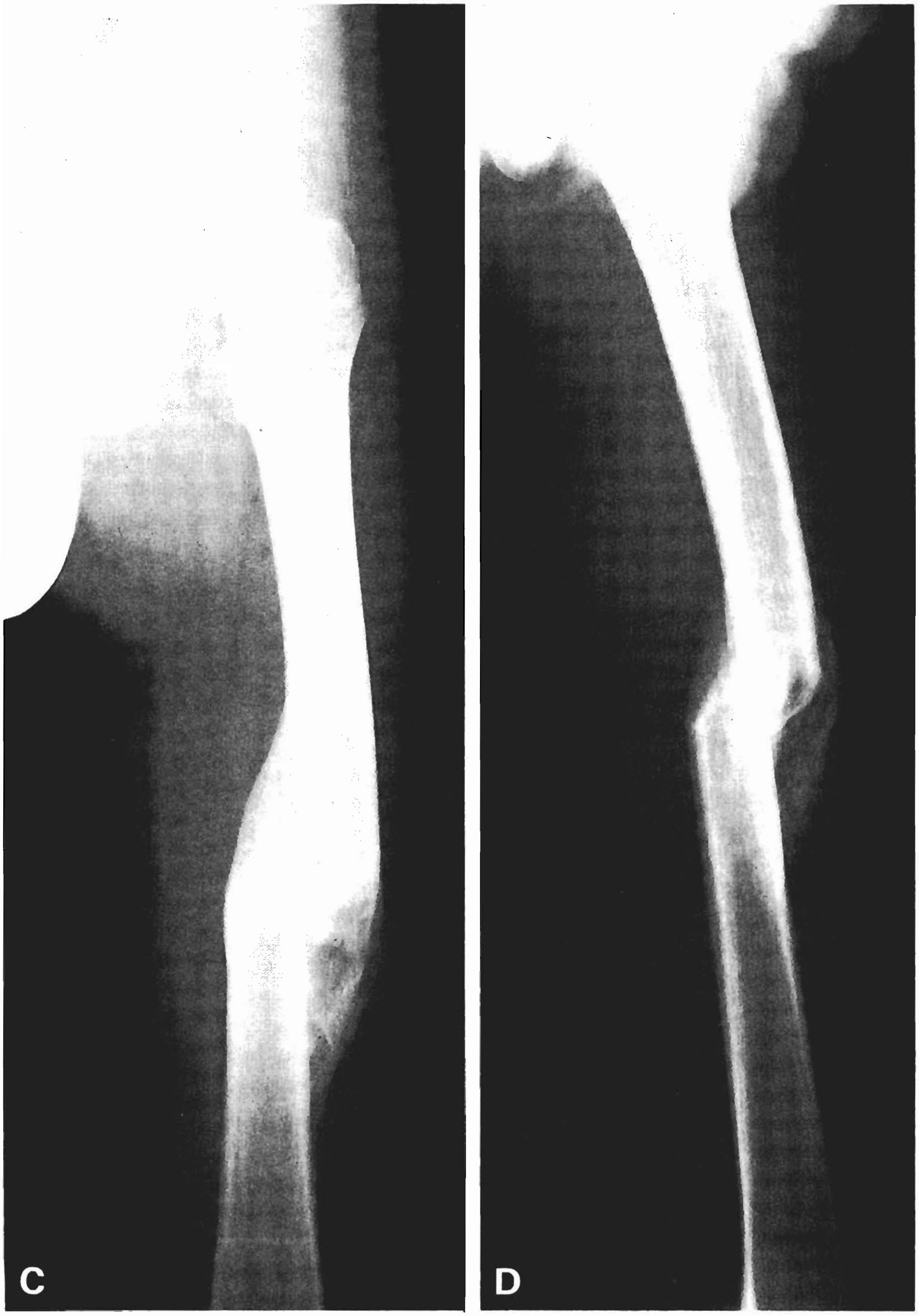


Fig. 17-3. A typical fracture of the midshaft of the femur in a boy aged 10 years. *(A)* Initial appearance. Note that the diagnosis was made on clinical signs and the splint was applied before radiographs were taken. *(B)* At 17 days the fracture is clinically united and ready to go into a spica. *(C)* At 10 weeks. *(D)* The lateral view shows that the normal anterior bow of the femur has been maintained.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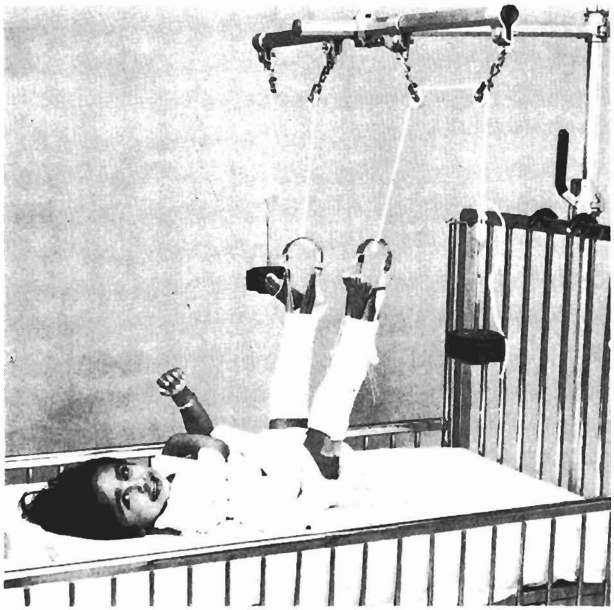
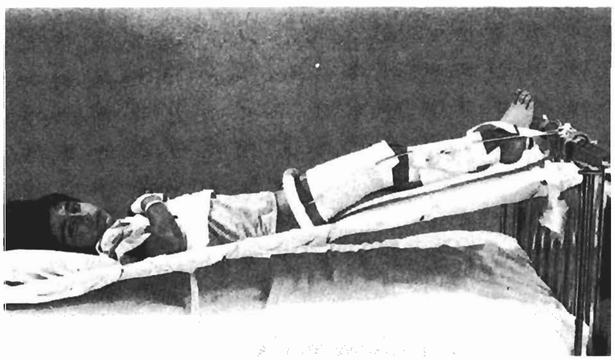


Fig. 17-4. Gallows traction for children under 2 years of age.

Fig. 17-5. Fixed Thomas traction on a Bradford frame. Skin tapes are tied to the end of the splint, which is tied to the bed end.



I am frightened by the risks. I prefer to learn from other peoples' mistakes. I use an immediate spica for spiral fractures and Hamilton Russell traction if overlap requires correction.

Children 2 Years to 10 Years (Fig. 17-5). Fixed skin traction using a Thomas splint on an inclined Bradford frame provides comfortable fixation. It is wise to lift the end of the frame only a few inches for the first few days. Later it can be elevated about 18 inches. This reduces the chance of ischemia. Be sure that the band behind the calf is causing no excessive pressure.

Radiographs should be taken the day after injury to see that the position is adequate. Then radiograph each week to check alignment. Malunion is only malposition that has been neglected; at this site malposition is easily corrected by adjusting the traction. Length is best assessed with a tape measure, because radiographs can be misleading (Fig. 17-6). If more than 1 cm of overriding is present, raise the foot end of the Bradford frame; lower the foot end to correct distraction. Never accept more shortening at this stage than you would accept in a year's time.

During the course of the third week a mass of callus can be felt, then toward the end of that week the fracture sets overnight and movement is no longer possible. The fracture is "sticky" which is defined as a fracture that will angulate but will not shorten. A hip spica can be applied without an anesthetic. Much care should go into molding the cast to prevent the bone bending. The padding should be even and the lateral surface of the thigh should be flat when checked with a ruler so that there is no spare room for a lateral bow. I leave the foot out or apply a walking boot. The hip and knee are slightly flexed—without abduction—so that the apparent length of both legs is the same. A 1-inch raise is applied to the shoe of the opposite foot. Not all children learn to walk, but at least they can stand and sit.

As soon as the cast is hard the child goes home. A check radiograph is obtained 2 weeks later; the cast is removed in clinic in 6 to 8 weeks. It has been helpful to provide parents with a printed handout when their child is admitted to explain this pattern of care. From the outset they appreciate that the child will be on crutches for about 2 weeks after the cast comes off, and will go on limping for about 3 months.

There is little to be gained by advising definite periods of nonweightbearing after cast removal. Mothers cannot enforce your advice and only worry. Tell mother that children have an unfailing sixth sense to protect themselves from putting too much weight on the leg or discarding crutches too soon. Leave it to them. Children should be seen about a month after the cast is removed; a few who are making very slow progress require physiotherapy at this stage. Leg length should be assessed a year after injury.

Youngsters 10–16 Years. Shortening is the main risk because of increasing muscle strength brought on by puberty and because of decreasing help from overgrowth. Skeletal 90–90 traction allows better length control. The leg can be supported in sheep-skin slings or by below-knee cast, as advocated by Childress.[6] Movement should be encouraged to speed union and to minimize stiffness. The fracture is usually sticky at 3 weeks, and then a spica can be applied.

Spica or Cast Brace? The majority of diaphyseal fractures occur in children aged 7 or less; stiffness of the knee is so infrequent that a cast brace is not worth the added complexity and expense. Furthermore, angular deformity may develop in three-quarters of midshaft fractures.[15]

A cast brace is preferred for fractures of the distal third of the diaphysis in children over the age of 10 or 12 years. They do not bend. More proximal fractures have been treated with a spica with a knee hinge. The use of a hip-hinge, thigh cast brace using Crystona sounds promising.

Alternative Methods. Methods used in other institutions include: (1) *Hamilton Russell traction,* which I have always found requires constant adjustments; (2) *Perkin's traction,* which is excellent for adults, but does not offer sufficient immobilization for children to be comfortable; and (3) *immediate hip spica.* In several large series reported, the results of cast fixation are just as good as those obtained with traction, in children between the age of 2 and 10 years. Spica fixation may be the method of choice because it saves hospital beds. Irani applies a single hip spica (with the sole of the foot cut out to prevent the child pushing up) without admission and without an anesthetic.[11] Allen used a double hip spica.[1] The leg should be cast with an almost extended knee and hip. Though setting the leg with the hip and knee flexed may seem to give better control, I have seen this produce a slough in the popliteal fossa with disastrous results. Judet noted unsatisfactory results in half the patients treated in casts with the hip and knee flexed to right angles.[13] Cast treatment may supplant traction for all these fractures, but it must be done well.

Adducted Fractures

When the fracture is subtrochanteric and oblique, the pull of the abductors proximally and the pull of adductors distally tend to produce an outward bow. Often this will correct in routine traction. If it does not correct, either apply a little pad at the site of the bow, or put blocks under the side of the bed as well as the end to increase abduction of the distal fragment.

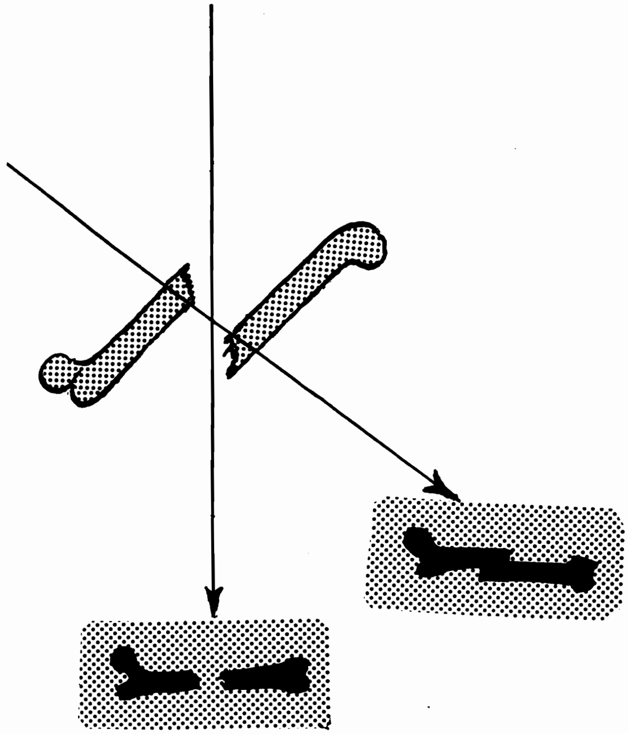


Fig. 17-6. A fracture may appear distracted or overlapping depending on the angle at which the radiograph is taken. Judge length with a tape measure.

Extended Fractures

The degree of displacement of a subtrochanteric fracture depends on the direction of the fracture line (Fig. 17-7). Psoas tends to flex the proximal fragment if the direction of the fracture line permits. Some transverse fractures may be so flexed that they produce a bone-on-end appearance on anteroposterior radiographs.

If angulation is slight, raise the end of the Thomas splint. If angulation is gross, the distal fragment should be flexed using 90–90 traction maintained with a supracondylar pin (Fig. 17-8). It is safer to place the pin in the femur than the tibia. The tibia

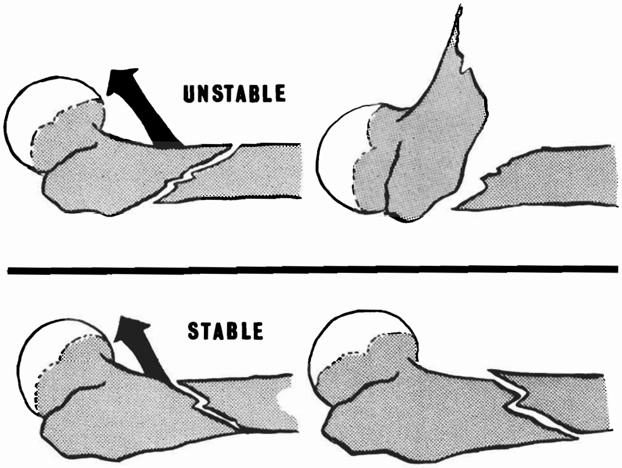


Fig. 17-7. The direction of the fracture line determines whether a subtrochanteric fracture will be unstable or stable. Unstable fractures require 90–90 traction; stable fractures are managed in a Thomas splint.

may subluxate anteriorly and the ligaments may be stretched. An infected high anterior tibial pin may cause recurvatum owing to growth damage.[20]

While an assistant holds the leg in this position, a Steinmann pin is inserted from the medial side. Do not put the pin in with the knee extended if you wish to avoid impaling and trapping tensor fascia lata. Try to get the pin square to the leg. Because it is easier to be sure where the pin goes in than where it will come out, the medial approach is recommended to avoid risk to the femoral artery.

After 3 to 4 weeks in traction the pin is removed and a hip spica is applied (Fig. 17-9).

Abducted Fractures

This is unusual except in low fractures with a suitably oblique fracture line. The medial bow may be corrected with a medial pad or by putting a little traction on the normal leg to level the pelvis and to reduce the pull of the adductors.

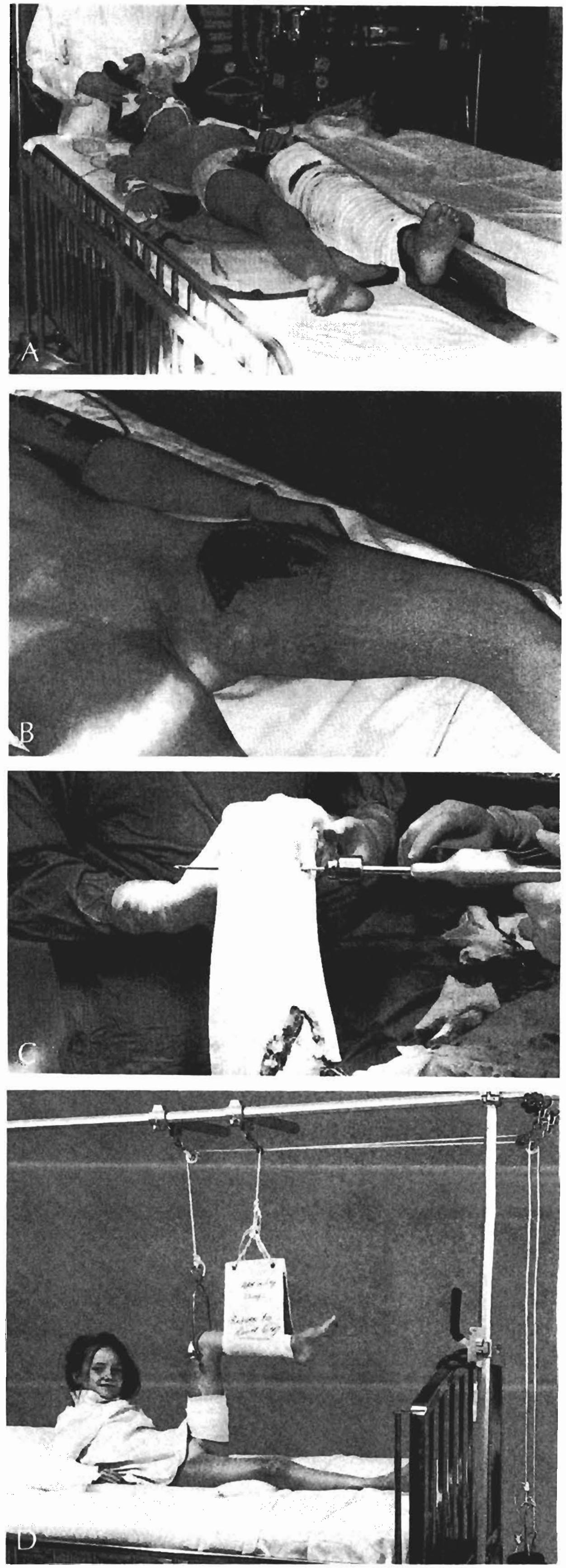


Fig. 17-8. Open subtrochanteric fracture. *(A)* This girl arrived well splinted. Only when she was anesthetized was the wound inspected. After debridement *(B)* a pin was placed through the distal femur for 90–90 traction. *(C)* The anesthetist's view of the insertion. Ask the anesthetist to tell you to raise or lower the handle of the drill to obtain a horizontal pin. *(D)* Five days later the patient was surprisingly comfortable.

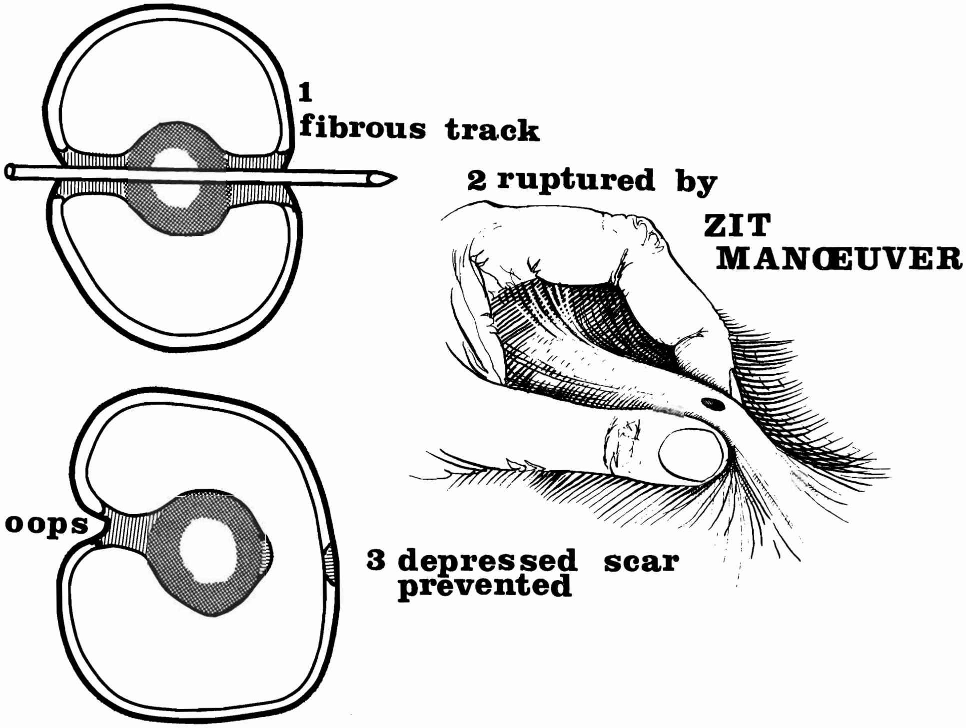


Fig. 17-9. Squeeze the track of the pin immediately after removing the pin. Feel the fibrous track pop. This will avoid the need for plastic surgery later.

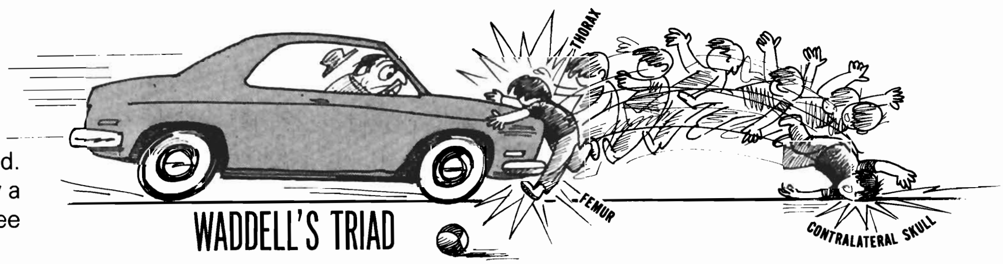


Fig. 17-10. Waddell's triad. When a child is struck by a car always look for three injuries.

EARLY PROBLEMS

Multiple Injuries

Many children with fractures of the femoral shaft have head injuries. Most children with severe, life-threatening multiple injuries sustained in traffic accidents have a fracture of the femur. This is because the femur of a child is at car-bumper level (Fig. 17-10).

It has already been remarked that shock in a child with apparently nothing more than a fracture of the femur *always* indicates internal hemorrhage; most commonly, a ruptured spleen.

Management. Look after serious injuries first and immobilize the femur temporarily in a Thomas splint with the patient flat. Head injuries render the head-down position undesirable. The skin against the ring should be checked and treated several times a day by the nurses to prevent pressure areas. This is usually safe for a day or two. If the child cannot go into head-down traction at this time, choose another form of definitive treatment.

Traction. Hamilton Russell traction or 90–90 degree traction works well if the child lies fairly still and does not require turning.

Intramedullary Fixation. Though rarely indicated, intramedullary fixation greatly facilitates nursing care for children with prolonged decerebrate restlessness or those with chest or spinal injuries (Fig. 17-11). Nailing should be done early, because vascular spasm may be precipitated if overlap is corrected at a week. After nailing, the fracture can be forgotten. The main objection to nailing is the risk of sepsis. The special objections in childhood are the risk of slight disturbance of growth in the greater trochanter at the site of

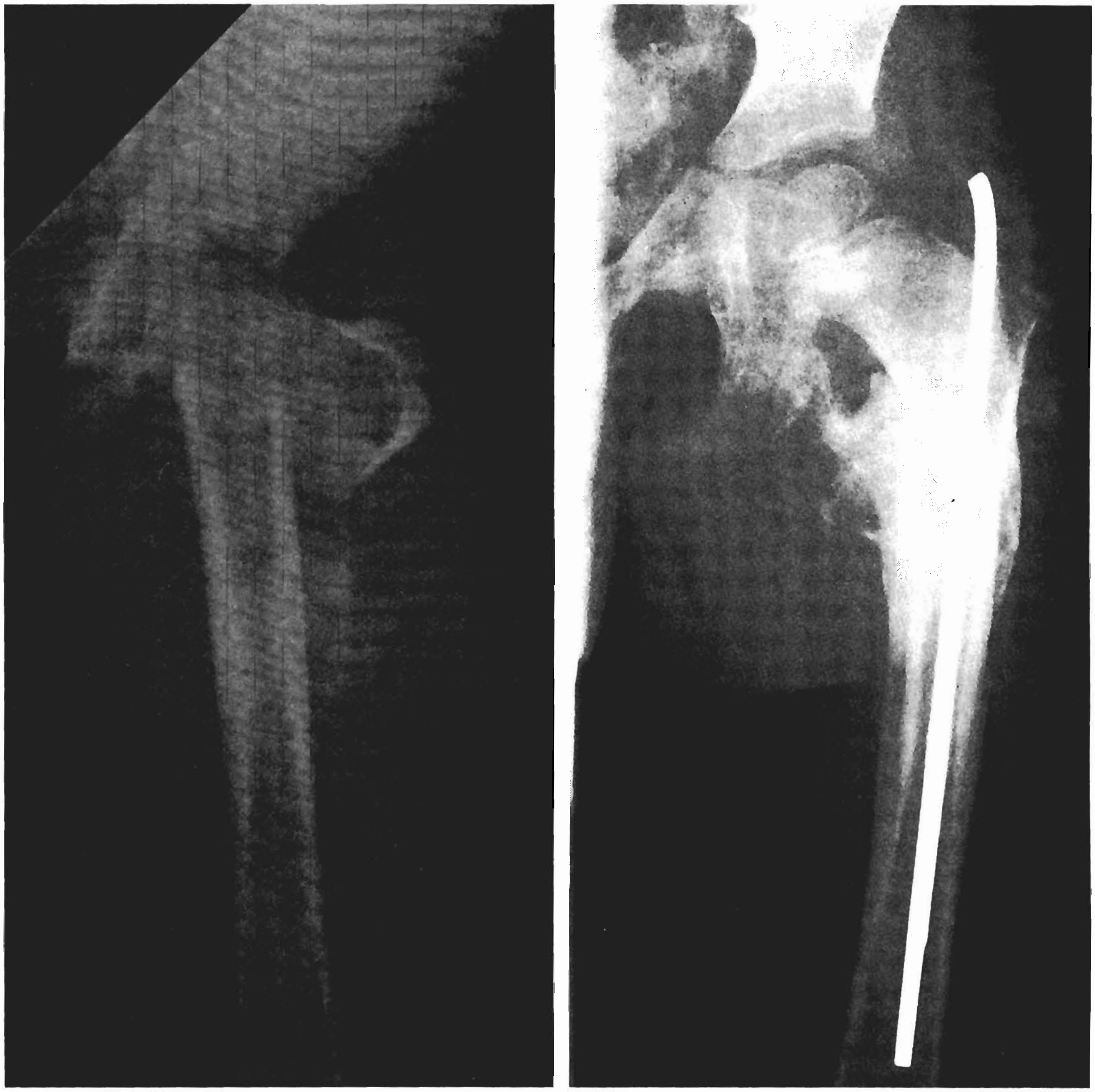


Fig. 17-11. Subtrochanteric fracture in a girl of 3 years. She shows the bone-on-end appearance, because the proximal fragment is flexed 90 degrees. The fracture could not be held in any sort of traction because of severe protracted decerebrate rigidity. She was on a respirator for a week. The fracture was pinned on the third day after injury, when it was obvious that the fracture could not be treated by traction and that the decerebrate rigidity was going to last. She started to walk independently after 6 months and has a residual hemiplegia and some intellectual impairment.

entry of the nail, and an overly long leg owing to bringing the fracture out to length. Intramedullary nailing using a *big* nail through the trochanteric fossa carried a 50% risk of coxa valga and a 15% chance of necrosis or dysplasia of the head in one series.[9] Campen overcame the problem using a Rush nail introduced either below the greater trochanter or just above the lateral condyle through a diagonal hole.[5] Of course a supplementary spica is needed to hold rotation.

I wish I had used this method in a child with bilateral diaphyseal fractures who convulsed for a week after a head injury. When he came out of 90–90 traction—at about 6 weeks—he refractured both femora during spasms. His radiographs, taken during convulsions, were permanently left up on the view box in the ICU by the nurses, in an attempt to make me change my ways. Every doctor on the staff who had ever treated a fracture of the femur offered me advice. Massive callus left him with a quadriceps contracture, which, happily, resolved after 6 months before his legs became perfect.

Mediocre results are common in brain-injured children, as Fry, Hoffer, and Brink have shown.[8] The subject is discussed further on page 63.

Fractures of the Femur and Tibia on the Same Side

This subject is discussed on page 304.

Ischemia

Individual experience with ischemia will be limited. Early recognition is a prerequisite to successful care in every patient. Feel the pedal pulses; test toe movement and sensation; and look for an ischemic cause of unexpected pain.[12] Ischemia is an emergency. Minutes make the difference between mere survival of muscle and full functional recovery.

Early Ischemia. This may be due to a lesion of the artery or to displacement of the fracture. I well remember a child with a fracture at the level of Hunter's canal. Pedal pulses could not be felt on admission very soon after the accident. Within an hour the foot became cold and the girl lost toe movement and sensation. When the fracture was reduced under general anesthesia, the foot suddenly became warm and the veins filled. As soon as the girl awoke after the anesthetic her toes moved and were sensitive, but it was about 2 weeks before her pulses returned. Her artery was not explored because the peripheral circulation was adequate.

If the circulation does not return as well as this, the artery should be explored and the fracture fixed internally.

Late Ischemia. Tight bandages over skin traction or inelastic bandages supporting the calf are the main causes. The risk of ischemia is greater in the presence of hypotension produced by other injuries. If the patient is unconscious, ischemia passes unnoticed. Arterial exploration with a Fogarty catheter and fasciotomy will be needed (see Chap. 4).

Fat Embolism

Approximately half the children with a fractured femur in a series we studied showed biochemical evidence of fat embolism. Clinical fat embolism, though unusual, resembles that of the adult form.[21]

LATE PROBLEMS

The incidence of late complications is low. Most potential problems are related to leg-length inequality.

Leg Length

After any diaphyseal fracture, longitudinal growth is accelerated, but the exact amount is not predictable. Femoral growth may increase from the normal rate of 1.3 mm/month to 1.8 mm/month.[17] In the femur this amounts to about 1 cm and occurs during the 18 months after injury. No further growth acceleration or equalization takes place after this time. Overgrowth is useful because most fractures of the femur resist pulling out to length exactly. One centimeter of overriding is ideal (Fig. 17-12).

A *short* leg is the result of excessive overriding or gross bowing, or is exceptionally due to growth arrest. Hunter and Hensinger describe an 11-year-old who closed all the growth plates in an injured leg treated by 6½ months' immobilization.[10] We have seen distal femoral growth arrest probably caused by an epiphyseal injury at time of fracture.

A *long* leg occurs if there is end-to-end apposition (particularly if this is obtained with intramedullary

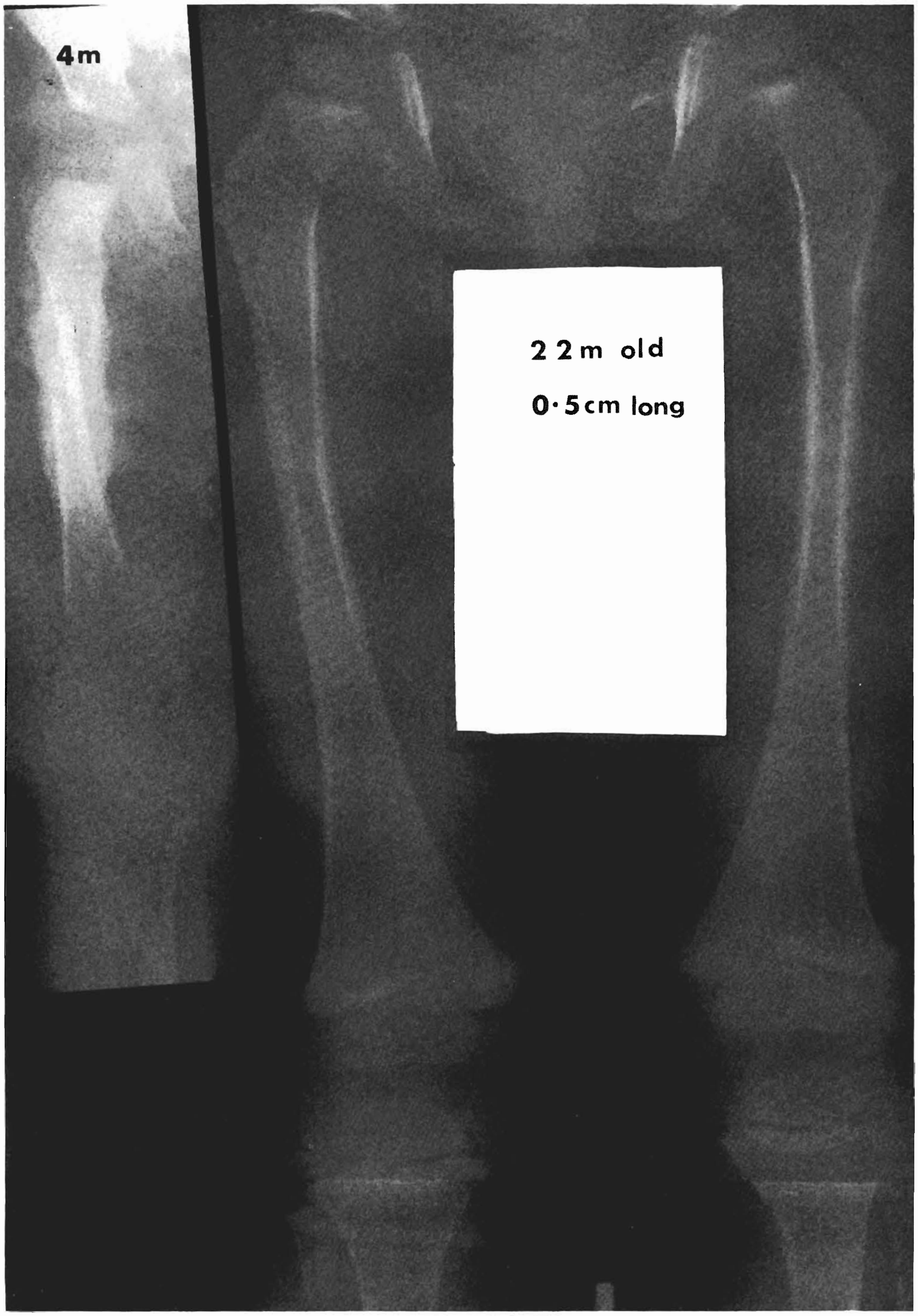


Fig. 17-12. Remodeling is excellent after fractures of the femur. At 3 weeks this fracture is united with a 0.5-cm overlap. The right lower extremity is 0.5 cm long 18 months later.

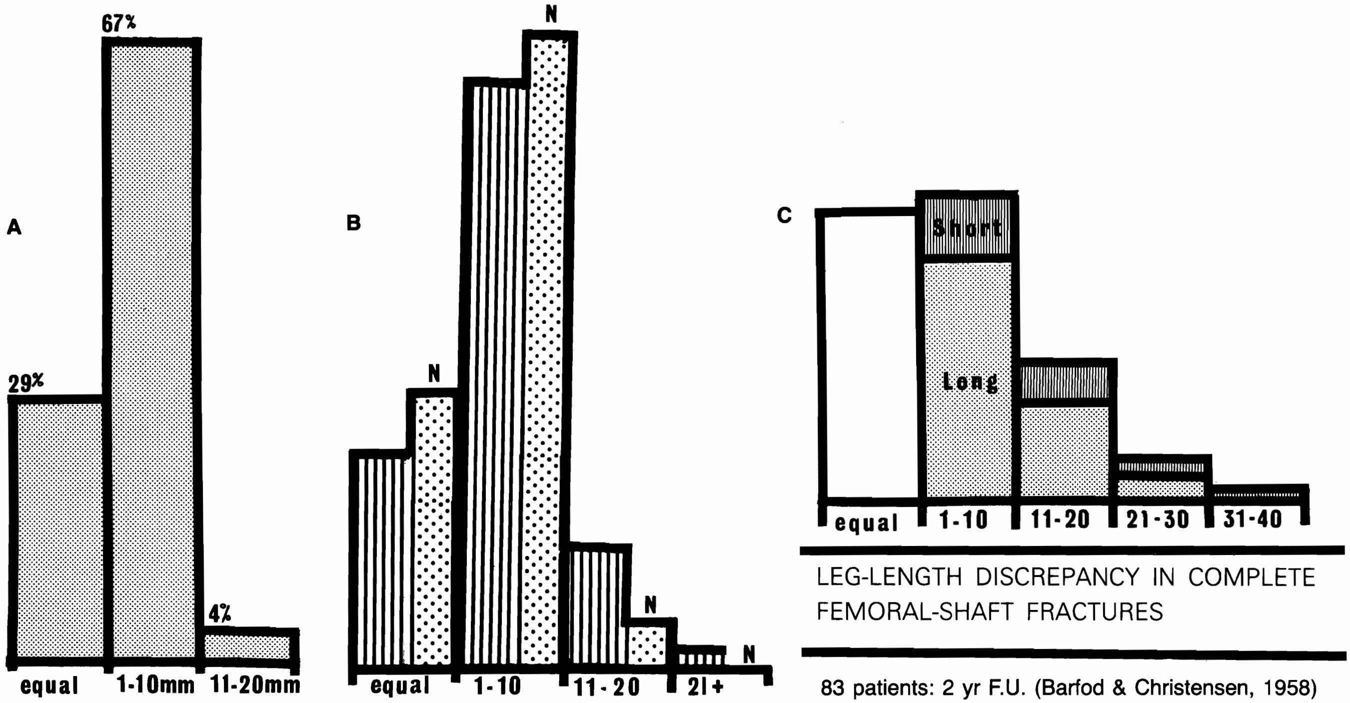


Fig. 17-13. *(A)* Leg-length discrepancy in a population of young fit soldiers. *(B)* Relationship between backache and leg-length discrepancy. Leg-length was measured radiographically in soldiers with nonspecific backache (striped column) and compared with fit soldiers (stippled column). In those with discrepancies greater than 1 cm, more had backache than were fit. *(C)* Leg-length discrepancy in one series of children's fractures. Perhaps a quarter of these children have a greater risk of backache in later life.

fixation). Refracture stimulates growth again, and the greatest overgrowth I have seen was due to refracture of an undisplaced fracture.

In a small child, a leg-length discrepancy of 1 cm may produce a limp because the legs are short and the pelvis is narrow. As the child becomes taller the discrepancy becomes insignificant.

Lawyers are very interested in possible sequelae of leg-length discrepancy. In reports, I usually deal with the problem under these headings.

Limp. One cm and under produces no limp in an adult, but it may in a small child.

Backache. Rush and Steiner measured leg length very accurately in 100 fit soldiers and in 100 soldiers with backache without apparent cause (Fig. 17-13).[18] They concluded that a leg-length discrepancy exceeding 1 cm may be a cause of backache.

Osteoarthritis of the Hip. On the side of the long leg the femoral head is less well covered by the acetabulum, a circumstance that may cause osteoarthritis of the hip. The importance of this is unknown.

Spurs

On two occasions I have seen children with butterfly fragments in the vastus lateralis, or under the skin. One of these was so prominent that it was removed. Bony spurs may form that are painful when stuck, and may require excision (Fig. 17-14).

Quadriceps Contracture

Quadriceps contracture in children is much less common than in adults. The same management is required.

Fig. 17-14. This 11-year-old has a large butterfly fragment. After 4 weeks in traction the shaft united, leaving the isolated butterfly fragment as a lump under the skin. It was excised before she was placed in a spica. Two years later a spur was easily palpable and occasionally painful.

Fig. 17-15. Malunion in a teenager. Treated in traction, she healed with anterior bowing. Within a few weeks she refractured; the deformity was a stress concentrator. She healed again in traction with the malunion shown above. After the quick recovery from osteotomy and nailing she wondered why she had not been treated like this initially. What would you say?

Angulation

Muscles will hide minor degrees of angulation. Even the gross example shown in Figure 17-15 produced little deformity; recurvatum at the knee concealed the anterior bow. But the leg did not feel right.

Malrotation

Perhaps because the hip is a ball-and-socket joint, malrotation is an uncommon problem. Does malrotation remodel? This is a contentious issue. Burton and Fordyce found malrotation in 37%.[4] Benum and others found that 18% of patients had more than 10 degrees of malrotation (the greatest was 17 degrees) but none had complaints.[2] Oberhammer reexamined 128 children up to 10 years of age at the time of fracture and found that malrotation corrected itself.[16] Brovwer and associates came to the same conclusion.[3] Clearly the surgeon should keep both feet pointing in the same direction, but minor degrees of malrotation will remodel. The Weber block system of exact control of rotation seems unnecessary.

The Three-Week-Old Case From Elsewhere General Hospital

Fame may bring you a child whose fracture is healing with gross angulation or overlap. When the fracture is no more than 4 weeks old, angulation is easily corrected by manipulation under anesthetic. A rotatory force will loosen things up. After this time manipulation becomes more strenuous but still possible. A drill osteotomy leaves little scar and facilitates correction. Overlap may be corrected by manipulation followed by skeletal traction, with the child at a steep angle. One case was treated effectively using a leg-lengthening apparatus.

SUPRACONDYLAR FRACTURES

Buckle Fractures

Buckle fractures occur in preschool children and in older children with osteoporosis. The young will protect these fractures themselves. A padded, stovepipe cast will allow the older child to move about (Fig. 17-16).

Fig. 17-16. Greenstick fractures in infants may present as sudden refusal to walk.

Stress Fractures

Stress fractures should be protected to relieve pain (Fig. 17-17).

Displaced Fractures

If there is sufficient violence to fracture the femur, the periosteum usually tears, allowing the fracture to displace, with the risk of arterial damage. I find a displaced uncomplicated fracture very hard to treat because it is a very unstable fracture and it angulates in every direction. Malunion carries the penalty of obvious deformity and prolonged knee stiffness. It is possible to hold position with a Thomas splint, but an inordinate amount of adjustment is required. One solution to this problem is to leave the resident to treat the fracture with the misleading suggestion that the fracture is easy to treat, requiring only a little intelligence and aptitude. Only when failure is inconceivable will union in an adequate position be achieved by placing a little pad here or there, adjusting the degree of knee flexion, and fiddling a little bit every day. Some transverse fractures are most easily managed by manipulation and immobilization in a hip spica. If all else fails, plating is an easy way out and it may be the best choice (Fig. 17-18). Steinmann

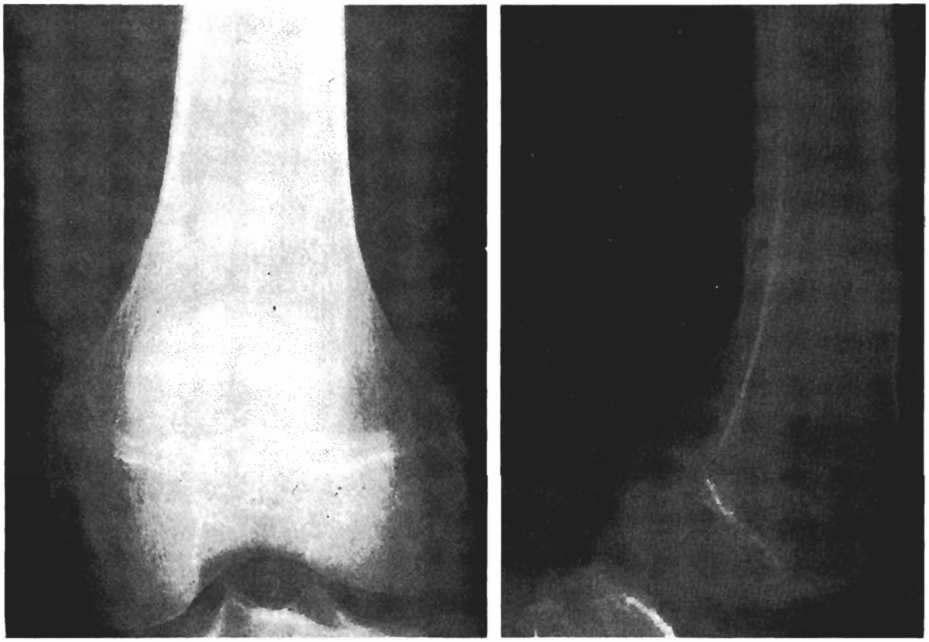


Fig. 17-17. A stress fracture of the femur.

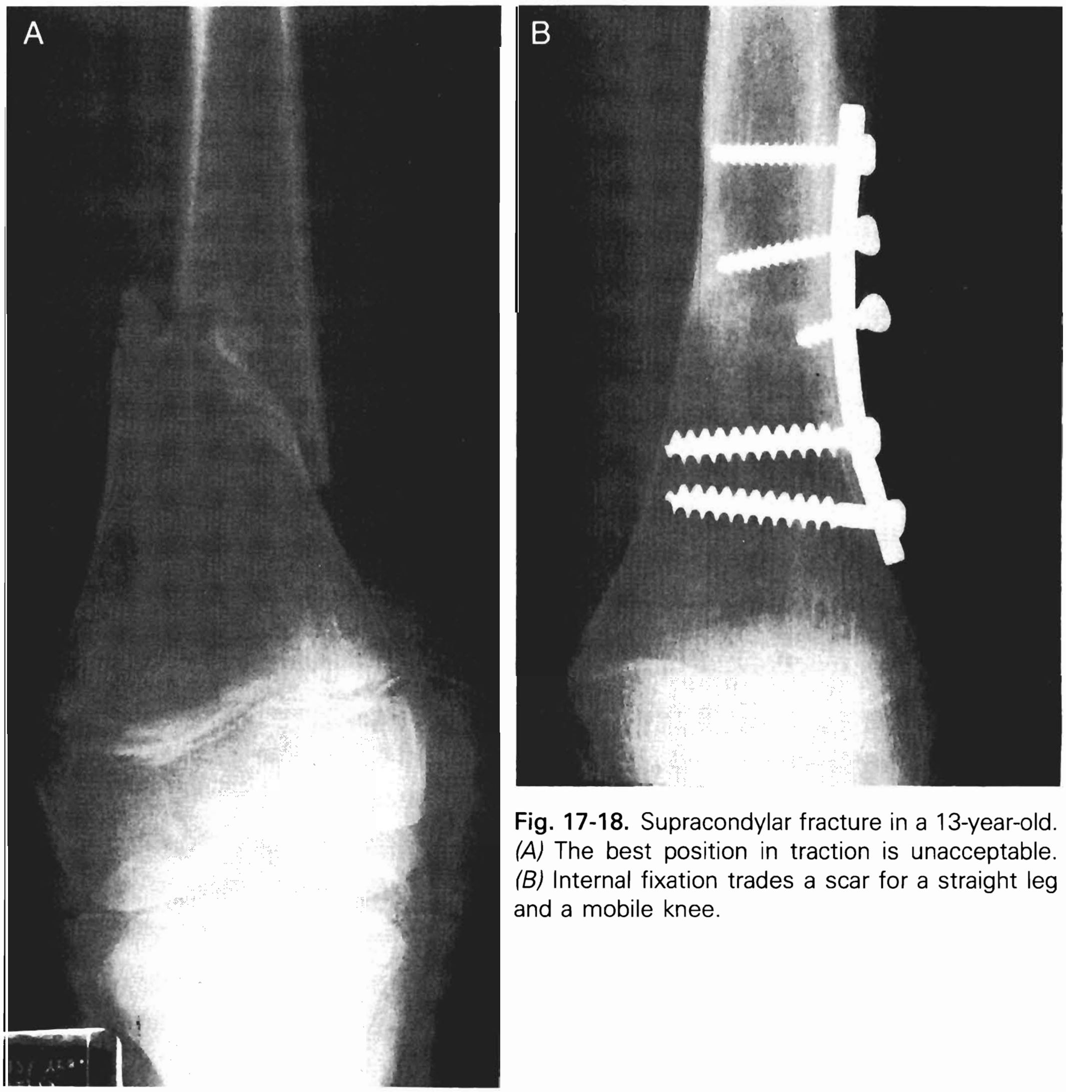


Fig. 17-18. Supracondylar fracture in a 13-year-old. *(A)* The best position in traction is unacceptable. *(B)* Internal fixation trades a scar for a straight leg and a mobile knee.

pin traction—with the pin through the distal fragment—does not prevent the fragment from spinning. After the growth plate has closed, there should be no hesitation about inserting an ASIF blade plate.

Separation of the Distal Femoral Epiphysis

In the days when children stole rides on buggies these injuries were common and often accompanied by vascular injury. Children caught the leg in the spokes of the wheel as they fell off. Today, hyperextension injuries of the leg are unusual.

Extension Type. The epiphysis together with a small metaphyseal fragment is usually displaced anteriorly. Reduction is most easily obtained under anesthesia with the child *prone*. Lift up the foot, maintaining traction as the knee is flexed to about 110 degrees, just as you would reduce a supracondylar fracture at the elbow. This is much easier than trying to reduce the fracture with the patient supine. A well-padded, above-knee cast is applied in this position. After 3 weeks, flexion is reduced to about 60 degrees, and, 3 weeks later, the cast can be removed. Movement is usually slow to return (Fig. 17-19).

Rarely, the reduction is unstable. Do not hesitate to insert two Kirschner wires through each condyle into the shaft of the bone. The secure hold will allow the leg to be immobilized in about 30 degrees of flexion.

Valgus Type. Valgus fracture forces are sustained during football and may masquerade as injuries of the collateral ligaments (see Fig. 2-12); stress films make the distinction. The deformity should be corrected exactly under anesthesia before applying a cast.

Intra-articular fractures of the distal femur are discussed in the knee section.

Not all epiphyseal separations continue to grow normally. Considering all kinds of growth-plate injuries, Lombardo and Harvey noted that about one-third developed valgus or varus and one-third had a leg-length discrepancy of 2 cm or more.[14] Parents should be warned. Naturally the risk for Type-II injuries was less in undisplaced fractures or fractures that were reduced than in fractures that were not satisfactorily reduced. In the first group the average

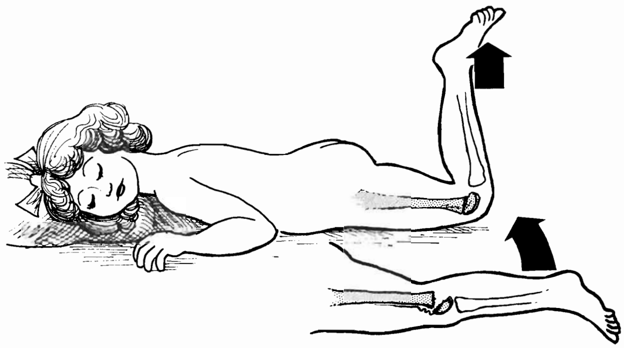


Fig. 17-19. When separated distal femoral epiphysis is displaced anteriorly, gravity can be used to secure reduction.

leg-length discrepancy was 4 mm, compared with 36 mm in the second group.

Criswell and associates reviewed 15 abduction injuries.[7] None had leg-length discrepancy, but four required osteotomy to correct angular deformity. Pinning was minimally more secure than spica fixation. Traction did not hold a reduction.

Salter and associates found good results in 72% of 29 epiphyseal separations.[19] Accurate gentle reduction is the first step for success. The next step is careful follow-up to detect early bony bridging.

The following story was published over a hundred years ago:

> SENTENCE ON A FRENCH BONE-SETTER. On August 26th, 1859, an infant aged 15 months, in the department of Mayence in France, fell from the arms of a little girl who was carrying it. A bone-setter, named Lefaux, a farmer, was called in. He declared the thigh to be fractured, employed extension and violent pressure, and, after wrapping the thigh in a handkerchief soaked in soap and water, he left, promising to return in a fortnight, but first receiving a fee of sixteen *francs*. At the end of the fortnight, he did not come, and messages were sent to him in vain. In the meantime, a large abscess had formed, and the ends of the bone had become exposed. A medical man was then called in, and succeeded in procuring union of the bone only at the end of five months, and at the expense of considerable shortening of the limb. An action was brought by the father of the child against Lefaux; who, on February 25th, was condemned to a fortnight's imprisonment, to a fine of two hundred *francs,* and to the payment of a thousand *francs* damages to the child, and the expenses to which the father had been put in the course of the illness.

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18/ Knee Joint

When an old lady injures her knee, she is most likely to sustain a bumper fracture. A football-playing undergraduate tears a cartilage or ligament. Children are spared most of these injuries because:

1. Articular cartilage and growth cartilage are thick and absorb energy, which otherwise may injure bone or ligament.
2. Ligaments are stronger than growth plates. Epiphyseal separations are more common than ligamentous disruption.
3. Osteoporosis comes later in life.

The pattern of children's injuries is different. For example, if mother says the child's leg was bent through a right angle or that she heard it crack, you must find something amiss. It is most unlikely to be a ligamentous tear; much more likely it is a spontaneously reduced separation of the femoral epiphysis, which may show only on stress films (Fig. 2-12).

Always take obliques and skyline radiographs (even an arthrogram) if there are clinical signs of a major injury without radiographic confirmation on the initial pair of films. Arthroscopy is being used more and more for the diagnosis of nonosseous injuries. The knee must be flushed clear and the surgeon must be able to do a difficult arthroscopy without too much bluffing and faking. Hemarthrosis, rather than being a contraindication for arthroscopy, is, in fact, one of the best indications.[3]

The following intra-articular injuries are seen in children.

TRAUMATIC HEMARTHROSIS

Traumatic hemarthrosis is an unsatisfactory diagnosis; translated, it means "something is injured in this bloody joint and I don't know what it is." After you have tested ligaments, patellar stability, and menisci, and have studied oblique films and stress films, you will still find many patients who fall into this category. Aspirate the hemarthrosis if it is tense and painful; fat in the aspirate suggests a fracture. In days gone by it was considered adequate to apply a Robert Jones bandage and send the patient, on crutches, to physiotherapy for isometric quadriceps exercises. If you were right in concluding that the injury is no more than a synovial tear, he will be well again within a month. However, today a more aggressive policy makes sense. (See the section on ligament tears, p. 290.)

TIBIAL SPINE

Injuries that rupture the anterior cruciate ligament of an adult will avulse the tibial spine of a child. The spine repairs by bone when reduced and yields much better results than a complete tear of the ligament (Fig. 18-1). The majority of fractures are produced in road accidents, particularly falls from bicycles. If a child presents with a swollen knee after falling from a bicycle, he should be presumed to have a fracture of the tibial spine until proved otherwise.

Some patients are unaware that anything is seriously wrong until the following day, when the hemarthrosis has become tense and painful. The radiologic diagnosis is easy. But the radiograph only shows a little of the damage. Above the small ossific spine are wide radiolucent wings of articular cartilage from the weight-bearing surface of the tibia. Much more than the spine is lifted up. The fragment is usually partially detached. The anterior part lifts; the posterior part hinges. The femoral condyles will usually ram the wings of articular cartilage back into position when the knee is extended. When the fragment is completely detached, interposed meniscus or rotation of the fragment may prevent closed reduction.

In our series of 15 patients with this injury, eight fractures were reduced by extension of the knee (often accompanied by aspiration), usually under anesthesia, and the patients were immobilized in a stovepipe cast for about 4 to 6 weeks.

Five out of 15 were treated by open reduction, because the fractures could not be reduced by closed means. The knee is opened through a medial parapatellar incision. Two holes are drilled through the epiphysis, and the fragment is tied down (Fig. 18-2). Closed reduction had failed in one patient because the medial meniscus was trapped in the fracture and in another because the fragment had rotated. Good results were obtained.

Two patients who were left unreduced lost full extension. The diagnosis was missed in one other patient (Fig. 18-3).

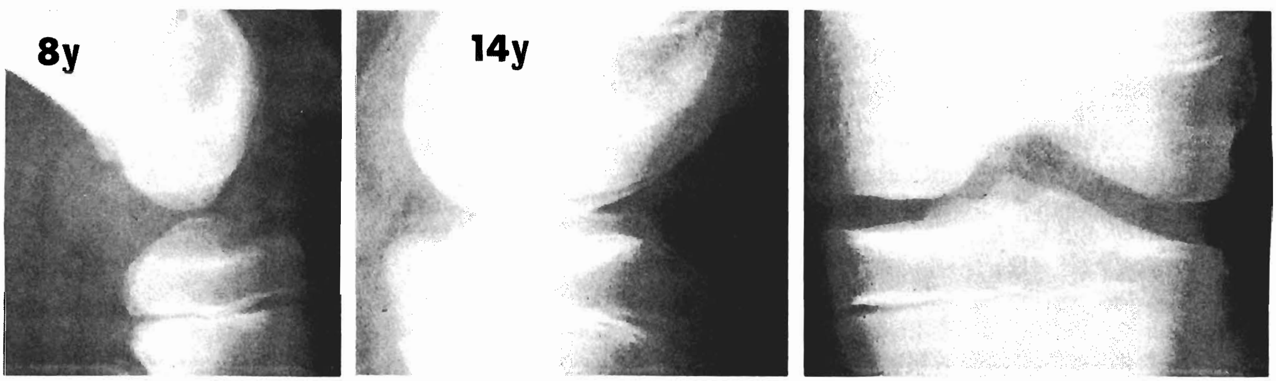
Myers and McKeever (1970) reviewed 47 fractures in children and concluded the following (Fig. 18-4).[8]

1. Type-I and Type-II injuries predominated, and no attempt to reduce the fracture should be made because the fracture may become a Type-III injury. All produced excellent results when immobilized for 6 to 12 weeks in a long leg cast applied with the knee flexed 20 degrees.
2. Type-III injuries (15%) required open reduction and the fragment sutured back. Again the results in children were excellent.

Zaricznyj drew attention to comminution and used K-wires to hold the fragment.[15]

Molander and associates in 1981, reviewed 28 children.[7] A smaller projection was seen at follow-up after open reduction and after immobilization in extension than after immobilization in flexion. In the absence of any bad results in 14 Type-III fractures

Fig. 18-1. Partially displaced fracture of the tibial spine in a boy of 8 years. This was reduced by extending the knee. Six years later the knee is clinically normal, but the tibial spine is large, and the medial tibial plateau has a turret.



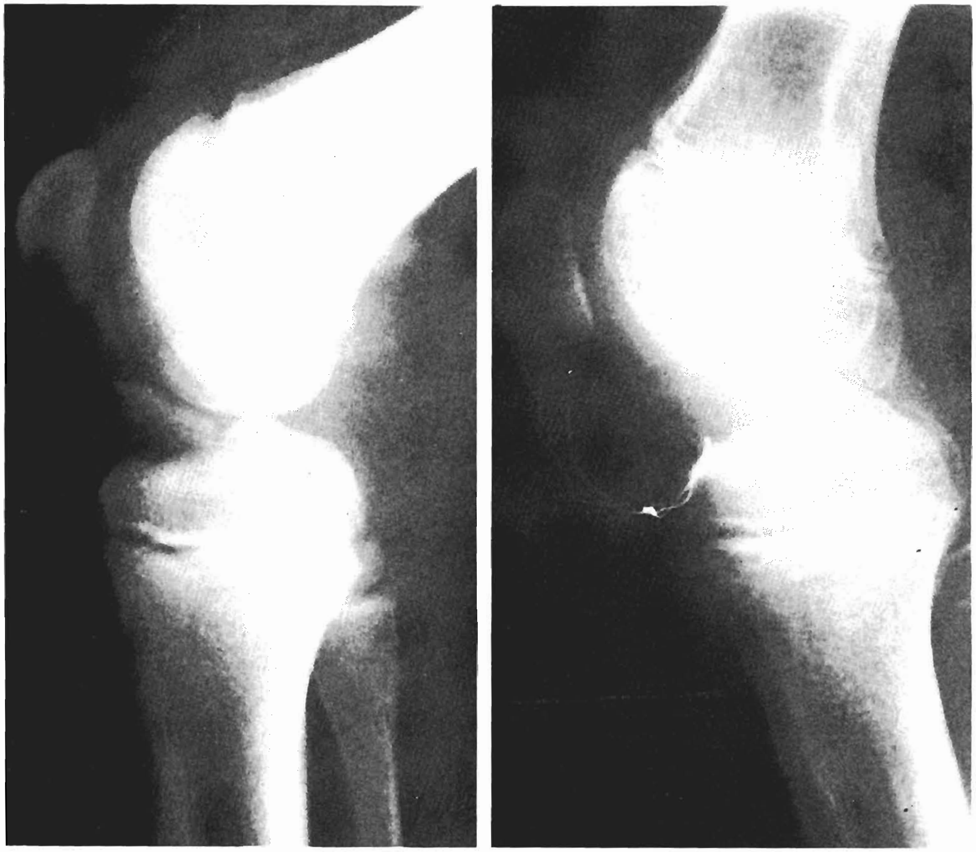
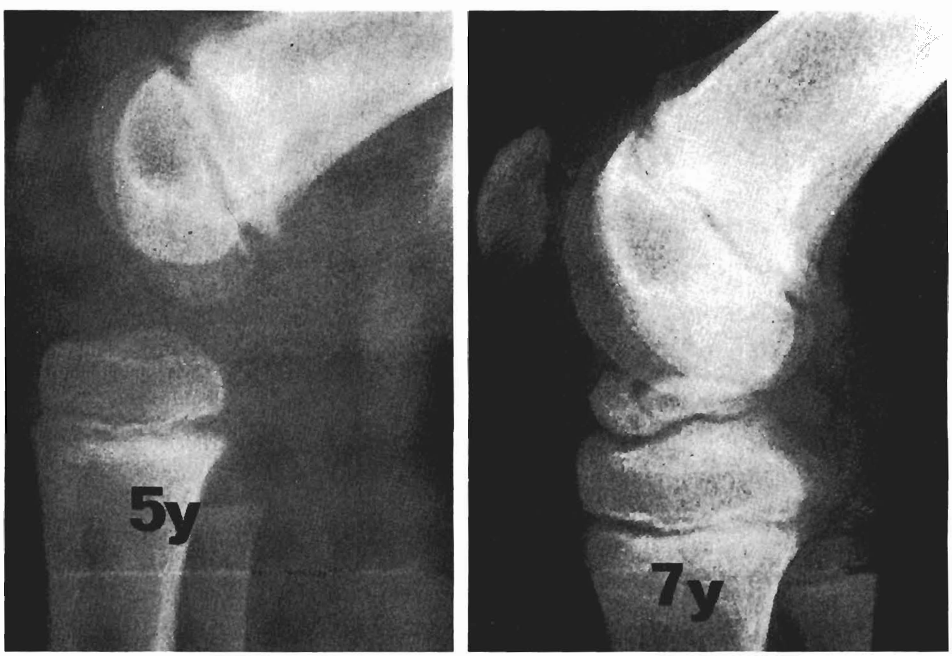


Fig. 18-2. Complete fracture of the tibial spine. Closed reduction failed. At open reduction, holes were drilled through the epiphysis (avoiding the plate) to hold the fragment in place. The wires later required removal. Boy aged 9 years.

Fig. 18-3. At the age of 5, this boy sustained a traumatic hemarthrosis. The roentgenogram was interpreted as normal. He was never able to extend the knee fully, and a roentgenogram made 2 years later shows the reason: a displaced ununited fracture of the tibial spine. This was excised with good result. At the time of the initial injury the cartilage model of the tibial spine was avulsed. Could this have been diagnosed by testing the range of movement of the knee?



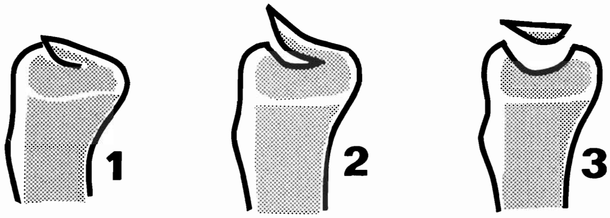


Fig. 18-4. Myers and McKeever classification of fractures of the tibial spine.

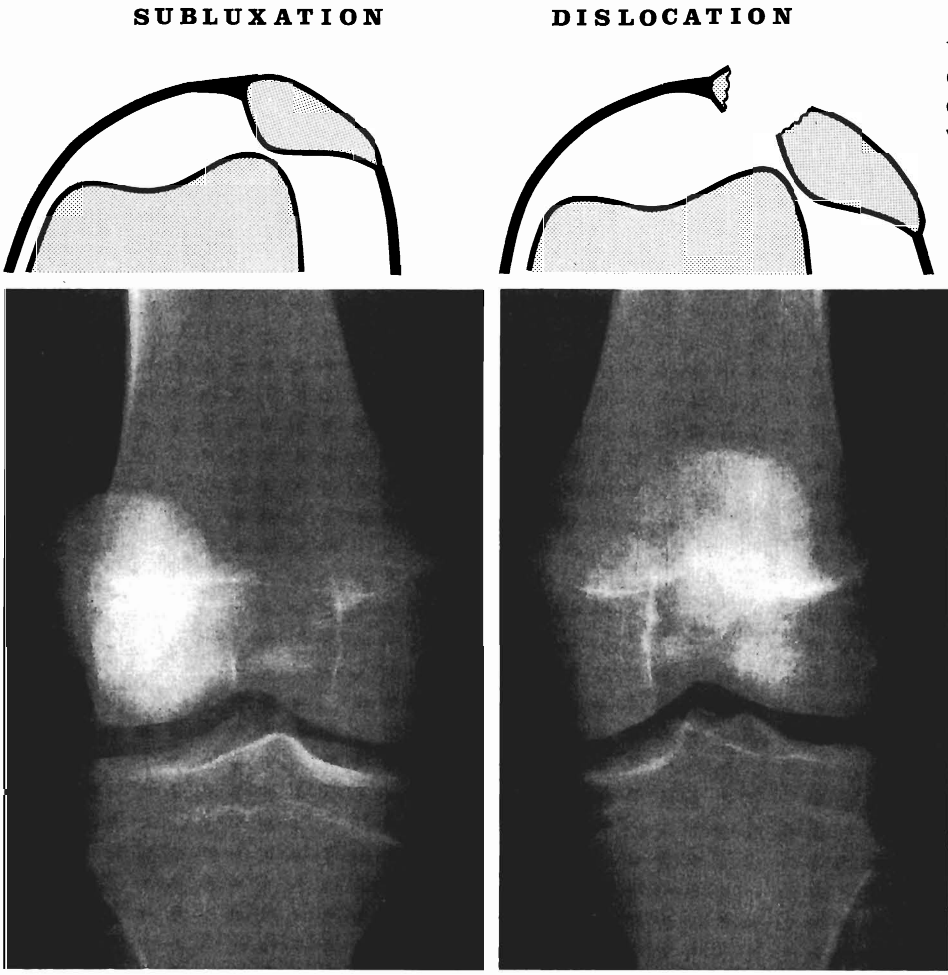


Fig. 18-5. Acute dislocation of the patella. Usually the dislocation reduces before the radiograph is taken. Girl aged 13 years.

treated conservatively, they concluded that this was justified.

Oddly enough none of these large series with excellent follow-up notes any late instability, yet in the recent work on ligament ruptures in children, several children combined medial ligament tears with fractures of the tibial spine. The combination is certainly something to seek.

DISLOCATION OF THE PATELLA

In some children dislocation of the patella is an episode in the history of recurrent dislocation. In others, it is the result of injury (Fig. 18-5). Most dislocations are reduced before the child comes to the hospital, either spontaneously or by the child or a buddy. Certain diagnosis is not always easy. The signs are he-

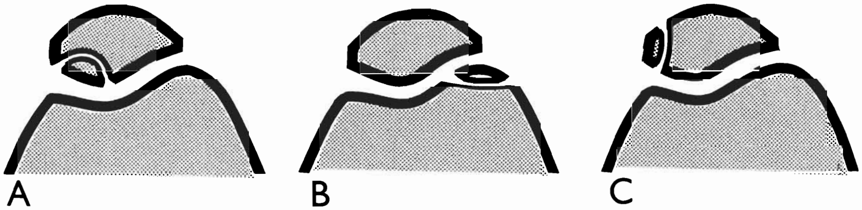


Fig. 18-6. Sites of osteochondral fracture in association with dislocation of the patella.

Fig. 18-7. Osteochondral fragment associated with acute dislocation of the patella. This was removed at arthrotomy.

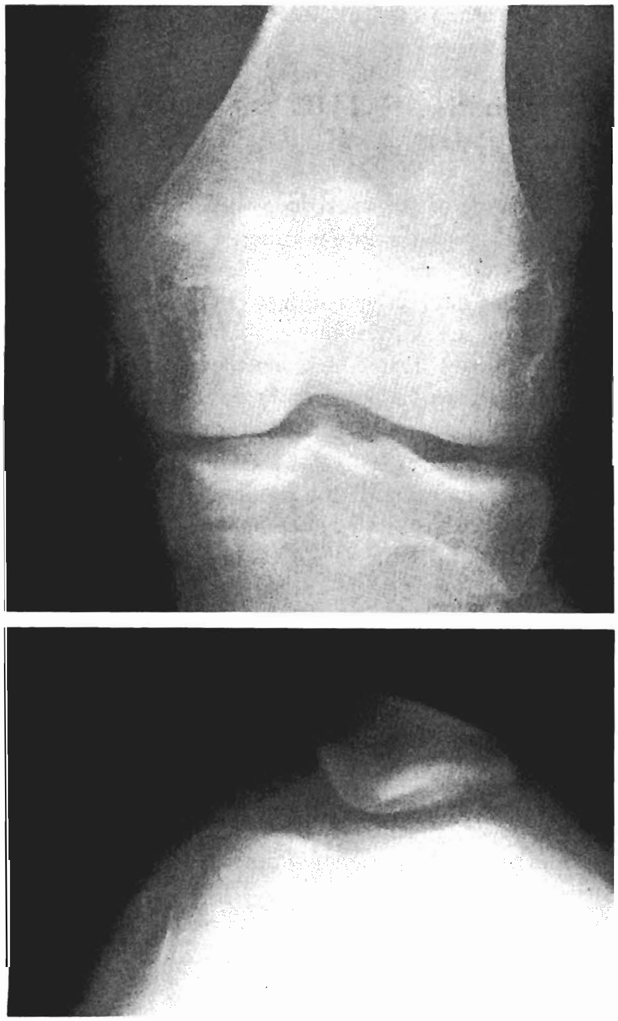
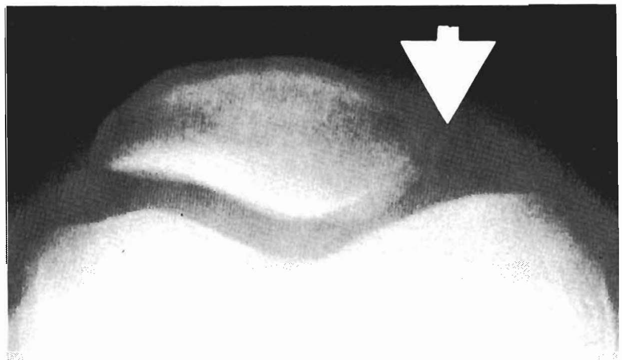


Fig. 18-8. New bone along the medial border of the patella.



marthrosis, tenderness along the medial border of the patella, and increased lateral movement of the patella.

Always look for a loose fragment knocked off the lateral femoral condyle or medial aspect of the patella during the process of recoil (Figs. 18-6, 18-7). Between 5% and 10% of acute dislocations are complicated by an osteochondral fracture. Rorabeck and Bobechko showed the best treatment is immediate arthrotomy and excision or replacement of the fragment plus repair of the dislocation.[11] Small fragments are discarded; larger fragments are refixed with ASIF mini-screws or Smillie pins. If the fragment is removed and no repair performed, the dislocation will recur.

First Dislocations

There is much argument about the treatment of first dislocations. Should they be managed by immobilization in extension for 4 weeks, or should they be repaired surgically? We have always been conserva-

Fig. 18-9. Intra-articular dislocation of the petella.

tive, aspirating the effusion and applying a Robert Jones bandage reinforced with medial and lateral slabs, and the results have been satisfactory. If radiographs are taken some weeks after injury, new bone can be seen along the medial border of the patella on the skyline view (Fig. 18-8). Others have argued in favor of repairing first dislocations when there is arthrographic evidence of a capsular tear. I have been unable to trace any review comparing operative with nonoperative methods. When we looked at the outcome of 28 acute first-time dislocations treated conservatively, we found that one child in six will develop recurrent dislocation, and these can be treated by realignment. Two children in six will have minor symptoms, and five out of six show radiologic signs of patellofemoral dysplasia. It is our impression that a dramatic acute dislocation occurs in a normal knee, and the dislocation does not recur. Recurrent dislocation, on the other hand, begins "not with a bang, but a whimper," because the cause is anatomic and not traumatic.

Recurrent Dislocations

Recurrent dislocations in growing children should be managed by semitendinosus tenodesis.[1] This is preferable to transfer of the tibial tubercle, which frequently produces genu recurvatum owing to growth arrest of the anterior part of the tibia. Transfer of the tendon of semitendinosus into the patella has excellent results.

Intra-articular Dislocation

In this variety of dislocation, first described by Middelfart, the patellae pitch poles.[6] The upper border lies aimed at the joint line. Closed reduction under anesthesia is usually successful (Fig. 18-9).

INJURIES OF THE EXTENSOR APPARATUS

All the force of the quadriceps muscle is focused on the patella and the tibial tubercle. The lower pole of the patella and the tibial tubercle can be avulsed during the course of running, jumping, and kicking. They are often injuries of the take-off leg. Acute injuries result in displaced fractures while chronic repetitive injuries produce the Sinding–Larsen–Johansson lesion of the patella and the Osgood–Schlatter lesion of the tibial tubercle. Children with fractures of the tibial tubercle commonly show a preexisting Osgood–Schlatter lesion.

Patella

The characteristic avulsion fracture in childhood occurs at the lower pole. It has been named the sleeve fracture by Houghton and Ackroyd because the cartilaginous lower pole of the patella is plucked off with little or no bone.[4] Diagnosis is difficult (Fig. 18-10). Radiograph the other knee to check the height of the patella. Recognition is important, because some of the articular surface of the patella is displaced with the fragment. Without treatment an extensor lag will remain and a pseudarthrosis will develop. Open reduction, repair of the retinaculum, and rigid internal fixation of the fragment and cast immobilization for 4 weeks are necessary to secure healing. It is a bit like sewing two rope ends together. If you are not confident about the repair (or you imagine effect of the postanesthetic-fluothane shakes), insert a wire loop between the patella and the tibial tubercle for protection.

Transverse fractures through the substance of the patella are common, except in older teenagers. When they are widely separated they are best treated by the ASIF technique (parallel Kirschner wires and a tension band), but the majority are not sufficiently displaced to require anything more than aspiration of a tense effusion and a Jones bandage reinforced with medial and lateral slabs. After a week or two, this is changed to a cast. Total immobilization time need not exceed 4 weeks. Occasionally marked overgrowth follows injury in infancy (Fig. 18-11). Excision is occasionally indicated.

A bipartite patella is occasionally confused with a fracture. The ossicle is always in the upper outer quadrant, has rounded edges, and is not tender.

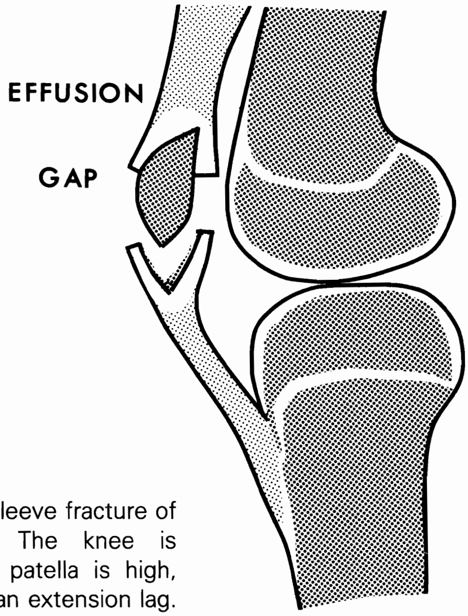


Fig. 18-10. Sleeve fracture of the patella. The knee is swollen, the patella is high, and there is an extension lag.

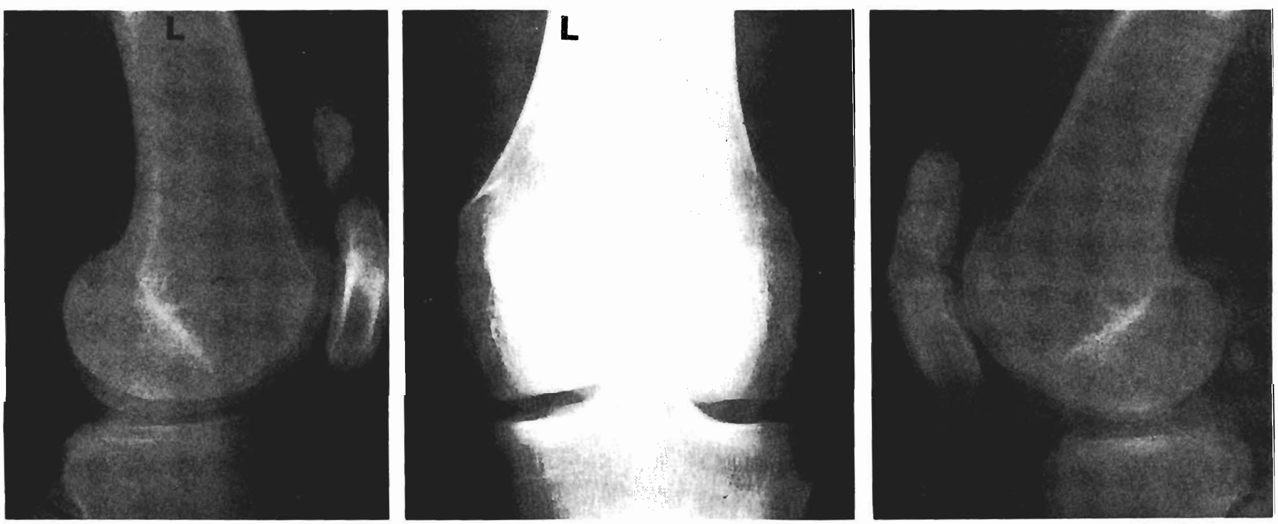
Avulsion of the Tibial Tuberosity

The tuberosity is only susceptible to avulsion for a brief few years—between ages 13 and 16. Like other Type-III injuries, it only occurs when the growth plate is partially closed. Hence growth is never disturbed. The plate under the tuberosity remains open when the plate under the plateau has closed. Watson Jones described three types, and Ogden and associates have recently looked at this again (Fig. 18-12)[10,13].

Watson Jones types are as follows:

1. The tubercle is hinged up without displacement of the proximal base. Closed reduction and a stovepipe cast in extension for 6 weeks is sufficient treatment.

Fig. 18-11. The result of fractures of the patellae in a boy aged 2 years when he was dragged on his knees behind a milk van, losing much of the skin off his knees. At the age of 16 both patellae were enormous and painful. A bilateral patellectomy has produced a good result.



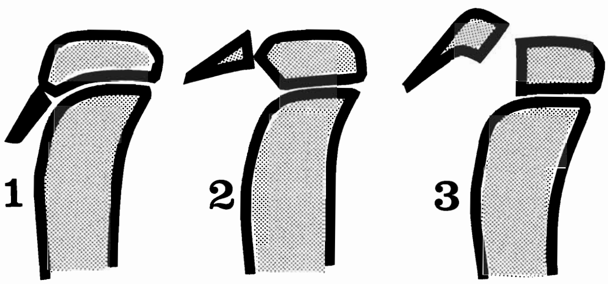


Fig. 18-12. Watson Jones classification of injuries of the tibial apophysis.

Fig. 18-13. Roy was an excellent jumper at the age of 14. He felt something pop on the takeoff leg, so he tried the jump again. On the second takeoff he collapsed with a comminuted avulsion of the tibia tubercle—Type II. The patella is high. He could not extend the knee actively. Open replacement put him back on the track.

2. The hinge fractures so that a small portion of the tubercle is avulsed and retracts proximally.
3. The tubercle, together with a portion of the articular surface, is displaced. There may be soft-tissue interposition of the periosteum or meniscus.

Good results are obtained by open reduction and internal fixation of Type-II and Type-III injuries. Pins, K-wires, and screws can be used with equally good effect (Fig. 18-13).

INTRA-ARTICULAR FRACTURES OF THE FEMUR

The posterior part of a femoral condyle may be displaced. This may be replaced with a compression screw; through a long posterolateral approach one of the heads of gastrocnemius is lifted from the femur. The fragment must be replaced without devascularizing it (Fig. 18-14). Type-III injuries are unusual and should be anatomically reduced with a transepiphyseal screw. Type-IV injuries will produce partial growth arrest and a disturbed joint if not reduced and held with internal fixation (Figs. 18-15, 18-16).

FRACTURES OF THE TIBIAL PLATEAU

Tibial-plateau fractures are rare, except in children with osteoporosis. Oblique radiographs may be required to see these fractures; gentle stress examination films under anesthesia and arthrography may assist in assessment. Aspiration eases pain. Protection in a three-point molded stovepipe cylinder for 6 to 8

Fig. 18-14. Separation of the posterior part of the femoral condyle. This is an unstable injury. It was held with threaded Steinmann pins inserted through the nonarticular surface of the femur. Girl aged 14 years.

Fig. 18-15. Comminuted Type-IV injury. Without open reduction this would certainly have undergone growth arrest. Two years later the knee is slightly enlarged but functions well. Some crushing of the growth plate must have occurred, but slight enough for growth to continue. (Courtesy of Dr. T. Barrington.)

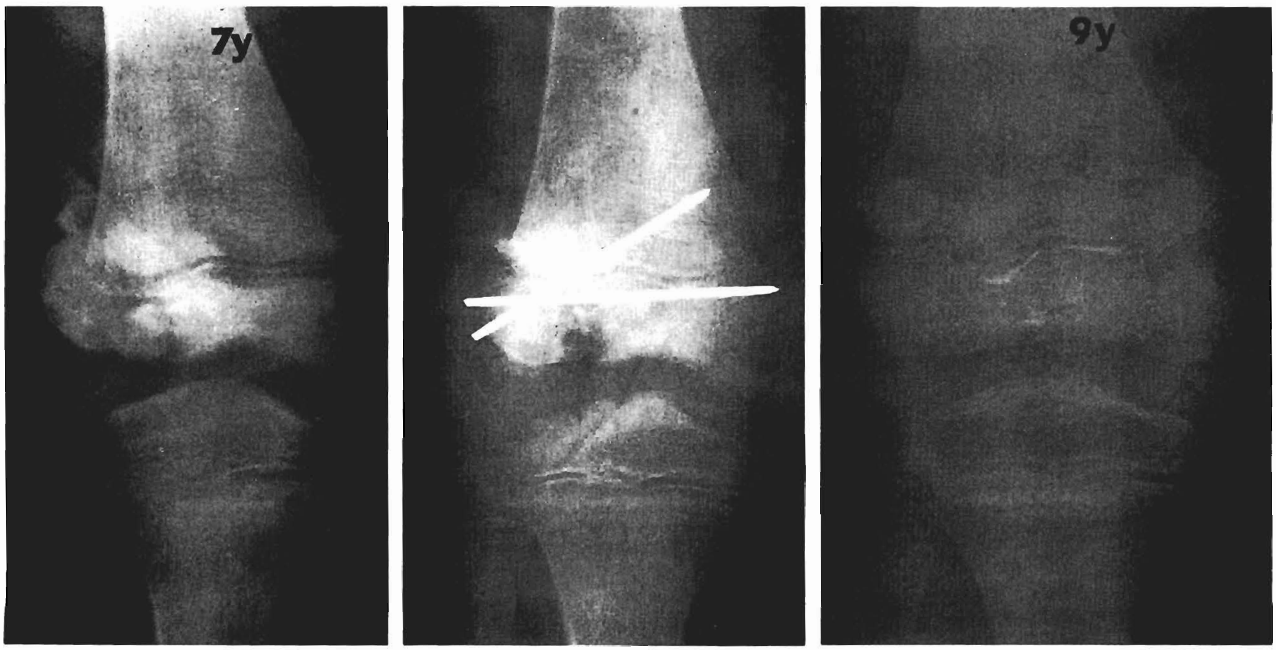


Fig. 18-16. Neglected Type-IV injury sustained at age 2½ years. A bony bridge between epiphysis and metaphysis partially arrests growth. (Courtesy of Dr. Lipmann Kessel, who collected it from a source he was sworn not to divulge.)

weeks has been sufficient, in my slight experience. Warn the parents to expect a slight valgus deformity.

LIGAMENTOUS AND CAPSULAR INJURIES

Seven years ago I wrote, "Complete ligamentous disruption occurs only after growth-plate closure." Wrong. Recently several excellent papers have described ruptures of the posterior cruciate, anterior cruciate, and medial and lateral collateral ligaments in more than 20 children with open growth plates. These have required repair.

The posterior cruciate has been avulsed from its femoral attachment with a flake of cartilage. There is no bone, so it does not show on x-ray film. The injury has resulted from putting a leg out to stop a merry-go-round. Posterior swelling and a posterior drawer sign (confirmed on stress radiographs) have made the diagnosis. Reattachment by means of drilling holes through the medial femoral condyle has yielded better results than ignoring the injury.

The anterior cruciate ligament has been avulsed from the tibial attachment—this has been well described for many years as a fracture of the tibial spine, but some "in-substance" tears have also been described. What is fascinating and new is the observation by Clanton and associates that fractures of the tibial spine may be accompanied by tears of the medial collateral ligament and peripheral detachment of the medial meniscus.[2] This is the childhood equivalent of O'Donaghue's triad. Perhaps it should be called Clanton's triad. The medial collateral ligament has been torn in its midportion twice as frequently as it has separated from the tibia. A torn meniscotibial ligament has left the meniscus detached. The results of suturing the meniscus back are better than meniscectomy. But we are still far from knowing whether a Grade-III medial ligament injury should be repaired at operation or protected in a cast while it scars up. If arthroscopy shows a detached meniscus or a ruptured meniscus, the knee should be repaired.

Minor Ligamentous Injuries

During the ski season many children under the age of 10 arrive with pain and tenderness where the medial ligament crosses the joint line. They hold the knee flexed, but it can be coaxed straight. The knee is stable. They have a Grade-I medial collateral ligament injury. Left alone they will not put the leg to the ground for 2 to 3 weeks. A walking stovepipe cast for 3 weeks provides comfort, even if it does nothing for healing strength.

Grade-II medial collateral ligament injuries have pain, tenderness, and some laxity, but no gross instability.

Ligamentous injuries may be the silent partners of fractures of the shaft of the femur and tibia. Always look for a knee effusion in these fractures, because the unstable knee may be more memorable than the fracture. Walker, noting that patients with a fracture of the midshaft of the femur had 48% knee ligament injuries, advocated careful examination, arthroscopy, and early repairs.[12]

Practical Management of the Acutely Injured Knee Without Fracture

Perhaps in the future all patients with these knee injuries will have stress radiography and an arthroscopy.

Certainly arthroscopy for adults with a Grade-I ligament injury and an acute traumatic hemarthrosis has uncovered much unsuspected pathology and has shown the unreliability of a history of "popping." The Cincinnati series, for example, revealed 44% with a complete cruciate tear (yet only 24% of those with a complete tear had a positive Lachman test), 50% with a torn meniscus, 2% with a complete tear of the medial ligament, and 8% with a chondral fracture. Are children and adolescents just small adults when it comes to knee injuries? Probably not. Most complete cruciate disruptions in childhood are radiologically apparent, because the tibial spine is avulsed.

Our current practice is to:

1. Look for effusion and instability. Aspirate any effusion and carry out examination under a general anesthetic or after local anesthetic has been injected intra-articularly. If there is cruciate instability, a pivot shift sign or block to full movement or clunking in the knee on arthroscopy is performed.
2. Look for extension block. When there is a block to full extension but no effusion, a day or two in traction will extend the knee fully. If it does not, an examination under anesthetia and arthroscopy are arranged.
3. Look for signs of patella dislocation. If there is tenderness around the patella and a positive apprehension sign, oblique and axial radiographs of the patella are requested.

Definitions*

Sprain—an injury limited to a ligament
Strain—a stretching injury of a muscle or its tendinous attachment to bone
Sprain: Grade I—a tear of a minimum number of fibers of the ligament with localized tenderness but no instability
Grade II—a disruption of more fibers with more generalized tenderness but no instability
Grade III—a complete disruption of the ligament with resultant instability

THE MENISCUS IN CHILDHOOD†

Meniscal pathology is the second most frequent indication for arthrotomy in the growing child. (Patellar stabilization is the most common.) In the past 10 years at the Hospital for Sick Children, 96 meniscectomies were performed for torn and discoid menisci.

The typical patient was a 12- or 13-year-old athletic boy with a history of sport trauma. Girls were not immune to meniscal problems, but more often had patellofemoral pathology. Tears presented with a history of 8 to 9 months; discoid menisci had been troublesome for years. Specific complaints, such as buckling and locking, occurred in a minority. Physical examination proved more useful. Quadriceps wasting and joint line tenderness were seen in most, but the traditional signs, McMurray's locking and effusion, were seen in less than half.

Diagnosis by implication was difficult. Errors, we feel, are best avoided by deferring judgment in acutely injured knees and by the use of arthrography and arthroscopy. No knee should be opened without prior arthroscopy.

Treatment

With an established diagnosis of a torn meniscus, removal is warranted. A word of caution: hypermobile menisci or discoid menisci should be left in until a tear and significant disturbance of function is proven. At surgery much the same type of tear seen in adults can be anticipated, but a bucket-handle tear is more frequent in children. Discoid menisci account for one-third of our meniscectomies. Usually they are not a problem until they tear, which they are more prone to do than a normal semilunar meniscus.

We have conducted studies of late embryonic and fetal knees and concluded, as have others, that a discoid meniscus is *not* a persistence of a normal stage in fetal development.

What is the outcome of menisectomy in childhood? When we reviewed our 61 cases after several years, most had excellent results. Since then it has become clear that menisectomy leads to joint breakdown. In some series about one normal meniscus was removed for every two abnormal ones; with good reason these children complained most afterward. In Zaman and Leonard's study of children 7

*Standard Nomenclature of Athletic Injuries. American Medical Association, Committee on the Medical Aspects of Sports, 1968

† The following two sections were contributed by Dr. Robert McMurty.

years after menisectomy only 42% were free of symptoms and only 27% had a normal radiograph. Medlar and associates had similar findings.[5]

The lessons to be learned are: arthroscopy before arthrotomy; do not remove normal menisci; consider meniscal suture or excision of a bucket handle before contemplating meniscetomy; and leave menisci alone, unless they cause a lot of symptoms. A chance to do a menisectomy is not a chance to cure; it is more like a visit to a loan shark.

LOCKING

The hallmark of a locked knee is incomplete extension owing to mechanical obstruction. True locking, however, must be distinguished from apparent locking.

Intra-articular mechanical obstruction is due to bone, cartilage, or both, being displaced and jamming between the articulating surfaces of the femur and tibia. This may occur with a dislocated patella that has caused an osteochondral fracture; after reduction, full extension is not restored. Torn meniscus and other internal derangements also occur, but less commonly.

Apparent locking is characterized by painful resistance to extension owing to hamstring spasm. The distinction between true and apparent locking can only be established by relieving pain so that the patient can relax. Generally this requires traction, time, and sedation, or even anesthesia.

"Benign locking of childhood" is a condition we have confronted quite often. It is the most common cause of "locking" in children under the age of 10 years. There is a vague history of trauma after which the child limps about on a flexed knee. The only physical sign is block to full extension. After a few days in traction, full extension returns, and the child becomes normal again. The cause is unknown.

SUBLUXATION OF THE PROXIMAL TIBIOFIBULAR JOINT

The proximal tibiofibular joint may be disrupted as an isolated injury or in association with a fracture of the tibia. Instability may produce clicking, locking, or giving way. Ogden reviews this subject well.[9] As in disruption of the sternoclavicular joint, the diagnosis is easily overlooked if too much reliance is placed on radiographs. Closed reduction is usually successful.

Fig. 18-17. No one suspected that a small laceration over the front of the knee was deep. But the air arthrogram effect on a routine film indicates a penetrating injury.

PUNCTURE WOUNDS AND FOREIGN BODIES

Hopefully most physicians will debride, irrigate, and close obvious open knee injuries. But some are easily missed. The knee is a subcutaneous joint. Small cuts may enter the knee; the wise emergency surgeon radiographs these for intra-articular air to make the diagnosis. Children also drive needles into their knees as they creep about on the broadloom (Figs. 18-17 to 18-19).

LAWN-MOWER INJURIES

Power mowers produce devastating injuries when they run over a child. Tissues are cut, lost, devascularized, and infected. The foot is most commonly injured, but we have seen the worst results from running over the flexed knee (Fig. 18-20). Even the most careful repair often leaves a stiff knee with a progressive angular deformity and a leg-length discrepancy. The angulation may be due to loss of growth cartilage or condyle so that looking for a bony bridge to excise is fruitless. Many end in amputation after well-meaning but unsuccessful salvage procedures.

Power mowing should be reserved for adults who wear tough shoes, who avoid wet grass, and who, on a slope, keep the mower on a lower level. Children and pets should be kept away.

REHABILITATION

Knee exercises are important after any injury. Sending children for physiotherapy is seldom as straightforward as it seems, and I have found it easier to hand out a knee exercise sheet, which is reproduced on page 295.

Fig. 18-18. Another laceration. The habit of always requesting a radiograph resulted in the disclosure of a piece of lead glass.

Fig. 18-19. This girl had no idea there was a needle in her knee. Presumably it had entered while she was crawling around the floor. Removal can be difficult when the needle lies hidden under a meniscus.

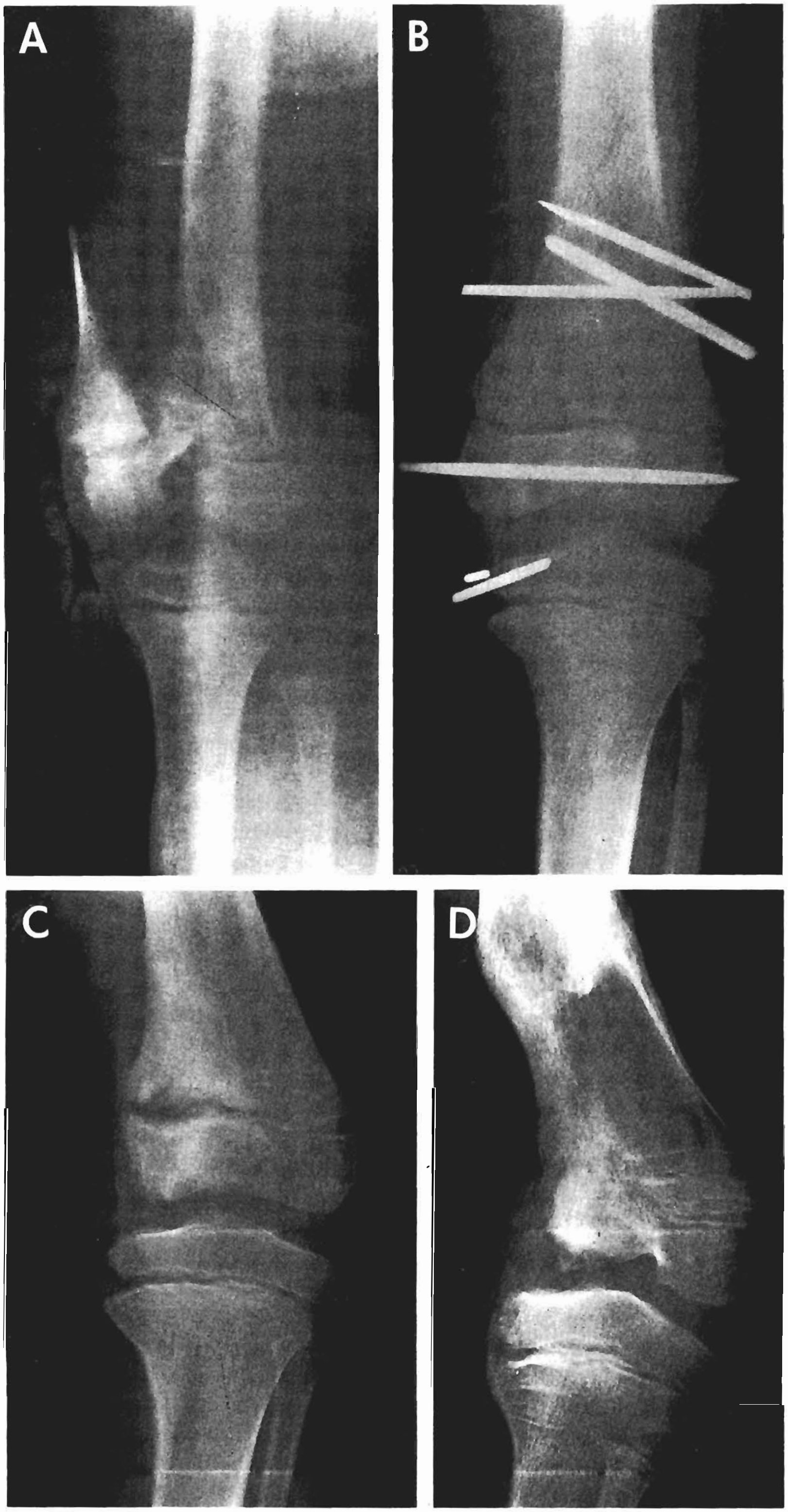


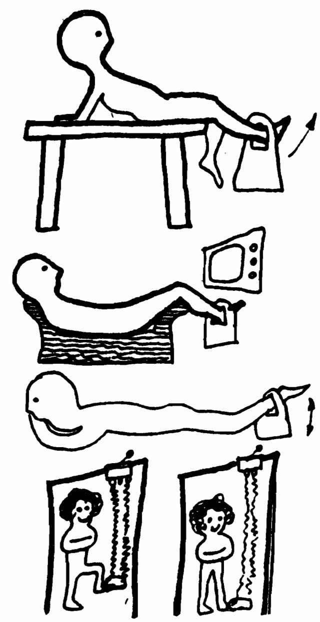
Fig. 18-20. Lawn-mower injury in a 10-year-old. *(A)* Initial. *(B)* After debridement. *(C)* Four months later. There has been a low-grade infection. Note the growth lines on the medial distal femur. *(D)* At 1 year and after an osteotomy the leg is angulated, short, and stiff.

KNEE EXERCISE SHEET

The Best Way to Avoid Injuring The Knee

1. Get into shape before going in for competitive sports.
2. Avoid deep knee bend and squatting exercises.
3. Check skiboot bindings regularly.
4. Avoid working out on a swollen painful knee.

Quadriceps Exercises



The key to a strong knee is a strong quadriceps muscle. The muscle is naturally thin in a few people. In everybody it becomes thin very quickly after the slightest injury. Just walking about does nothing to strengthen the muscle. Special exercises are required.

1. Get a plastic shopping bag and fill with 4 pounds of weight. Use cans of soup, packets of sugar, stones and so forth. Use scales to weigh these if the weight is not printed on the label.
2. Sit on the kitchen table; lean back.
3. Counting to ten, slowly lift the weight—keep the knee straight while you count to ten and then let it down slowly, counting to ten. Do it ten times. The quadriceps should ache after this if you are doing the exercise well.
4. Repeat this exercise two or three times daily.
5. When you have mastered 4 pounds increase the weight until you reach 30 pounds.

For Something Different

1. Watch the TV from a reclining position on the chesterfield and do the exercise twice every time a commercial comes on.
2. To strengthen the muscle at the back of the knee—the hamstrings—lie prone and lift the weight.
3. To strengthen the quadriceps and help the knee to bend do the following. Fix a spring chest expander to the top of the door frame (a nail over the laundry door will do); put the foot into the stirrup and push down, then let it up slowly. Repeat this ten times.
4. Bicycle.

The Injured Knee

Sudden twisting or a bad fall may stretch ligaments and cause bleeding or water in the knee. Children can repair most of these injuries given time, rest, and muscle-strengthening exercises.

At the beginning the treatment depends on the particular kind of injury, but after a short time most injuries require the same care.

1. Rest the knee:
   Avoid a lot of walking and sports while the knee is swollen.
   Avoid a lot of standing.
   Avoid Physical Education at school.
2. Do quadriceps exercises at least two to three times a day. This should be done as an alternative to Physical Education at school.
3. Wear tensor bandage to limit knee movement. Reapply at least twice a day to keep the pressure even. If the leg swells below the knee, the bandage is too tight.

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19/ Tibia

Tibial fractures heal so much more readily in children than in adults that they should be a joy to treat. The majority of children have a cast applied without an anesthetic and only require a pair of crutches, a lift on the shoe, and a note to arrange transportation to school. However, there is more variation to these fractures than is generally realized. If foresight is to be used to prevent problems, the fracture should be classified first. The classification scheme for proximal tibial injuries is depicted in Figure 19-1.

PROXIMAL GROWTH-PLATE INJURIES

Growth-plate injuries are more common in the distal femur than in the proximal tibia, because of the arrangement of the ligaments. The medial collateral ligament of the knee is attached to the tibial *metaphysis* and the femoral *epiphysis,* protecting the tibial growth plate from valgus injuries. Bohler, in 1951, could trace only 12 authentic cases of separation of the proximal tibial epiphysis in world literature.[1] The rarity of the injury is fortunate because two of the three separated epiphysis at our hospital produced vascular problems owing to the proximity of the popliteal trifurcation.

Stress views are sometimes needed to demonstrate these injuries (Fig. 19-2). Shelton and Canale have recently reviewed 39 cases: Type I—23%; Type-II—44%; Type-III—26% Type IV—8%. The average age was 14 years, and one-half were due to contact sports and one-quarter were due to motorcycle accidents. The results are excellent so long as neurovascular deficits are corrected and reduction is accurate.

PROXIMAL METAPHYSEAL FRACTURES

Masquerading as innocent little cracks with no particular reputation for evil, proximal metaphyseal fractures are among the worst. In the course of treating about 1000 tibial fractures in children, we have found that fractures in this region have been responsible for amputation (a late result of a Volkmann's ischemia) and the only corrective osteotomies. Two distinct types of fracture occur in this region.

Arterial Hazard Fracture

The anterior tibial artery passes over the proximal edge of the interosseous membrane into the anterior

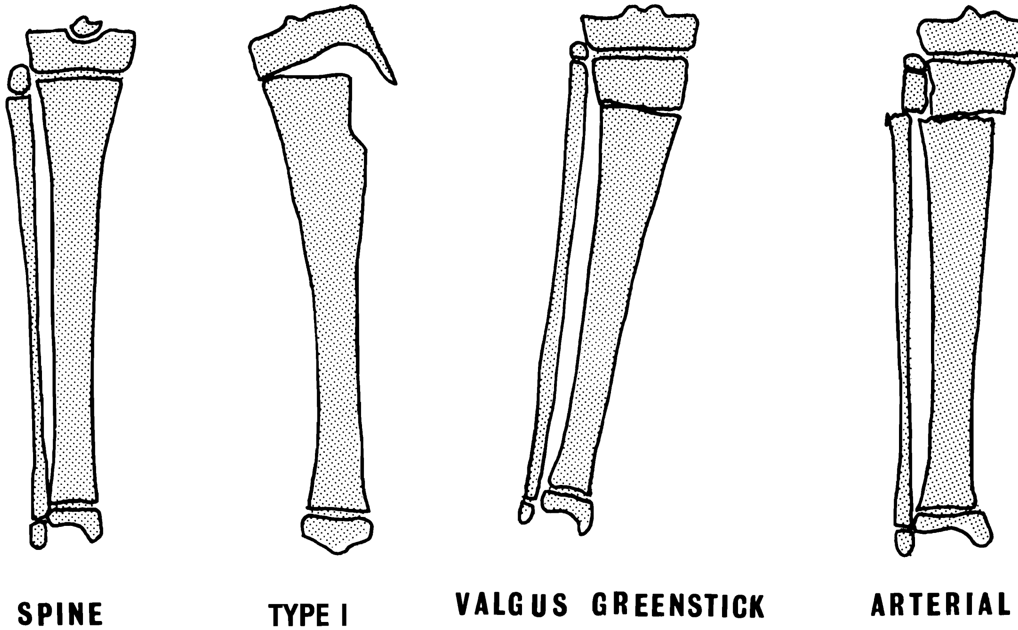
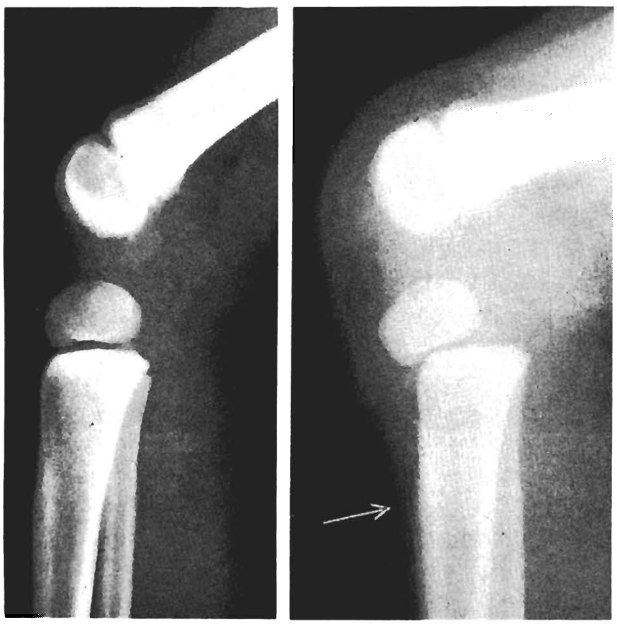


Fig. 19-1. Classification of high tibial fractures.

Fig. 19-2. Stress films were required to demonstrate this injury.



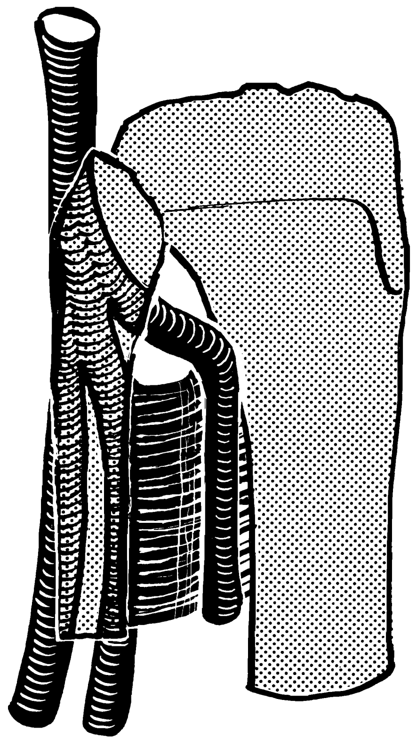


Fig. 19-3. Fractures of the tibial metaphysis can easily injure the trifurcation.

compartment and is closely applied to the tibia (Fig. 19-3). Because of this fixed position, the artery may be compressed, stretched, or torn. If it is stretched, the posterior tibial artery may also be occluded. The initial sign of vascular damage may be a cold, pale, pulseless leg that in about an hour, becomes anesthetic and paralyzed. Muscle ischemia alone is less dramatic; a warm skin has misled many.

When there is a high fracture of the fibula, the temptation to blame the neurologic signs of ischemia on local lateral popliteal nerve damage should be resisted. Treatment is urgent. Realignment of displacement and angulation may restore the circulation. If not, the vessels must be explored. Ideally, a vascular surgeon and an orthopaedic surgeon should collaborate.

Valgus Greenstick Fracture

In children between the ages of 3 and 10 years, metaphyseal greenstick fractures have attracted much interest. The cortex is slightly open on the medial side of the tibia. On radiographs, the amount of angulation is very unimpressive, and most of these fractures are accepted as undisplaced and are casted in situ. When the cast is removed, an unacceptable degree of knock-knee comes as an unpleasant surprise (Fig. 19-4). It does not improve with time. But if anyone had taken the trouble to look at the leg itself initially in the fully extended position, the deformity would have been apparent. Unfortunately, children hold the injured leg flexed, and in the flexed position the deformity is not apparent. The deformity should be corrected under anesthesia, and the leg should be immobilized in extension with varus molding (Fig. 19-5). Pollen advises wedging the cast.[5]

Taylor drew attention to this injury and suggested that valgus was due to the overgrowth of the tibia (because of fracture hyperemia) while the intact fibula acted as a tether.[7] Overgrowth plays a part, but it has been our experience that if the fracture is reduced, the leg remains straight. Weber explored two cases and found interposition of a flap of soft tissue.[8] Both the lower part of the pes anserinus and thick

Fig. 19-4. Greenstick fracture of the proximal tibial metaphysis. This was treated by a long leg cast with the knee flexed. Persisting deformity and overgrowth have produced the characteristic valgus deformity, which required osteotomy.

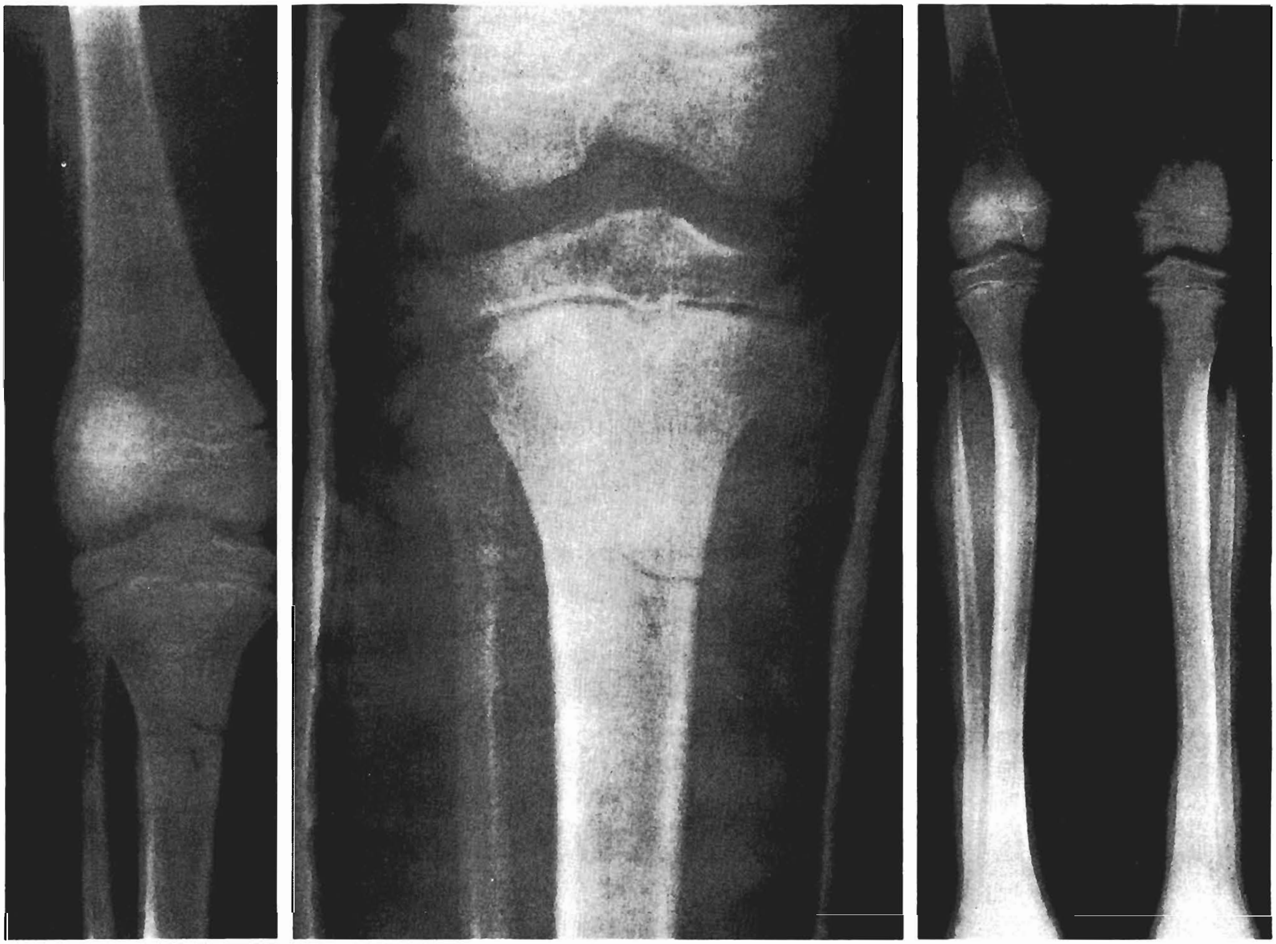


Fig. 19-5. This degree of valgus angulation is easily overlooked. After reduction under anesthesia the position is improved. Four years later the right tibia has slight valgus deformity and is slightly longer.

periosteum avulsed from the lower fragment were trapped. The gap was cleared and an anatomic reduction achieved. One case developed quite minimal valgus, and the other was straight but 1 cm longer a year and a half later.

Houghton and Rooker found that dividing the periosteum around the medial half of the proximal tibia produced valgus deformity.[4] This may be due to mechanical release of the restraint the periosteum imposes on the growth plate.

Perhaps there is truth in all the theories. I am planning to explore the next one I see and then repair the periosteum.

Osteotomy to correct the established deformity is hazardous and has been only moderately successful. The correction has been inadequate in some, and these children have required a second osteotomy. The fibula should be divided, and an anterior compartment fasciotomy is *essential* to minimize the risk of a compartment syndrome.

DIAPHYSEAL FRACTURES

Diaphyseal fractures are common and easy to treat in children. Last year, for example, we treated 101 fractures of the tibia. In the majority of children (70%) the fibula was intact (Fig. 19-6).

Most of the fractures (80%) were stable and undisplaced, because periosteum is more resilient than bone in a child; in the adult, bone is stronger than periosteum, so the periosteum is almost always torn when the bone is broken. In a child, the recoil of the intact periosteum holds the fracture in good position so that the majority of fractures can be casted without an anesthetic and without hospital admission. Only one child, who had been sent home, required admission the next day because of edema.

The remaining 20% of children had displacement that required correction. Displacement was much more common when both bones were fractured than when the fibula was intact (50% compared with 5%). The displacement could often be corrected by molding the cast, but a few children with gross displacement required an anesthetic. Only 5% of children redisplaced in the cast and required further correction. Only 10% of children were admitted.

Children of all ages were seen: babies who had been dropped, infants who had fallen down stairs, teenagers (who may also damage knee ligaments), injured in sports or road accidents.

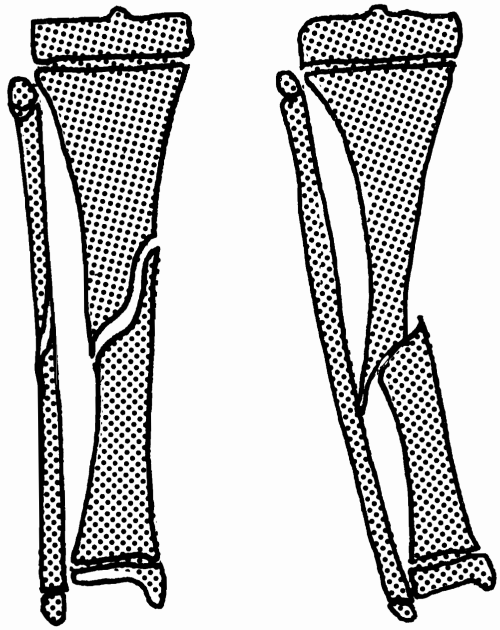


Fig. 19-6. In children the fibula is commonly intact.

Treatment

Because a fracture of the child's tibia unites certainly and quickly and does not lead to knee stiffness, we use an above-knee cast and do not feel bound to encourage early weight bearing. Only when reduction is necessary or when the leg is very swollen, do we admit these children to the hospital.

Apply the cast with the child lying down and the leg hanging over the side of the table. Use stockinette, because at some time you will want your assistant to hold the toes; without stockinette his grip will fail at the critical moment. Pad the cast. Ensure that rotation is correct by flexing the knee to 90 degrees and by comparing the thigh–foot angle on both sides. Try to hold the ankle at 90 degrees in midshaft fractures; but if this makes the tibia "dish," then let the foot drop into some equinus. Apply the lower half of the cast and then extend the knee to complete the thigh portion. For a stable fracture, the knee can be fully extended to facilitate walking. If you wish to prevent walking on an unstable fracture, flex the knee to 90 degrees.

Then radiograph the limb. What is an acceptable position? Rotation should be accurate. The knee and ankle are hinge joints so that malrotation is not masked. Avoid valgus angulation, which leaves such an obvious bump on the subcutaneous border of the tibia that parents always grumble. Valgus and varus should be kept less than a measured 5 to 10 degrees. Hansen and associates measured the remodeling potential and concluded that angulation improved by only 10 degrees.[3] However, they measured realignment of the shaft while it is realignment of the articular surfaces that count. Anteroposterior angulation should be kept below 10 degrees also. Overriding up to 1 cm is acceptable. The fractured tibia overgrows by 5 mm.[2,6]

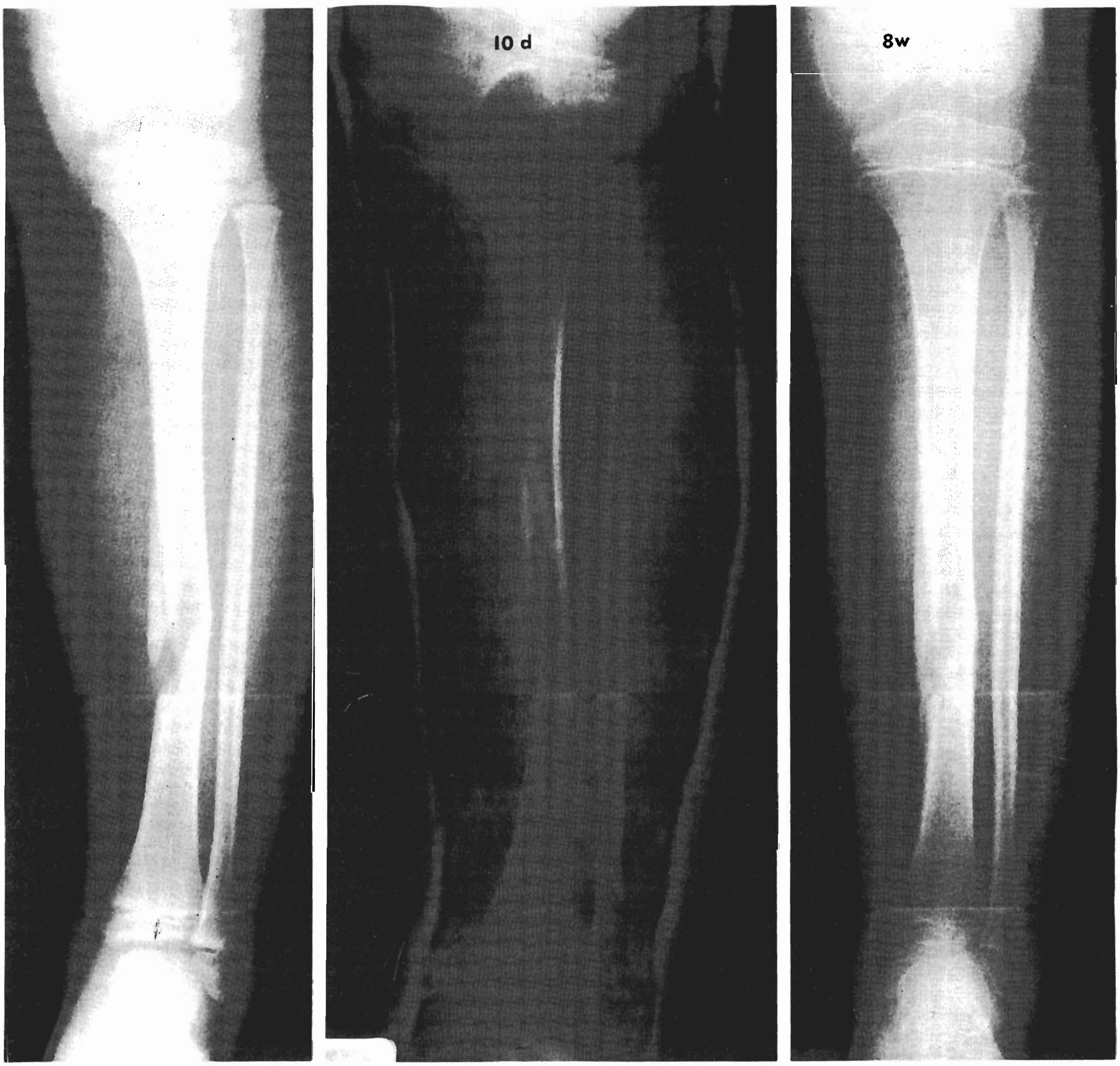
Corrections can be made by wedging the cast at the time or after a few days. The leg should be elevated for 3 or 4 days. Few children will want to bear weight before a week or two. A plaster boot is less trouble for everyone than a rubber heel, but it does need thick, plaster slabs on the sole of the cast. Some children need cajoling to prevent bone atrophy. A cast change is seldom needed. The leg should be radiographed every 2 to 3 weeks. The cast is usually removed after 6 to 8 weeks. In infants, the bone unites in 2 to 3 weeks while in some teenagers it will take 10 to 12 weeks. After 6 weeks we generally use a patellar-tendon-bearing cast.

When the cast is removed, some children will start to walk unaided immediately, but others need crutches for a week or two. Leave the children to decide for themselves.

A limp, owing to calf wasting, persists for several months after the cast is removed. Warn the parents about this to save many anxious phone calls.

There is almost no place for open reduction. "The trouble with the tibia," said someone, "is that it is so subcutaneous that it's easily opened to abuse." Open fractures should be left open and closed fractures should be left closed. During the past 8 years I can trace only three patients who have been treated with internal fixation; one had a gross degloving injury of the leg with an unstable fracture. Fixed with two screws, he had a superb result, but the bone fractured

Fig. 19-7. A typical varus drift fracture owing to an intact fibula. An artless cast has done nothing to help. A new cast with valgus molding was applied under anesthesia to produce a good result.



through a screw hole 6 years later. Another, with much shortening, was referred late; open reduction and internal fixation was selected to improve the position. The third patient was an Olympic skier with bilateral oblique fractures that, in some way, were thought to justify a single screw in each tibia. Despite much shaking of heads, he made an excellent recovery and was skiing in 9 weeks!

COMMON VARIATIONS

The Intact Fibula

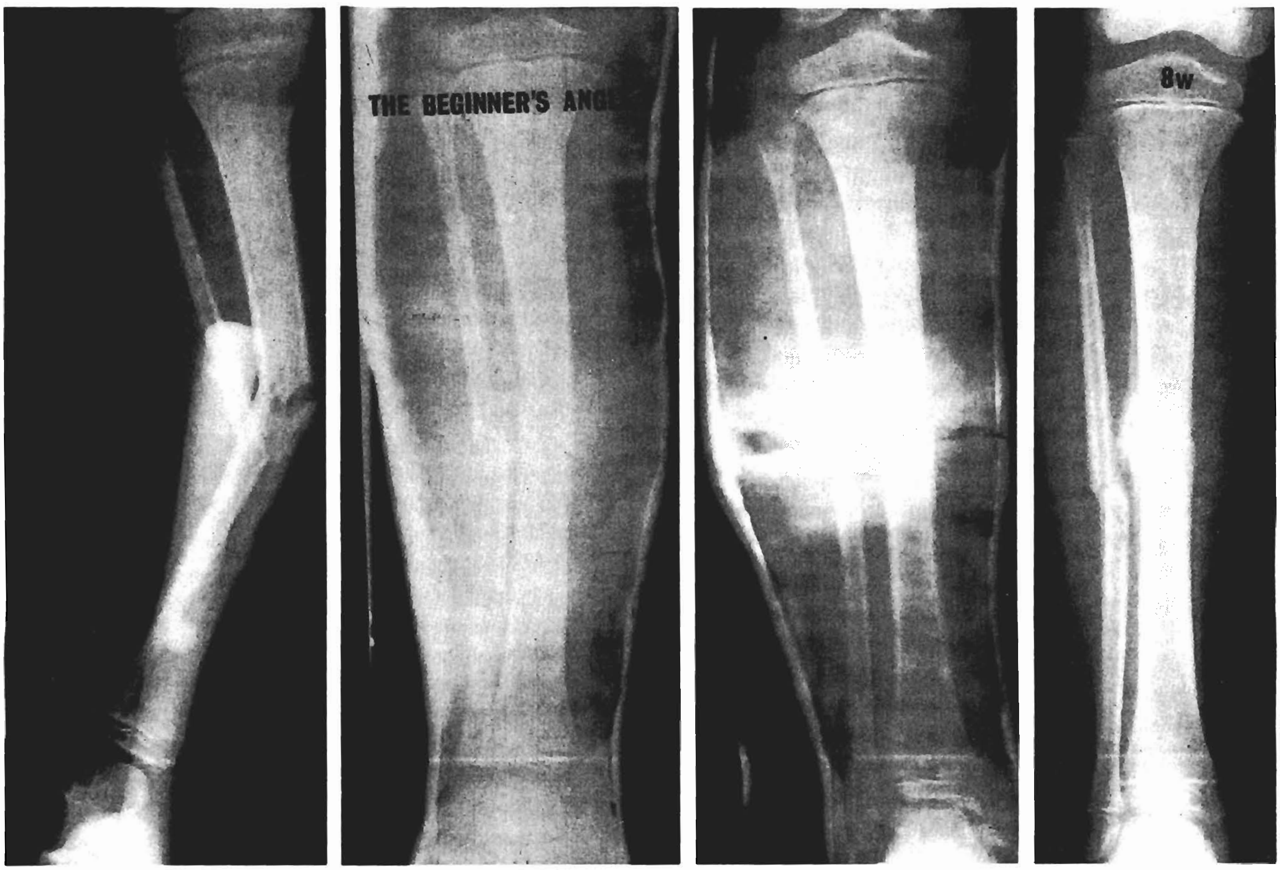
The fibula is a bone that will bend without obvious fracture. If you doubt this, radiograph the normal leg when next you see a child with an angulated fracture of the tibia alone, and compare the shape of the fibula on each side. Fracture of the tibia in children is more commonly associated with an intact, if bent, fibula

The intact fibula struts the bone ends apart. Varus deformity with posterior bowing is a common sequel unless the cast is molded into valgus (Fig. 19-7). The bowing may not be apparent in initial films but commonly develops in the course of 2 or 3 weeks if the cast is not suitably molded. It is a deformity more easily prevented than corrected.

Fractures of the Tibia and Fibula

Longitudinal stability can be achieved in almost all fractures involving both bones of the leg, because segmental fractures, butterfly fragments, and comminution are infrequent in children. Usually the bone ends can be locked, leaving only the problem of angulation and rotation to manage (Fig. 19-8). A good position can usually be obtained. But, if a good position cannot be obtained initially, or if the fracture slips, it is easy to correct rotation and angulation at 2 to 3 weeks when the fracture is sticky. If longitudinal instability is a problem, it is most easily controlled

Fig. 19-8. Most beginners, believing that the leg should look straight, produce valgus deformity. The cast should have a concave medial border. The medial part of gastroenemius is mobile, so the cast should be molded to the medial border of the tibia. The muscles of the lateral compartment are less mobile. Feel this for yourself.



with Steinmann pins above and below the fracture, incorporated in the cast (Fig. 19-9). Leg-lengthening apparatus has been used for children who presented late with more than a centimeter of shortening.

The Limping Infant

Children under the age of 2 years may present with a painful limp owing to a healing fracture a week old. Three percent of our fractures last year were in this category. Apply a cast for a week or two if this appears helpful.

UNCOMMON VARIATIONS

During the past 8 years we have admitted 143 children with fractures of the tibia. Although there are no exact figures for the total number of fractures treated, by extrapolation, these represent the problems from about 1000 injuries.

Open Fractures

Open fractures (2.3% of all fractures) are usually the result of being hit by a car. The wounds are usually small and represent punctures from within. They are easily debrided and we have had no infection, whether antibiotics were used or not. Three patients had runover injuries of the foot; two required skin grafting, and the third required Syme's amputation.

Open fractures (with more than a pinhole wound) should be treated with external fixation, and not with a cast.

Associated Injuries

Head injuries (2.8%), fractures of other bones, and visceral injuries occur but do not influence treatment except for the following.

The Floating Knee. A child usually sustains fractures of the tibia and femur in an auto wreck. Half of

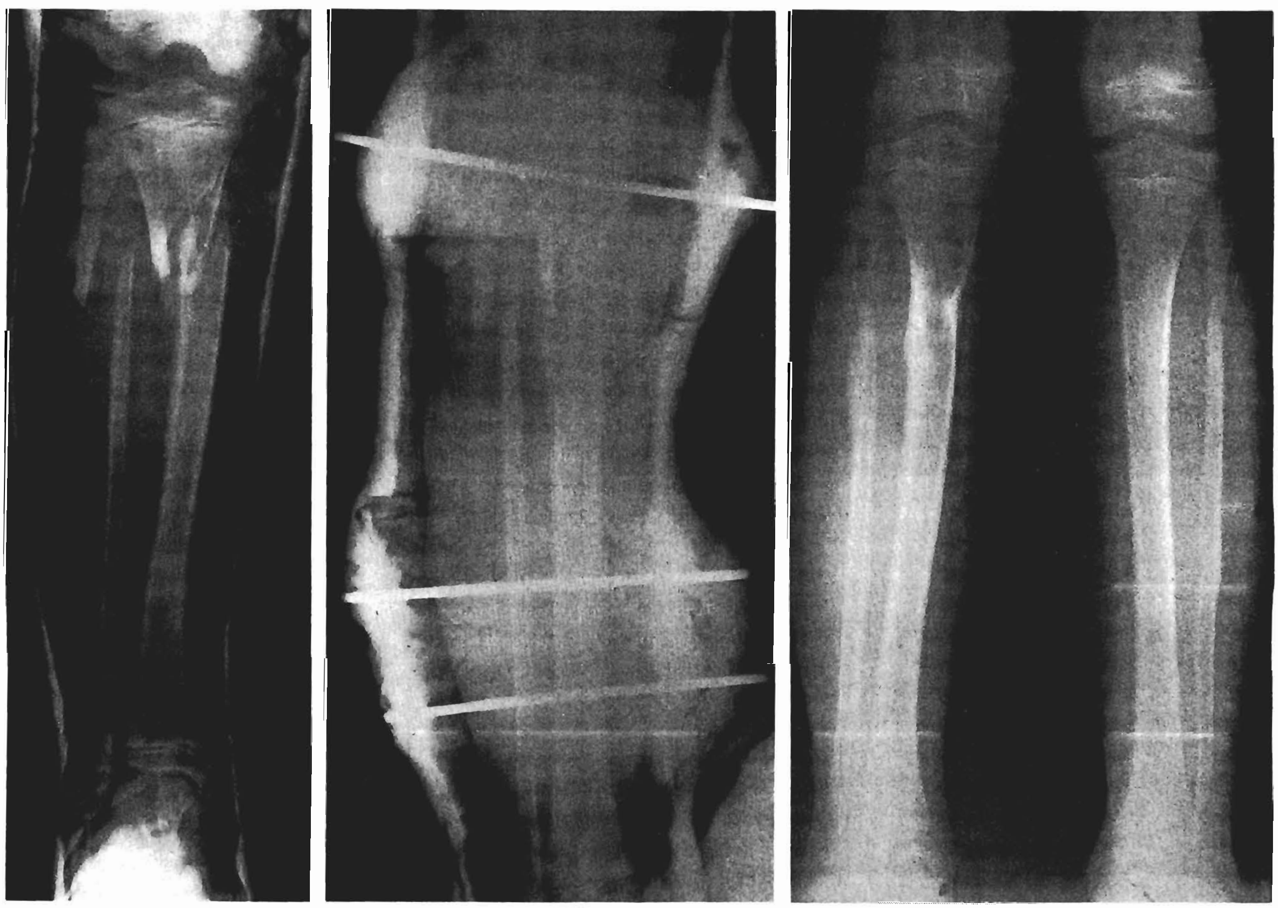


Fig. 19-9. This high oblique fracture in a child with transient decerebrate rigidity was difficult to control. Pins held the position firmly, with the leg in slight varus. Despite this precaution, overgrowth has produced slight valgus.

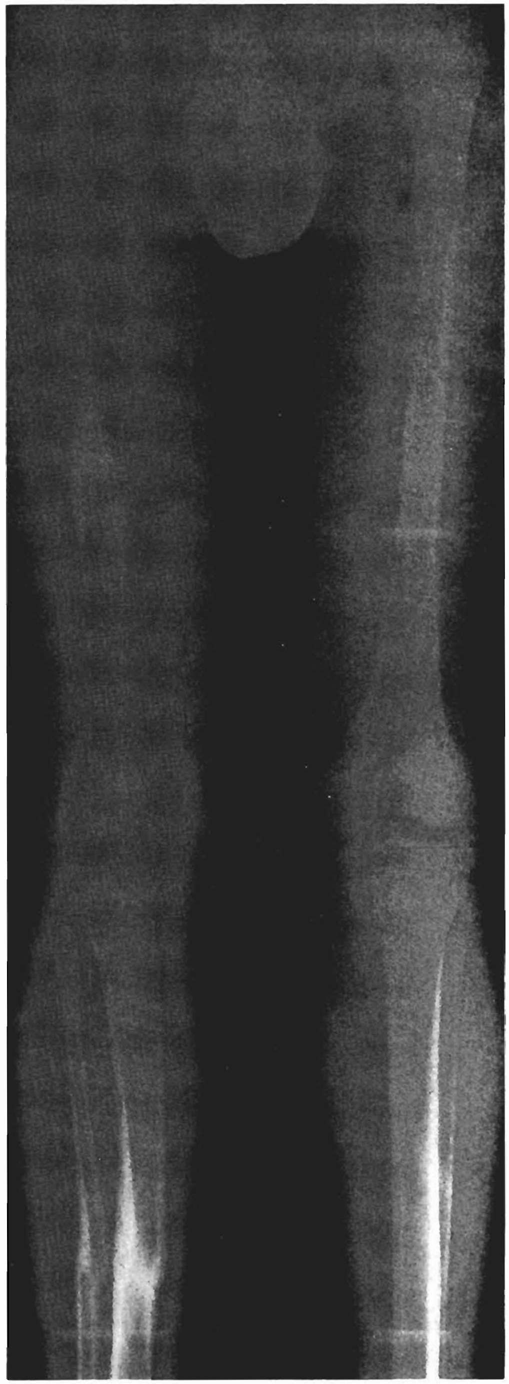
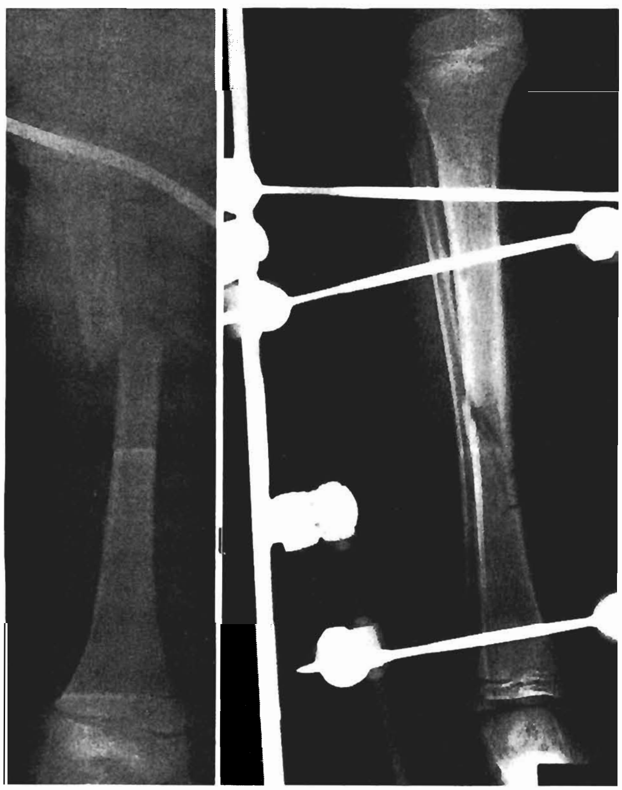



Fig. 19-10. Fracture of the femur and tibia in the same leg. Skeletal traction is applied through a tibial pin placed distally enough to avoid the growing tibial tubercle. A Thomas splint controls the femoral fracture, and a below-knee cast incorporated around the pin controls the tibial fracture. A hip spica was applied at 4 weeks and the child went home. Orthoroentgenogram at 1 year shows that the right leg is 3 mm short.

the children had parents killed in the accident, and this circumstance provided a major challenge in management. Five of the six patients had major wounds elsewhere (Figs. 19-10, 19-11).

The middle fragment must be held with a pin through which traction can be applied to the femoral fracture while the tibial fracture is held in a cast. Where should the pin go? There is no doubt in my mind that the pin should go in the tibia. The pin can easily be incorporated with a below-knee cast. Two out of three femoral pins allowed the tibial fracture to slip, and one of these children needed osteotomy for knock-knee deformity. Three out of three tibial pins were satisfactory.

Fig. 19-11. This 7-year-old cycled into the side of a bus. The back wheels went over this leg. The accident was so sudden that the driver did not have time to apply the brakes, sparing the boy an avulsed, degloved flap. The fracture of the tibia was open and unstable. He was treated by closing the wound with a skin graft over a rotated muscle flap and with Roger Anderson apparatus (to which traction was applied to control the femur). The arrangement was so rigid and permitted such ready inspection of the skin that his care was free of anxieties.



Pathologic Fractures (0.4%). Local lesions in this series included chronic osteomyelitis, nonossifying fibroma, and an undiagnosed area of sclerosis. Not included, though quite common, were fractures in osteogenesis imperfecta, meningomyelocele, polio, and muscular dystrophy.

Miscellaneous Associations

Battered babies (0.2%). The signs closely mimic those of osteomyelitis.

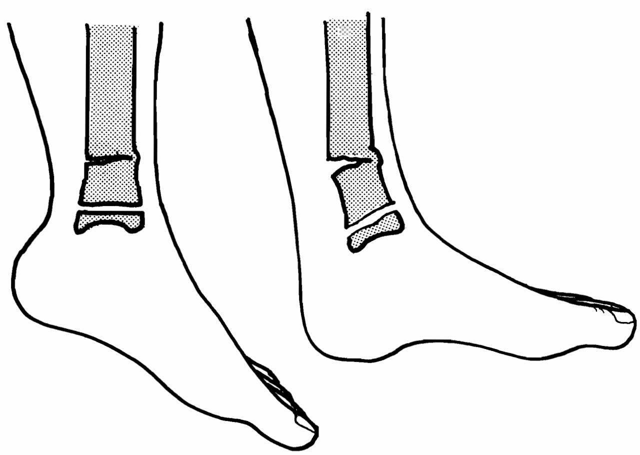
Coagulopathy (0.2%). If replacement therapy is provided for the first few days, the fractures heal normally. One boy had trouble with recurrent knee effusions afterward.

COMPLICATIONS AND PROBLEMS

Vascular Problems

Compartment syndromes are a feature of proximal fractures and runover injuries. At the first suggestion of trouble measure the pressure and prepare for fasciotomy. Fractures just above the ankle contuse the muscle belly of flexor hallucis longus, producing pain on dorsiflexion of the big toe. This closely mimics a compartment syndrome and can only be distinguished by pressure measurements.

Fig. 19-12. Robert Gillespie's fracture. Placing a fracture of this type in a cast with the ankle at a right angle produces deformity.



Nerve Palsies

If the cast is tight over the fibular head, a lateral popliteal nerve palsy may occur. Avoid this with padding. Remember that some of these are really compartment syndromes.

Remanipulation

Some fractures will slip in the cast and require correction (3%). Angulation is easily corrected, but serious loss of length is more difficult. The choice lies between the use of a leg-lengthening apparatus and open reduction with internal fixation.

ROBERT GILLESPIE'S FRACTURE OF THE DISTAL TIBIAL DIAPHYSIS

This little-known fracture is worth recognizing, as it is a potential source of grief. The injury appears to result from landing on a dorsiflexed foot. The anterior border of the tibia is crumpled while the posterior surface opens, producing slight posterior angulation. Seemingly innocent at first, by the time the cast is removed the angulation has increased to an unacceptable degree. Cast the leg with the foot in equinus to prevent this problem (Fig. 19-12).

METAPHYSEAL FRACTURES

Buckle fractures occur in the young child or the osteoporotic older child. It is customary to cast these for about 4 to 6 weeks.

Ski-boot fractures occur at the level of the top of the boot. These are compression failures of bone. There may be some comminution, but the periosteum is intact so that displacement is slight and easily held in a cast.

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20 / Ankle*

In 1898 John Poland made an extensive study of epiphyseal separations about the ankle. He noted that injuries in children differed from those in adults in three important ways:

1. The growth plate forms a plane of weakness directing fracture lines in patterns different from those of adults.
2. Ligaments are stronger than bone so that ligamentous injuries are almost unknown.
3. Certain injuries will affect growth.

To Poland's observations the following should be added:

4. Fractures rarely disturb the talotibial relationship, so that persistent disability owing to incongruity is unusual (Fig. 20-1).
5. From the age of 14 to 15 years onward, when the growth plate has closed, the adult pattern of fractures emerges.

APPLIED ANATOMY

The three major groups of ligaments are each attached to an epiphysis (Fig. 20-2). When the foot is forced into an abnormal position, tension and compression forces are generated. The structure of the ankle appears to permit tension injuries most frequently with the result that avulsion injuries of the epiphysis are more common. Compression *injuries* producing Type-IV or Type-V fractures are unusual.

PROBLEMS OF DIAGNOSIS

Many people assume that there is no fracture if the radiograph appears normal. However, undisplaced epiphyseal separations show no fracture. The clinical signs and localized soft-tissue swelling on the radiograph should be sufficient to sustain the diagnosis. Disregard the radiologist's report if he fails to recognize the injury. We have missed some fractures about the ankle when we relied on only two views of the ankle (Figs. 20-3, 20-4). *Always* take an oblique view.

FRACTURE PATTERNS

Customarily ankle fractures are classified on the basis of divination of the direction of force at the time of injury. This method is so conjectural that it is unusual for two people to agree about the classification of any particular injury (Fig. 20-5). Furthermore, this specification does not guide treatment, and we prefer the Salter–Harris method.

Type-I Injury of the Fibula

Type I is by far the most common injury to the fibula. It is recognized by swelling and tenderness over

*Dr. Alex Finsterbush did much of the work for this chapter and assisted with the follow-up review on which it is based.

the growth plate; the radiographs are usually normal. Stress films under anesthesia will demonstrate injury (see Fig. 1-1) but are unnecessary as a routine, and we neither use nor advocate this technique.

A walking cast for 3 weeks reduces disability. If no cast is applied, the injury will heal, but the parents, watching their child hop around on crutches, will be an endless source of trouble to you because of their unrelieved concern. When the cast is removed, there is nothing to be gained by further radiographs, because nothing abnormal will be seen. Movement quickly returns, and sequelae are almost unknown.

Fig. 20-1. The ankle joint is less often disrupted in children *(left)* than in adults *(right).*

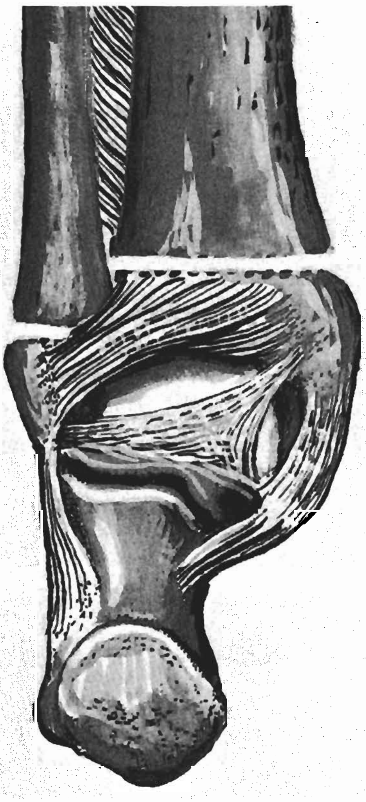
Type-II Injury of the Tibia

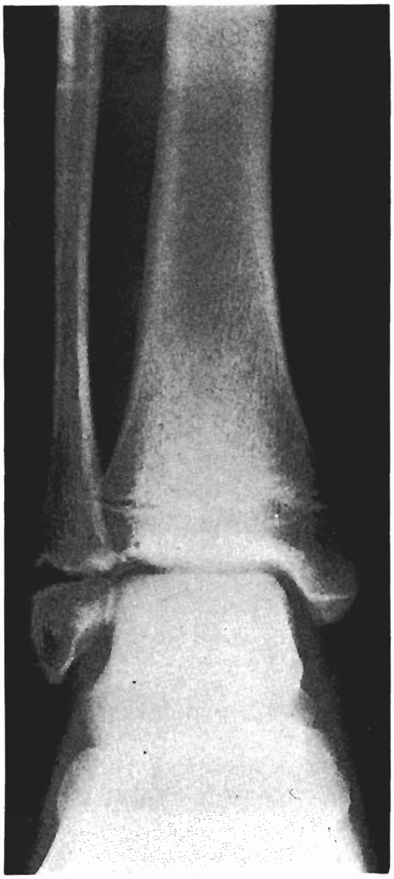
Plantar flexion and eversion injuries may produce gross displacement of the distal tibial epiphysis accompanied by a greenstick fracture of the fibula (Fig. 20-6). Gross displacement sometimes produces ischemia of the foot, which can be relieved, as a first-aid measure, by partially reducing the fracture gently without anesthesia. The fractures are easily reduced by closed manipulation with the knee flexed. Because growth cartilage lies in the fracture line, no bony crepitus is experienced during reduction. The radiologic degree of reduction is usually much better than clinical impressions would suggest. We have not had to operate on these fractures. Up to 20 degrees of valgus can be accepted in the expectation that remodeling will reduce the valgus to insignificance. A long-leg cast with a walking heel for a period of 6 weeks provides sufficient immobilization. Because the talotibial joint has not been disturbed in any way, recovery is speedy.

Type-I injuries of the epiphysis do occur but are exceptional (Fig. 20-7). Sometimes the injury cannot be recognized on radiographs until subperiosteal new bone appears after 2 to 3 weeks.[1]

Growth disturbance is unusual. In our series of 14 children with Type-II injuries who were followed up to maturity, only two demonstrated shortening, and that was so slight it proved to be clinically insignificant. Siffert has described avascular necrosis after this injury.[6] Soft-tissue interposition may produce a bizarre appearance later (Fig. 20-8). Spiegel and associates reviewed nearly 100 Type-I and Type-II injuries.[7] The results were excellent. No patients had required operation. Slight angulation corrects Type-I

Fig. 20-2. Strong ankle ligaments attached to the epiphyses account for epiphyseal separation being more frequent than epiphyseal fractures.





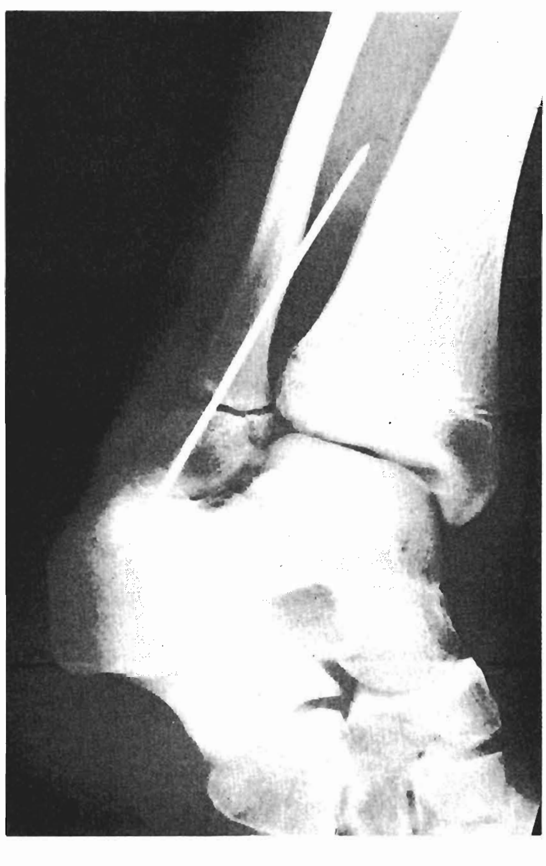
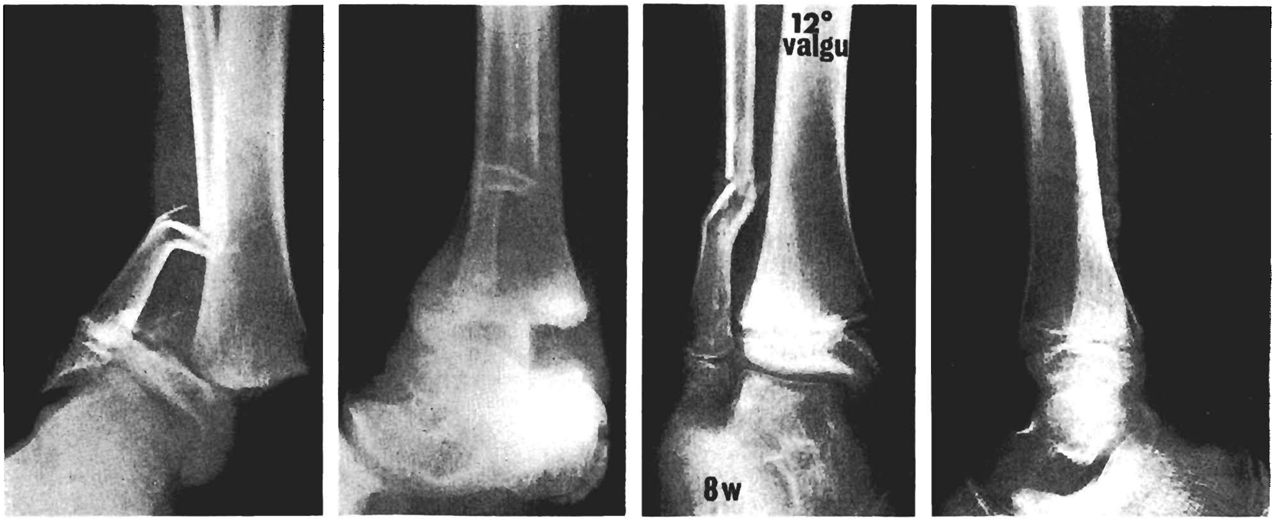


Fig. 20-3. The ankle was swollen laterally; these two views show the fibular growth plate was wide, indicating a Type-I injury. An oblique view was required to avoid missing the rest of the diagnosis (see Fig. 20-4).

Fig. 20-4. The oblique view shows a displaced fragment of the fibular epiphysis. This was replaced at open operation, and a pin was used to hold the mobile fibular epiphysis in place.

Fig. 20-5. One surgeon demonstrating to another the mechanism of an ankle injury.



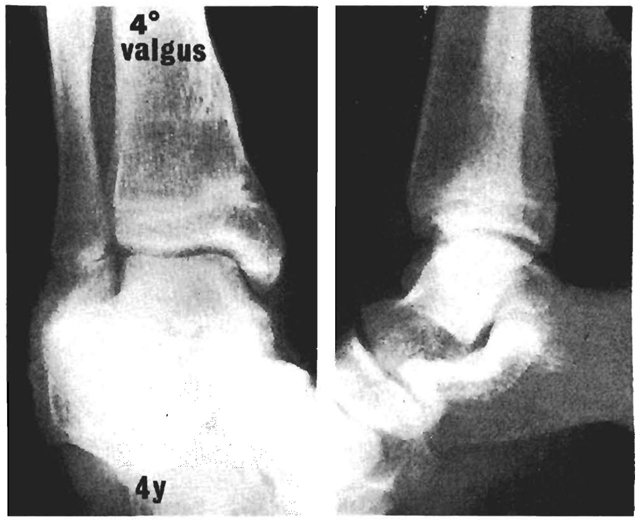


Fig. 20-6. Severely displaced Type-II injury of the tibia. Though incompletely reduced, some remodeling has occurred. The clinical result is excellent.

injuries that may show occasional overgrowth up to 1.5 cm and occasional shortening of a similar amount. Angular deformities in Type-II injuries often remain so that accurate reduction is worthwhile. Ten percent showed trivial complications—minimal angulation or shortening (due to uneven growth-plate closure) of no clinical significance.

Intra-articular Fractures of the Tibia

This group, including the Tillaux fracture, Frost's triplane fracture, and fractures of the medial malleolus, causes most of the problems in ankle fractures.

The Tillaux Fracture

A Type-III injury of the lateral part of the tibial epiphysis, this fracture was originally drawn on a scrap of paper by Tillaux. The drawing was found after he died by Chaput, who made the best of the ambiguous sketch. Kleiger and Mankin have written comprehensively on the fracture.[4]

At the age of 13 or 14 years, when the medial half of the distal tibial growth plate is closed, the lateral portion remains open. The anterior tibiofibular ligament links the tibial epiphysis with the fibular metaphysis. An external rotation force may avulse the anterior quadrant of the tibial epiphysis. This injury

Fig. 20-7. Type-I injury of the tibia. This only showed in the oblique view.

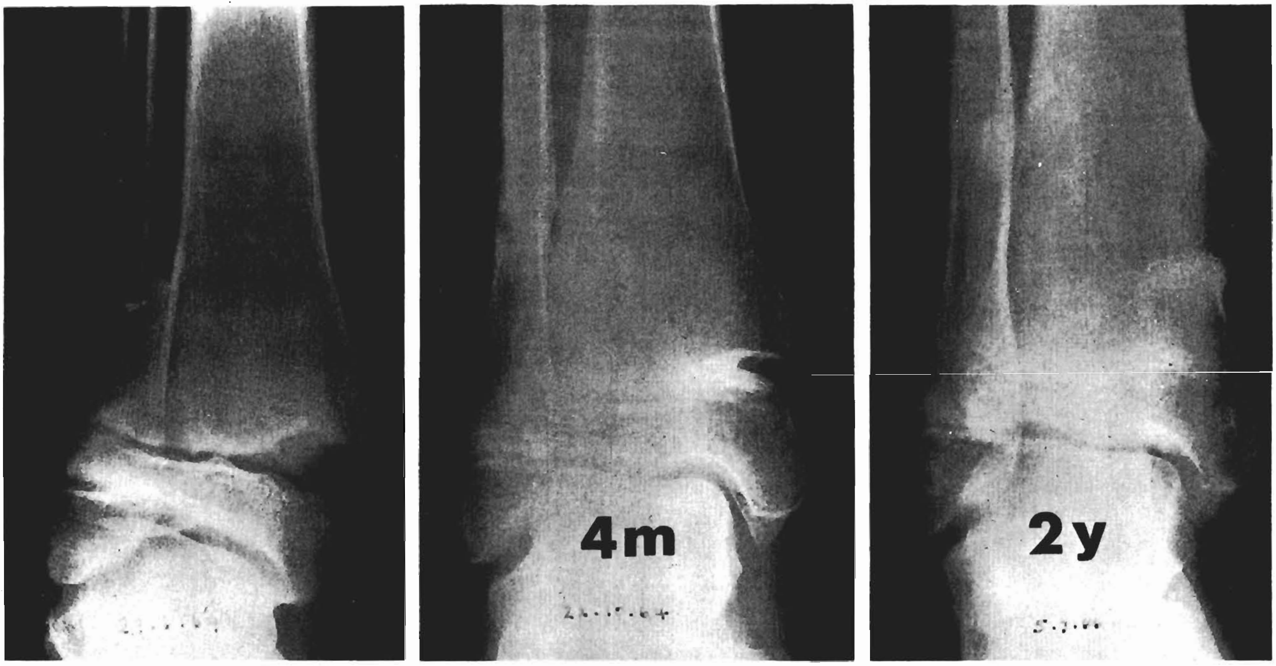


Fig. 20-8. Soft-tissue interposition in a Type-II injury. (Courtesy of Mr. Lipmann Kessel.)

appears to be the adolescent equivalent of diastasis (Fig. 20-9).

In our experience of about 30 such fractures, we have considered the majority to be so minimally displaced that no reduction is required, and that immobilization in a below-knee cast is sufficient. A small number have required open or closed reduction. A follow-up review of eight patients indicated that pain and stiffness was common for up to 2 years after injury, despite well-healed fractures. Kleiger and Mankin noted that rotatory instability, detectable by an examination under a general anesthetic, is a feature of this fracture, and for this reason they applied a long-leg cast with the foot in full medial rotation.[4] Their published results, from a very few children, appear better than those that we have obtained, and in the future I intend to follow their teaching.

The Triplane Fracture

This uncommon fracture marries a Type-II injury to a Tillaux fracture (Fig. 20-10). The radiographs are hard to interpret. The last word has yet to be said. Cooperman and associates, in a study of 15 cases, have used CT scanning and tomograms to define the fracture line and the degree of displacement exactly.[2]

They present clear evidence that the majority of triplane fractures are two-part fractures, and that three-part fractures are only seen when there is more displacement. We have treated few children with this injury by closed reduction, and maintained position with an above-knee cast for about 8 weeks (Fig. 20-11). If closed reduction fails, operate.

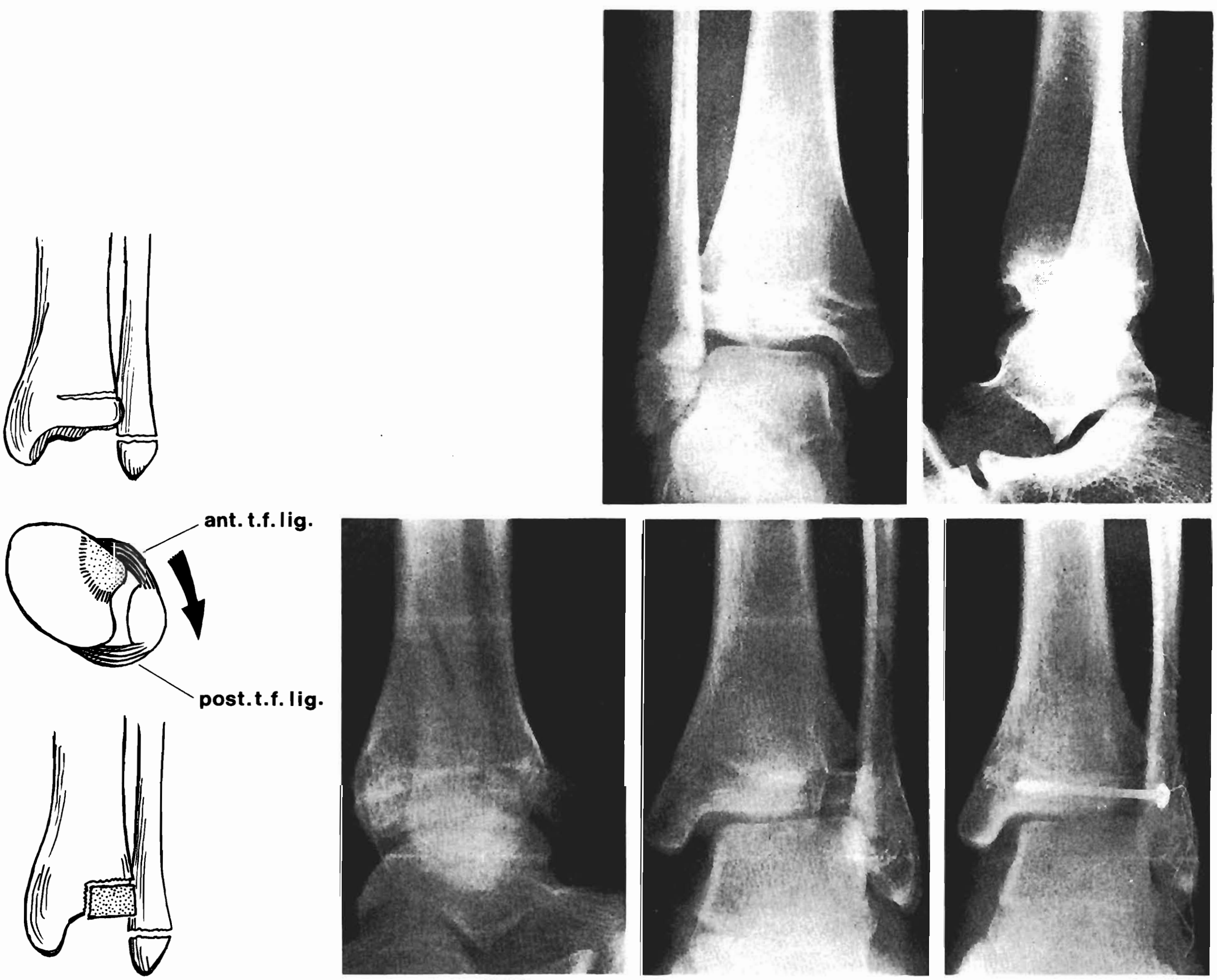
Fractures Around the Medial Malleolus

Growth-plate damage is common around the medial malleolus (Figs. 20-12 to 20-15), and will produce a varus deformity of the ankle and a short tibia, accompanied by relative overgrowth of the fibula.

In theory, the radiograph should allow the fracture to be classified into Type III, Type IV, or Type V, so that appropriate treatment and prognosis may be determined. In practice, the interpretation is seldom clear because a little comminution is common, and because the medial margin of the growth plate is poorly defined. Open reduction of the large fragment is essential, and transepiphyseal pins should be

Fig. 20-9. *(Top, right)* Paul Jules Tillaux, 1834–1904. (Courtesy of the Wellcome Trustees.) *(Below, left)* Anatomy of the Tillaux fracture. Characteristically, the fracture is difficult to see *(center, right)*. Frequently, the fracture line is overlaid by the fibula. *(Bottom, right)* The Tillaux fragment has locked in the displaced position, producing diastasis. The fibula shows a rotatory fracture. When the fragment is fixed back, the mortise closes. The young fibula is pliable and rarely fractures. In the usual Tillaux fracture, the fibula probably bends and then springs back, returning the fragment into place.

TILLAUX (PAUL-JULES)



used to achieve this. Reduction may be hindered by trapped, loose fragments that will require removal.

Grossly comminuted fractures usually do not appear displaced and are treated in an above-knee cast. Growth disturbances of varying degrees have ensued in some. In the teenager, tenting of the epiphysis will be unimportant, whereas in the younger child it will cause a major problem.

Type VI Injuries—Ablation of the Perichondrial Ring

Lawn-mower and degloving injuries may remove the perichondrial ring. Lipmann Kessel has shown that this permits a callus bridge to form between the epiphysis and metaphysis with resulting varus deformity and failure of growth (Fig. 20-16; for further discussion, see p. 24).*

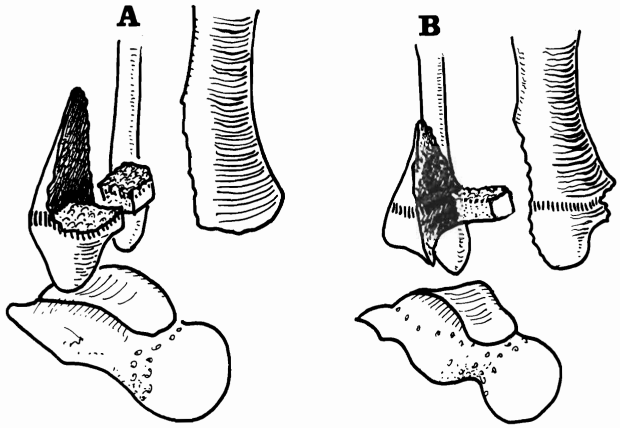
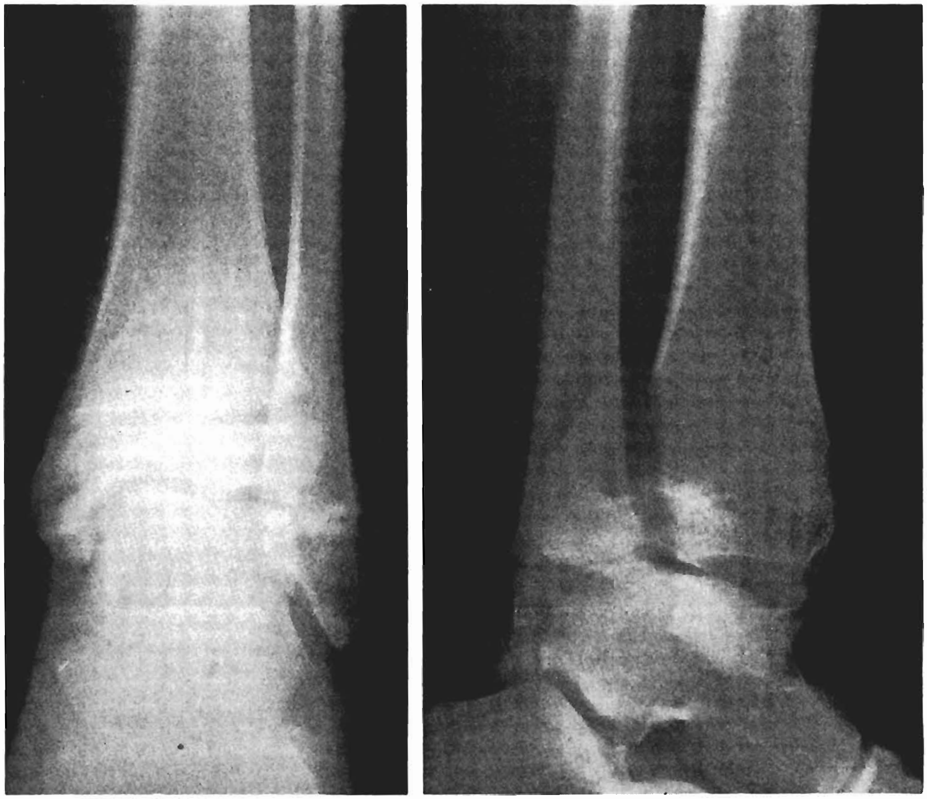


Fig. 20-10. The triplane fracture: Everyone agrees the fracture lines run in three planes, but beyond this there is uncertainty. *(A)* Three-part fracture. *(B)* Two-part fracture. (Cooperman DR, Spiegel PG, Laros GS: Tibial fractures involving the ankle joint in children: The so-called triplane epiphyseal fracture. J Bone Joint Surg 60A: 1040, 1978)

Fig. 20-11. A variant of the triplane fracture. The anteromedial portion of the plate has closed, preventing separation. Surprisingly, anatomic position was achieved with closed reduction. At follow-up 2 years later the ankle was perfect.

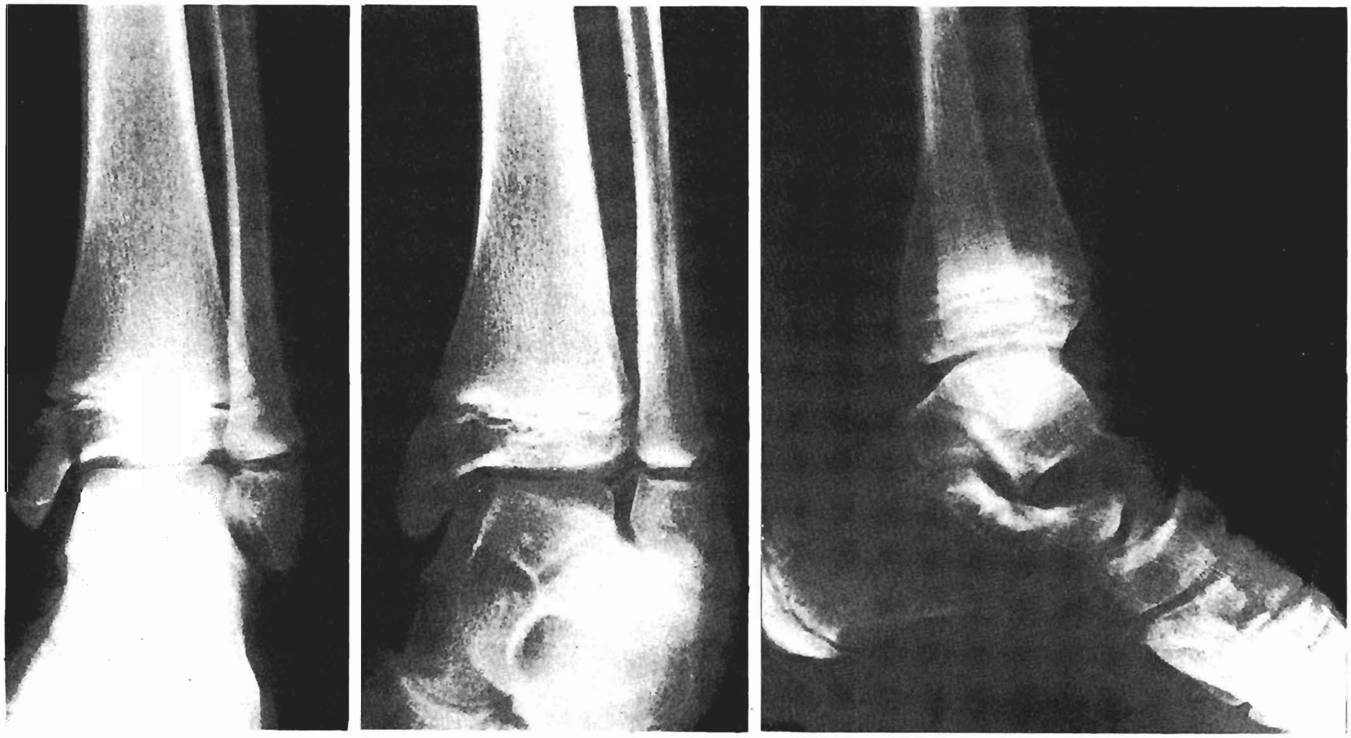


* L Kessel, personal communication

Fig. 20-12. A Type-IV injury. Accurate open reduction and internal fixation are required to prevent growth arrest.

Fig. 20-14. In a young child it may be difficult to be certain whether the fracture extends into the metaphysis or not. This was a Type-III fracture of the medial malleolus with a Type-I fracture of the fibula. A cast was applied; healing was sound.

Fig. 20-13. This Type-IV injury sustained at the age of 9 years was treated as a sprain by a chiropractor. Here, 5 years later, the result after tibial osteotomy and fibular epiphyseodesis can be seen. There is tenting of the articular surface and ankle varus.



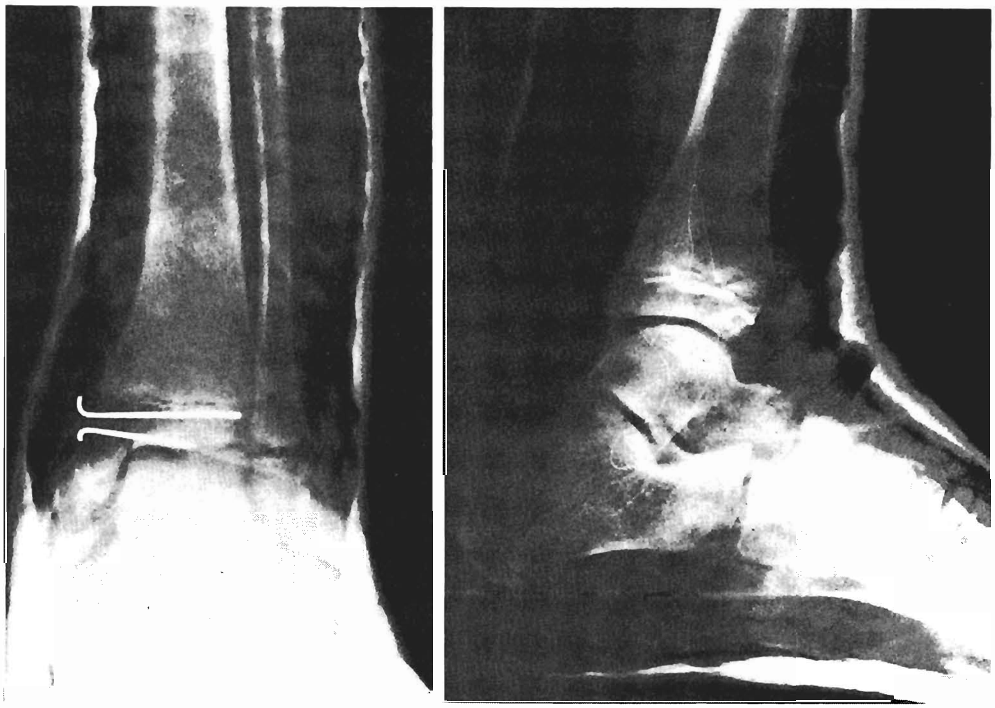


Fig. 20-15. This ankle was unstable. In addition to the Type-III fracture of the medial malleolus, there was a Type-I injury of the fibula with a loose intra-articular fragment. Open reduction, removal of the fragment, and transepiphyseal pinning is needed.

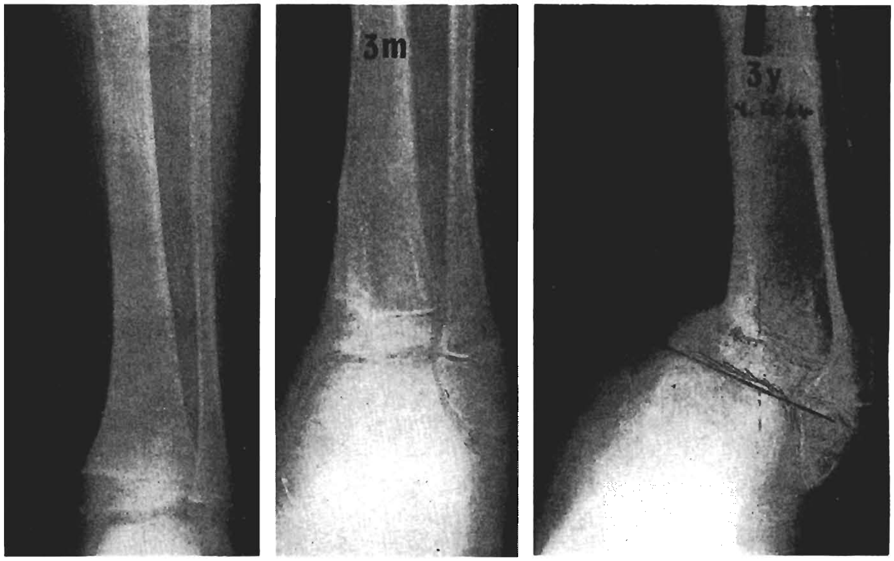
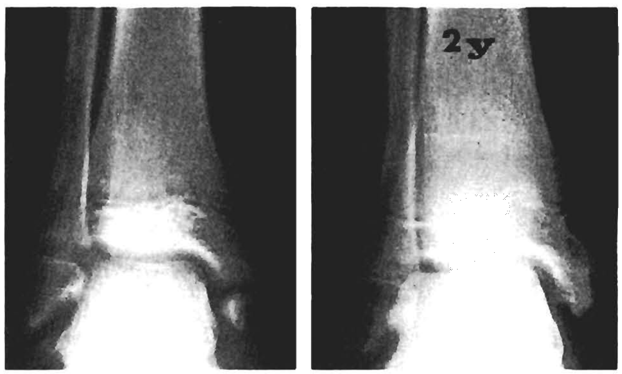


Fig. 20-16. Type-VI injury. At the time of a runover injury with massive degloving, the medial side of the growth plate was exposed. Within 3 months the plate closed partially, and varus deformity followed. (Courtesy of Mr. Lipmann Kessel.)

Fig. 20-17. Horizontal fractures of the medial malleolus are rare and require open reduction and internal fixation. This fracture in a 12-year-old was held temporarily with a screw. Two years later function was excellent.



MISCELLANEOUS INJURIES

Battered Baby Syndrome

The ankle is commonly affected. The heat, swelling and redness may simulate osteomyelitis.

Epiphyseal Fractures

The very tip of either malleolus is occasionally avulsed (Fig. 20-17).

The cartilaginous model is avulsed by a ligament. Initially there is just swelling, and radiographs are normal. After a month or more, the cartilage model forms an ossicle. The anterior talofibular ligament pulls a fragment off the anterior fibula; this is the adolescent equivalent to an adult ligament rupture (Fig. 20-18). Occasionally the ossicle remains symptomatic and can be excised with relief.[3]

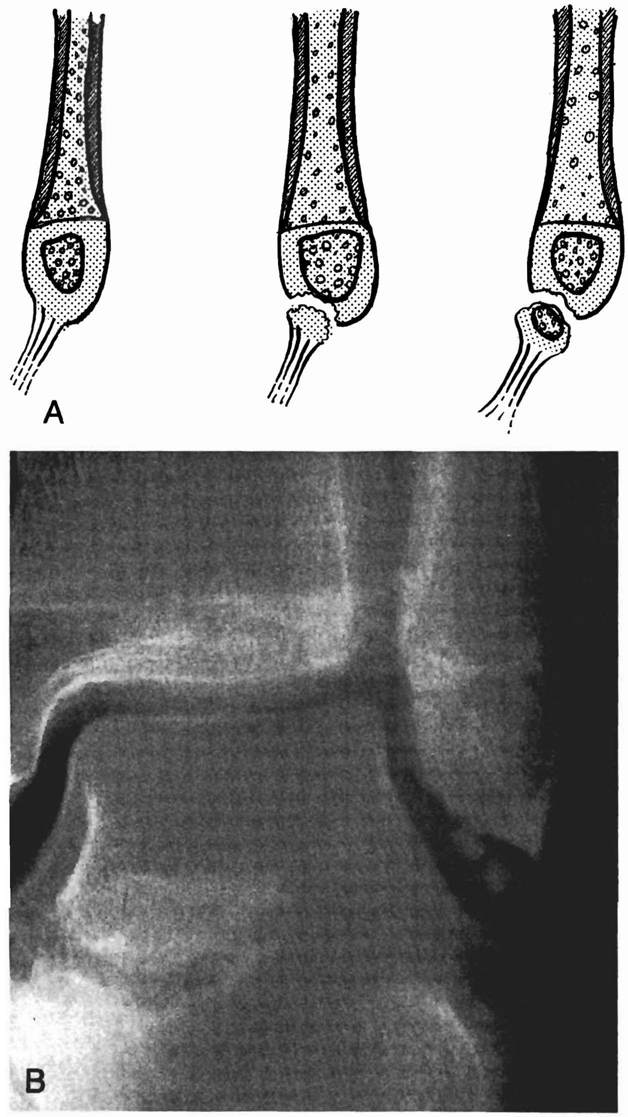


Fig. 20-18. *(A)* When a ligament is avulsed with a fragment of preosseous cartilage, the initial radiograph is normal. *(B)* After a month an ossicle becomes obvious.

Fracture of the Fibula with Intra-articular Fragment

The fragment may require operative reduction (see Fig. 20-3).

Rotated Fractures

The tibial epiphysis may be rotated through 90 degrees.[5] I have seen two examples in which the separated fibular epiphysis was displaced completely posteriorly (Fig. 20-19).

Loss of Fibula

A valgus deformity develops when the fibula is short owing to growth retardation or loss of part of the bone (Fig. 20-20).

Adult Fractures

Young people with closed plates who sustain fractures may come to a children's hospital. Their fractures are of the adult type, and they may require open reduction and internal fixation (Fig. 20-21).

Open Fractures

The skin over the ankle is thin, and there is little fat or fascia to cover tendons and nerves. Holding a fracture reduced is difficult when the overlying skin is damaged by degloving or by the bone bursting through. Figure 20-22 shows one method of management.

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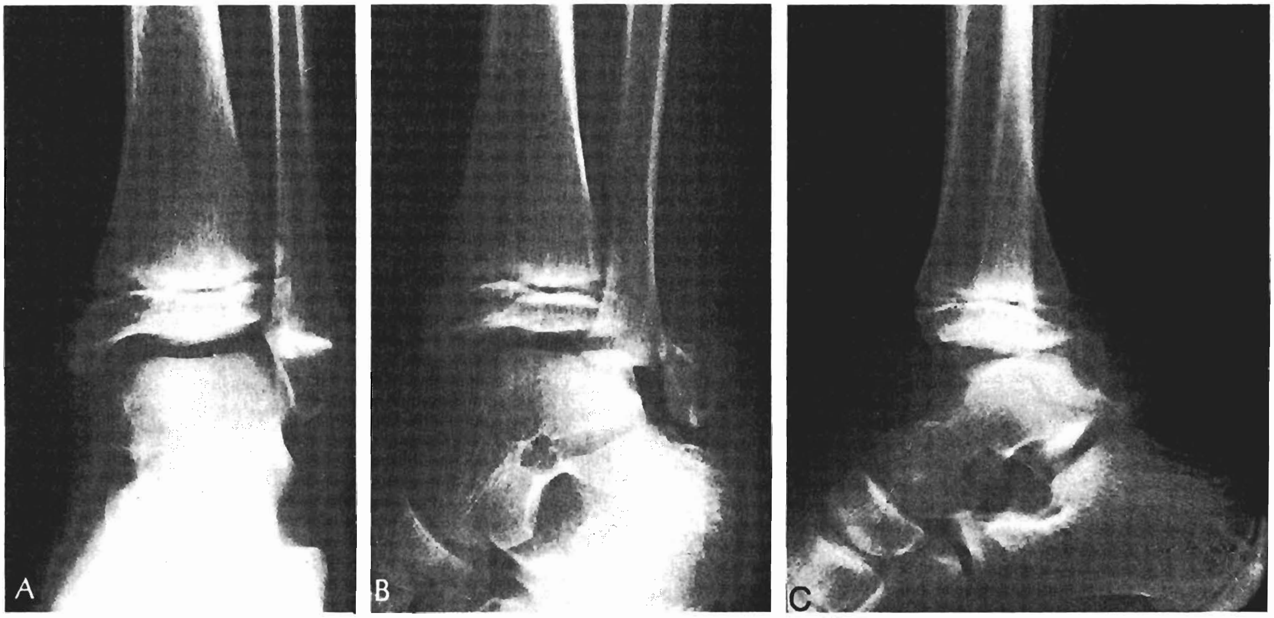

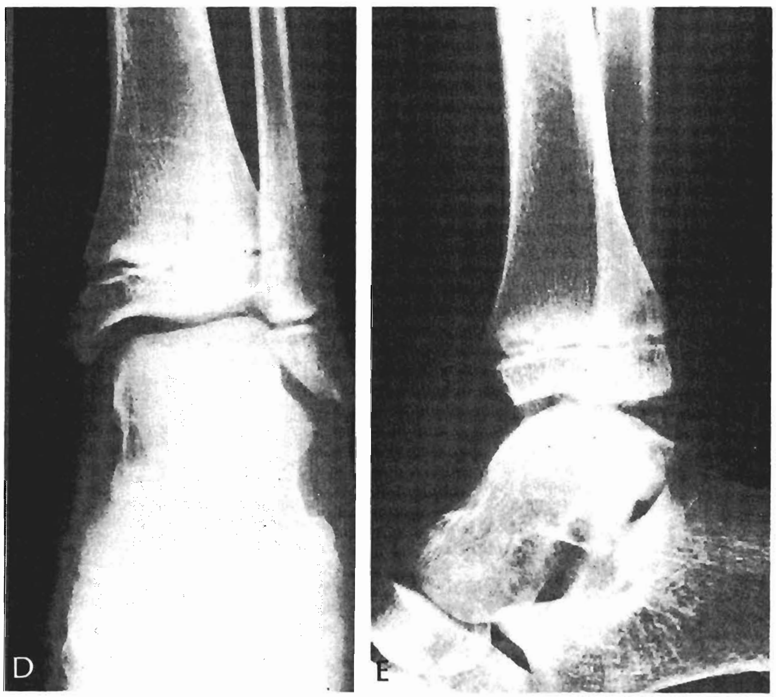

Fig. 20-19. *(A, B, C)* An external rotation of the ankle with rotatory subluxation of the ankle joint. *(D, E)* The displaced fibular epiphysis was manipulated back into position.

Fig. 20-20. Two years before, at the age of 4, this child lost the end of the fibula in a street accident. Though the foot is in varus, owing to loss of peroneal power, the ankle is in valgus and the talus is subluxed laterally. Repeated osteotomies and ankle fusion are likely to be required.

Fig. 20-21. Adolescents with closing plates sustain fractures of the adult type. Use internal fixation if stable, accurate closed reduction cannot be achieved. Boy aged 15.

Fig. 20-22. Like many people involved in industrial accidents, it was Patrick's first day at the car wash; the foot was almost torn off through the distal tibial growth plate by the continuously moving chain on the floor. The posterior tibial nerve, artery, and tendon were divided. The circulation to the foot was precarious for a time. The leg was debrided and the fracture was held with Roger Anderson apparatus. A wound extending halfway around the circumference of the leg was closed. Some skin subsequently became necrotic and was replaced with grafts. Rigid external fixation greatly facilitated the care of the soft tissues.

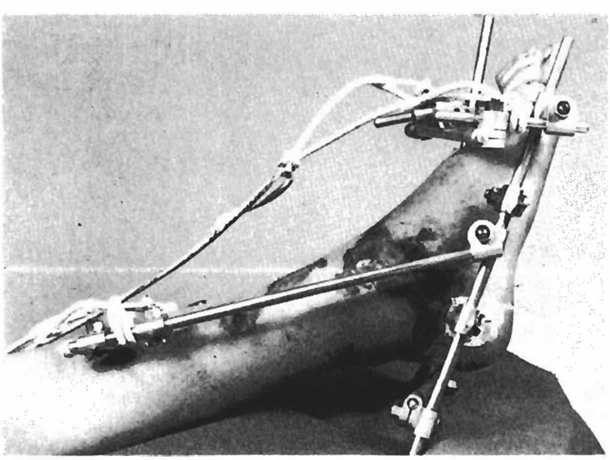

Fig. 20-23. Applying a below-knee cast. The easiest way to hold the ankle at a right angle is to have an assistant control the foot with the stockinette.

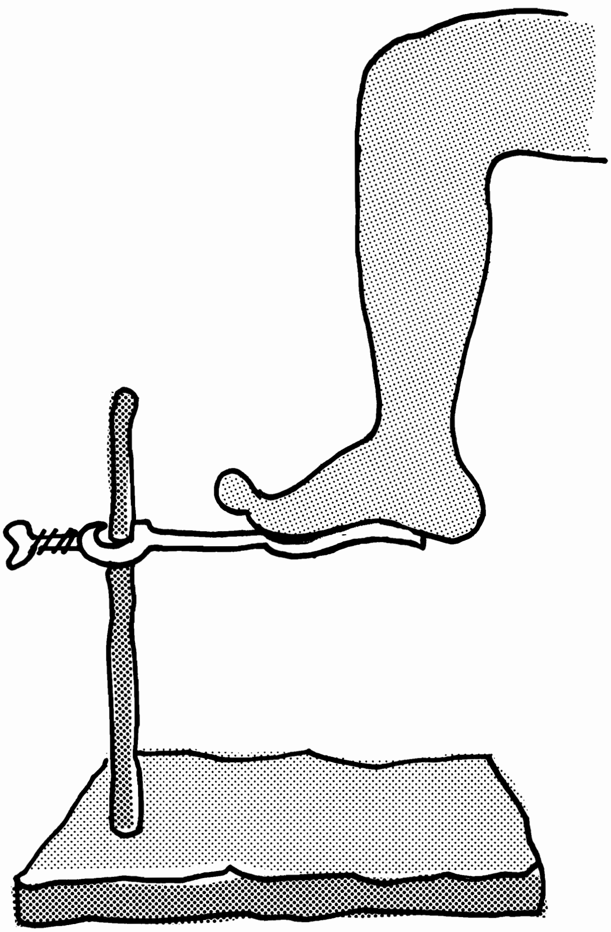

Fig. 20-24. A footstand is an alternative to an assistant.

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21/ Foot

Injuries to children's feet, despite all the little bones and joints, are remarkably uninteresting. Very few fractures will be encountered that display any subtleties or tricks; few are even displaced.

TALAR FRACTURES

Fractures of the talus are unusual in children. In 10 years we have been able to trace only 12 examples.

Neck

The majority of talar fractures are undisplaced fractures of the neck of the talus, which heal in casts without avascular necrosis. The only sequel in one case followed to adult life was that the talus was slightly smaller than its counterpart in the opposite foot. When the head is superiorly displaced in relation to the body, the foot should be immobilized in plantar flexion to avoid malunion (Fig. 21-1). Fracture of the neck accompanied by subtalar dislocation usually can be reduced by closed manipulation (Fig. 21-2).

Body

Displaced fractures through the body require open reduction. This may be difficult because wide exposure is required in order to demonstrate the fracture adequately and yet, to minimize the risk of avascular necrosis, care must be taken to avoid removing any soft-tissue attachments from the bony fragments. Multiple Kirschner wires across the fracture and across the subtalar joint will provide fixation. Subsequently, the subtalar joint remains stiff, and avascular necrosis of the body, a complication that requires protection with a patellar-tendon-bearing brace for a year or two, is a real hazard (Fig. 21-3).

Lateral Wall

Lateral-wall fracture, probably representing an osteochondral fragment avulsed by the anterior talofibular ligament, is seldom recognized initially. Persisting pain and point tenderness just in front of the lateral malleolus should indicate the need for oblique radiographs and perhaps tomograms, to show the small, loose body. Excision may be needed (Figs. 21-4, 21-5).

OS CALCIS FRACTURES

Children seldom fracture the os calcis. Displaced fractures involving the subtalar joint that require reduction are very unusual. Fractures in the sagittal plane are easily missed if axial views of the os calcis

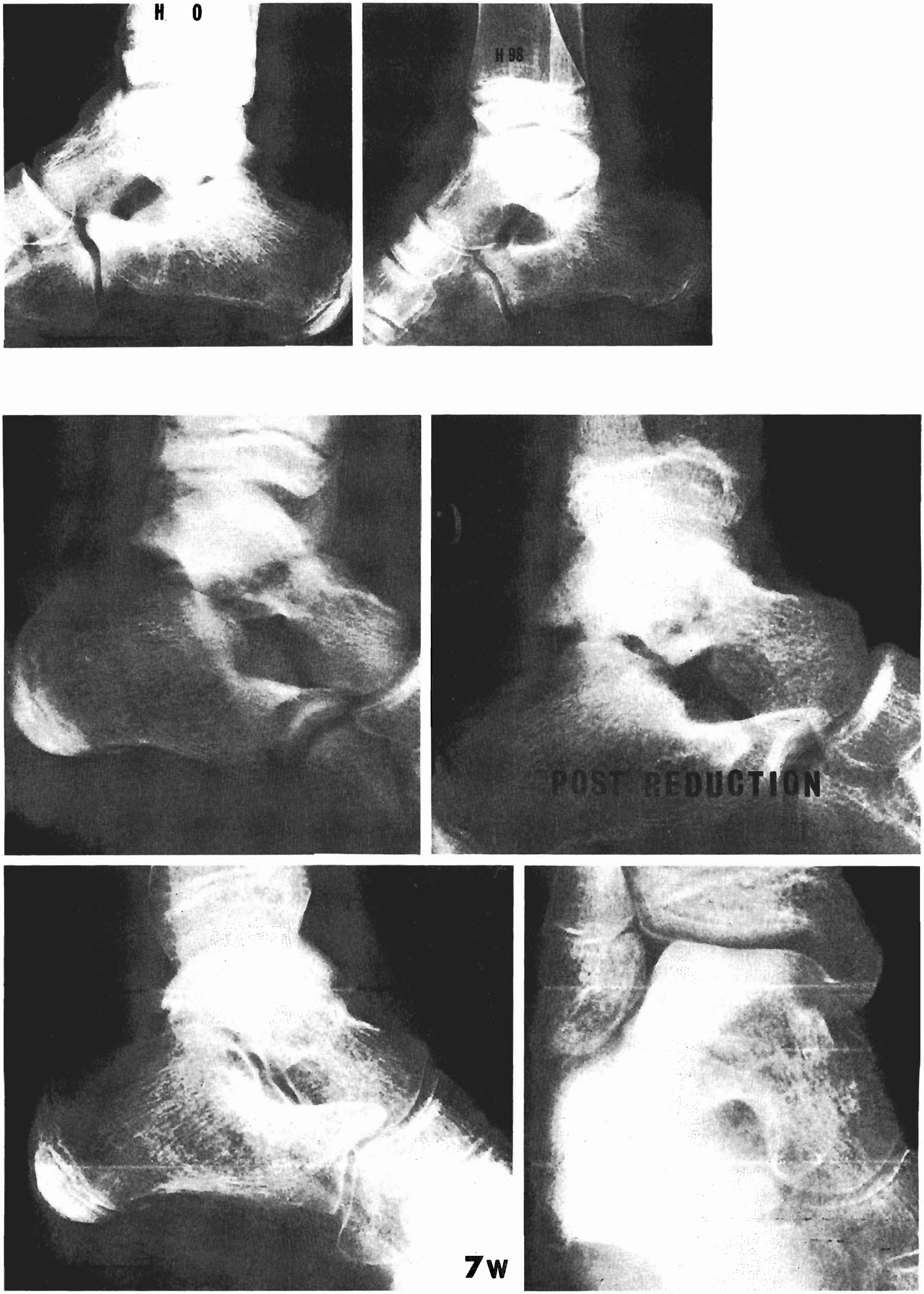

H 0
H 98
POST REDUCTION
7W

Fig. 21-1. Displaced fracture of the neck of the talus. This was not reduced. Ninety-eight days later the fracture was solidly malunited, and the patient was never able to put his foot flat on the ground again.

Fig. 21-2. Fracture of the neck of the talus (extending into the body) with dislocation of the subtalar joint. This was manipulated into good position. At 7 weeks the fracture was united, but the density suggests avascular necrosis. Bone scan showed normal uptake throughout the talus.

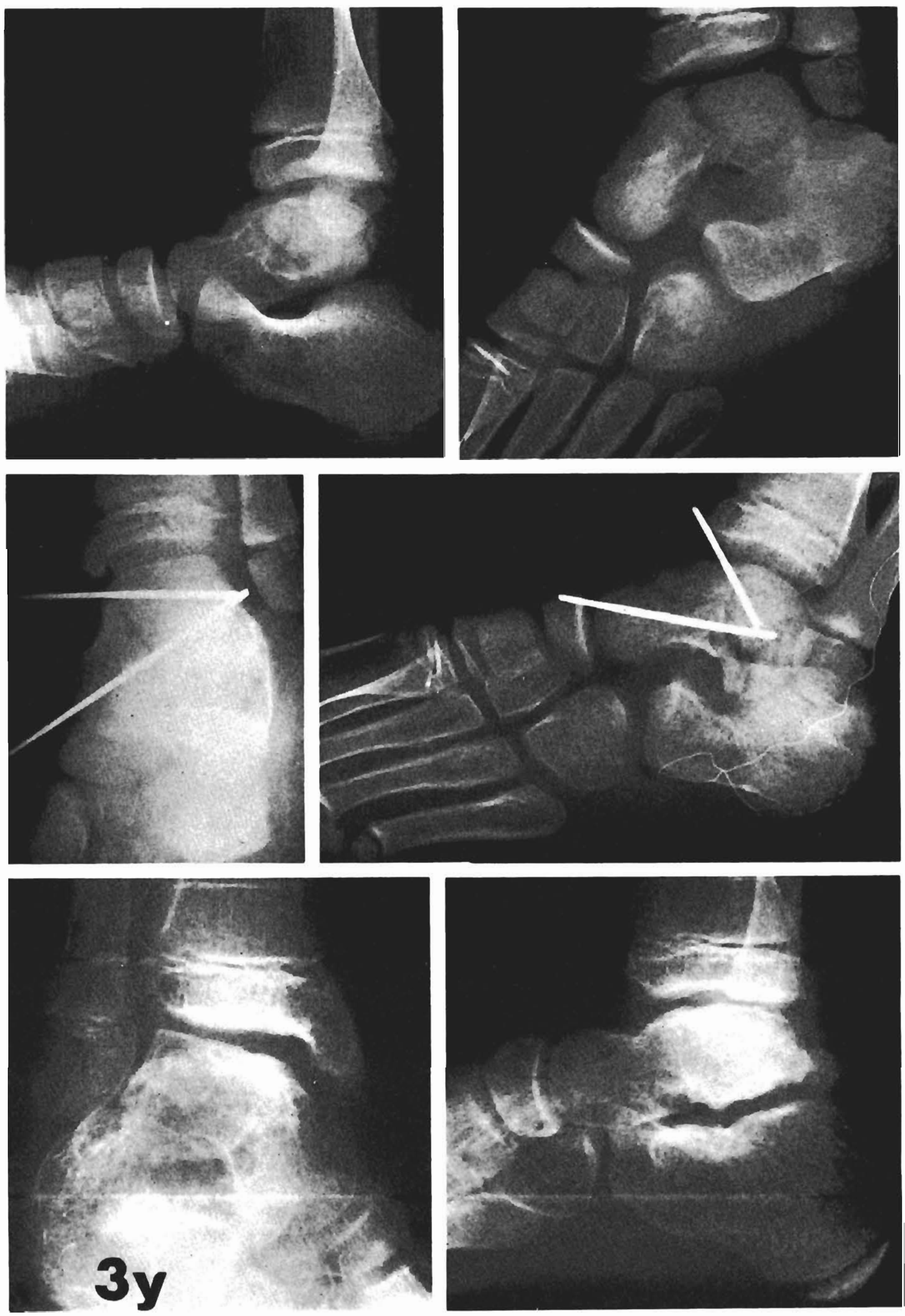
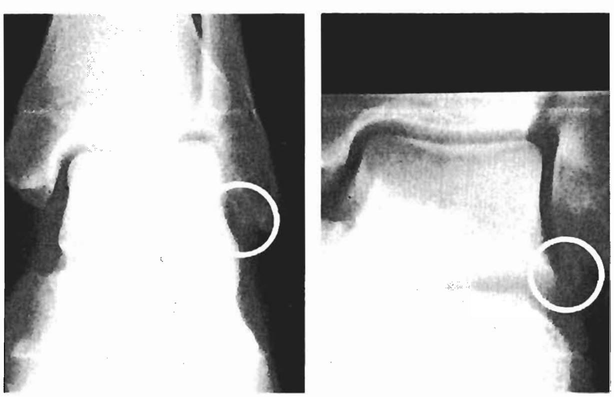


Fig. 21-3. Comminuted fracture of the body of the talus with 45-degree external rotation displacement more obvious clinically than radiographically. Assembled with K-wires at open reduction, the fractures healed but with signs of avascular necrosis. The patient wore a patellar-tendon-bearing brace for 18 months, and 3 years later he has a poor range of ankle movement and a stiff subtalar joint.

Fig. 21-4. A fracture of the processus lateralis. Probably not uncommon, this fracture is only recognized on a 10-degree internal rotation oblique film. Boy aged 12 years.

Fig. 21-5. Ossicles owing to an old fracture of the processus lateralis were excised because of pain. Boy aged 15.



are omitted. Most children require admission to elevate the leg for a few days and start early movements. The child should not bear weight on the heel until the fracture is united, so use a cast. Open reduction yields worse results than this technique in our hands. The os calcis has a predilection for simple bone cyst, which may initiate a pathologic fracture and require a bone graft (Figs. 21-6, 21-7).

MIDTARSAL INJURIES

Mechanisms that simulate a well-applied Thomas wrench can disrupt the midtarsal area. Valgus or varus deformities may be more apparent on clinical examination than on radiographs. Whether reduction is needed or not, the child should be admitted for elevation of the foot and for observation, since massive swelling is usual, and vascular impairment has been described. Decompression through the dorsum of the foot may be necessary when skin viability is threatened. Displacement should be corrected and held with percutaneous Kirschner wires. A well-pad-

Fig. 21-6. Fracture of the os calcis. Boy aged 11. After elevation of the foot for a few days he was immobilized in a cast for a month.

ded, soft bandage is the only safe means of support for the first week, after which a cast should be used (Fig. 21-8).

METATARSAL FRACTURES

Robert Jones Fracture of the Base of the Fifth Metatarsal

Fracture is distinguished from a normal growth plate by the direction of each (Fig. 21-9). The injury is common and painful; a walking cast for 4 weeks lessens morbidity. Frequently, local bony tenderness persists long after the cast is removed.

Solitary Fractures

Seldom much displaced, solitary fractures are treated in a walking cast for comfort.

Multiple Fractures

Considerable swelling is universal in multiple fractures. The foot should be aligned, not only to prevent valgus, varus, or splayfoot deformities, but to prevent depression of a metatarsal head. As the swelling recedes, alignment may improve. If it does not, intramedullary fixation with Kirschner wires is required, because nonunion may occur. Nonunion results in a short toe and in irregularity of the metatarsal heads with painful metatarsalgia (Fig. 21-10).

Stress Fractures

March fracture in children is unusual, but stress fractures of the fifth metatarsal are seen in partially corrected club feet (Fig. 21-11).

Fig. 21-7. This fracture of the lateral wall of the os calcis could easily have been missed if the axial view had been omitted. Boy aged 8 years.

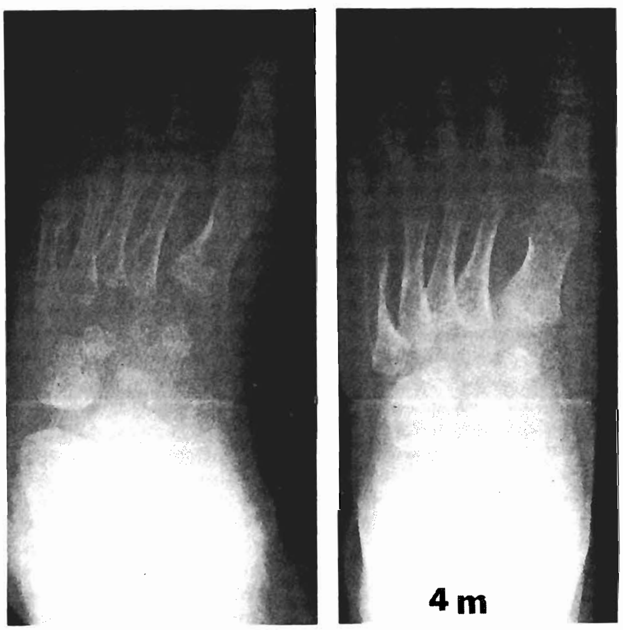
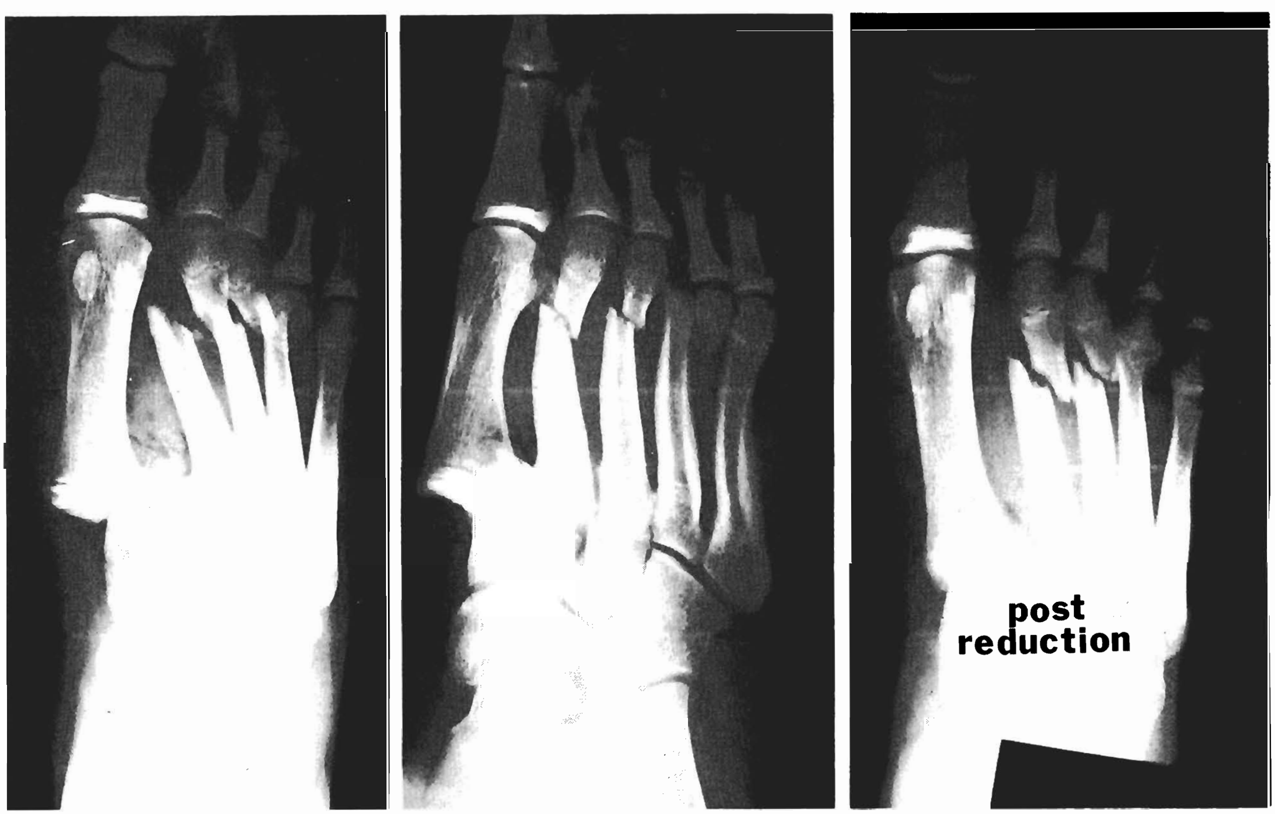


Fig. 21-8. Midtarsal joint injury in a 2-year-old child owing to a car running over his foot. There was massive swelling. Hemorrhage in the fat of his foot produced a mottled appearance on the radiograph. Undisplaced fractures of the fourth and fifth metatarsal bases were barely perceptible. The foot was elevated for 10 days before he could safely be allowed home in a well-padded, light cast. Callus 4 months later defines the fractures more clearly.

Fig. 21-9. *(A)* Fracture of the base of the fifth metatarsal bone contrasted with *(B)* normal growth plate. Note the different direction of the line.

Fig. 21-10. Fracture–dislocation of the forefoot. After elevation for a few days closed reduction was effected and maintained. Boy aged 14.



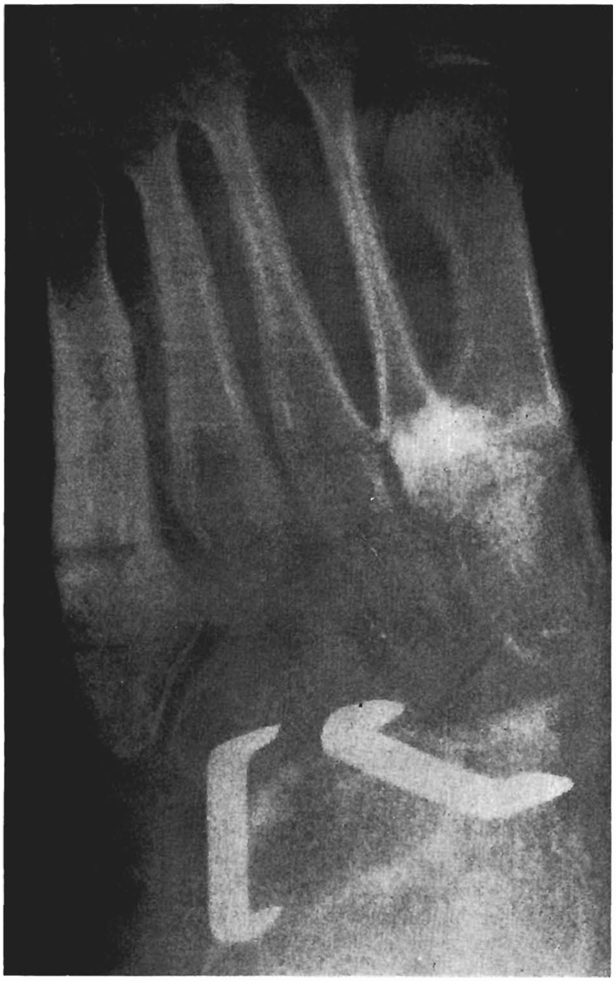


Fig. 21-11. This 15-year-old with an incompletely corrected club foot complained of pain owing to a stress fracture of the fifth metatarsal. The deformity was corrected by a triple arthrodesis, and the stress fracture is beginning to heal.

PHALANGEAL FRACTURES

Phalangeal fractures seldom require more than protection and sympathy (Figs. 21-12, 21-13). Intra-articular fractures of the big toe require accurate reduction, if necessary by open pinning, in order to avoid prolonged painful stiffness. Growth arrest is occasionally encountered after stubbing the big toe (Fig. 2-19). The stubbed great toe may sustain a Type-I injury with damage to the nail fold, as described in Figure 14-10. Infection may follow without adequate care.

Fig. 21-12. Fractures of the middle phalanges of the second and third toes and of the proximal phalanx of the fourth toe. The displacement does not look great on the radiograph, but the boy's toes were pointing in all directions like the roots of a tree. He required reduction and immobilization. Perhaps this point has been made often enough: If the appearance of the patient suggests that a fresh fracture should be put straight, put it straight irrespective of the radiograph.

PUNCTURE WOUNDS OF THE FOOT AND PSEUDOMONAS OSTEOMYELITIS

The smell of socks and running shoes is due to pseudomonas. Puncture wounds, as a result of a nail penetrating the shoe, can innoculate pseudomonas and produce osteomyelitis. Puncture wounds are common but this is rare—perhaps 0.6% of puncture wounds.[1]

Pseudomonas infection becomes apparent a week or two after the puncture because of increasing pain, swelling, and tenderness. If the joint was punctured, a septic arthritis is produced—commonly a metatarsophalangeal joint. Osteomyelitis follows bone penetration. X-ray film changes take 3 to 4 weeks to appear.

Try to recover the organism by probing the wound with a culture stick or by injecting a little saline and then culturing the aspirate. Because the chance of infection by pseudomonas is greater than

Fig. 21-13. Crush injuries may appear trivial on radiographs. Decompression did not save these toes from amputation.

any other organism, start treatment with gentamycin or another antipseudomonas drug for 3 weeks. Plan to debride the area under anesthesia. Joint and growth plates are usually permanently damaged by the infection, though chronic infection is rare.

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22/ Spine and Spinal Cord

GENERAL FEATURES

Vertebral fractures and spinal-cord injures are less common in children than in adults. Only 5% of cases of traumatic paraplegia occur in children.[8] The child's spine is more mobile than that of an adult, so that the force is dissipated more easily and over a greater number of segments. Dislocations of the spine are rare, because the ligaments are stronger than bone. The line of the growth plate may mimic a fracture or may cause *special types* of fractures. Separation of the epiphyseal end-plate of a vertebral body—a Type-I injury—is the most common birth injury of the bony spine. Here is another type from a few years ago: Adam fell over the bannister and landed on the top of his head. His neck was rigid, but radiographs were normal. There was little improvement after halter traction for 3 weeks. He went home in ruffs, only to return with a mildly spastic gait after another fall. Eventually, tomograms disclosed an epiphyseal separation at the base of the odontoid (Fig. 22-1). He went home in a Minerva cast and was soon normal again. Today computerized tomography allows fractures to be recognized that would otherwise be missed. Any child who appears to have a fracture that cannot be shown on plain films should have a CT scan (Figs. 22-2 to 22-4).

The rarity of spinal-cord injuries in children does not mean that back injuries should be taken less seriously. I can well remember the piping voice of a 12-year-old describing how she had hurt her back in a field. Her brother-in-law picked her up in his arms. "I felt a terrible pain in my back, and after this I could not move my legs. I have never been able to move them since." Perhaps only once in your life will you be at the scene of such an accident, but when you are, stand guard over the patient to organize the onlookers. Move the patient on a board or on a door.

Only a small proportion of paraplegic children owe their lesion to trauma. During a 12-year period, approximately 450 children have been admitted to the Ontario Crippled Children's Centre with a diagnosis of paraplegia. Of these cases, 12% were traumatic, 2% were due to acquired disease, and the remainder were due to meningomyelocele. The major cause of traumatic paraplegia is car accidents; under the age of 2 years child abuse is important. Sports, such as diving, surfing, and hotdog skiing, is the leading cause in older adolescents. Traumatic paraplegia outnumbers traumatic quadriplegia by 3 to 1.

22/ Spine and Spinal Cord

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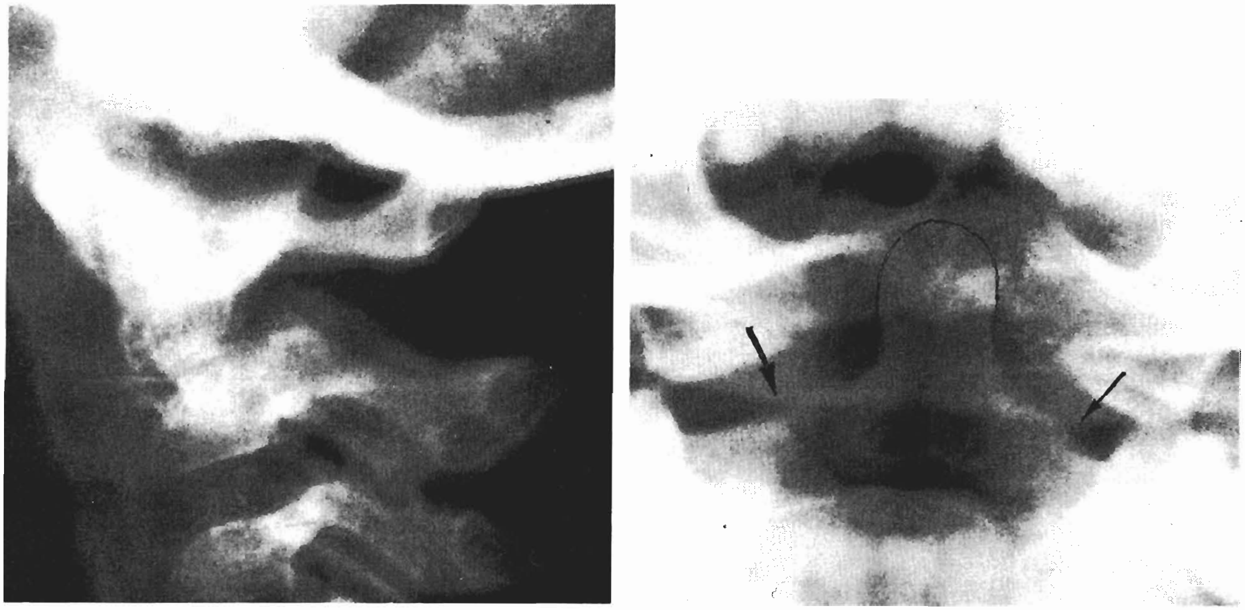
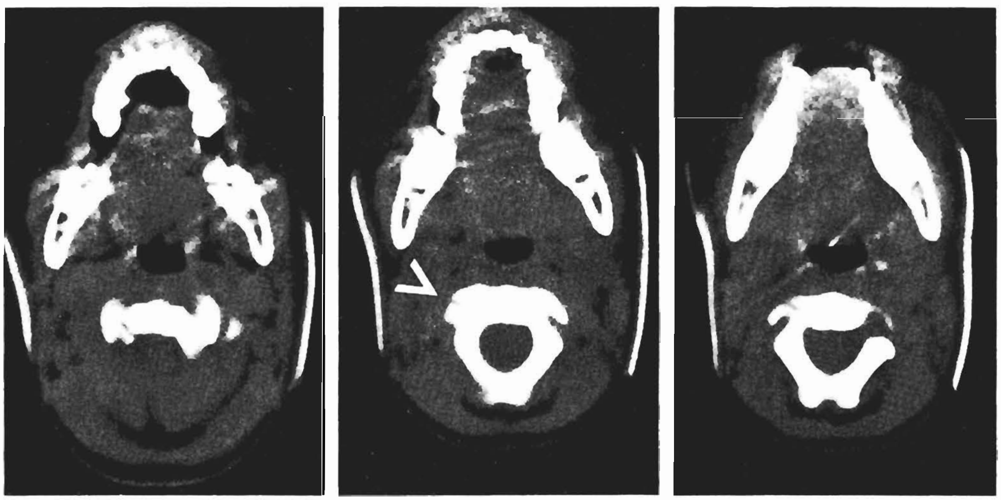


Fig. 22-1. Separation of the dens from the right neural arch *(indicated by arrows.)* Boy aged 4 years.

Fig. 22-2. CT scan shows a fracture of the lateral mass of C3. This child had pain in the neck after injury, but radiographs were normal.



CLASSIFICATION

Comparatively little is written about spinal injuries in children, and I have drawn mostly on our experience at The Hospital for Sick Children. During a 15-year period, approximately 85 children have been admitted with injuries to the cord or vertebrae. Table 22-1 shows the composition of the group.*

Trauma to the spine in children falls naturally into three groups: (1) cord injury without fracture; (2) cord injury with fracture or dislocation; and (3) fracture or dislocation alone. A cord injury without fracture is perhaps the most interesting entity. Though a rare combination in adults, apart from hyperextension injury of the cervical spine, it represents about one-quarter of all injuries to children with neurologic damage.

CORD INJURY WITHOUT FRACTURE OR OPEN INJURY

It is perhaps a mistake to look for one cause when there is cord injury but no fracture or open injury. Concussion, contusion, and infarction of the cord appear to produce the neurologic disorder. But what damages the cord? This is a matter for conjecture. A displaced Type-I injury of the cartilaginous epiphysis may spring back into position. This is seen in the leg and can be produced in the spine. These will heal without any radiographic signs. Another possible mechanism for this injury is excessive bending of the young spine, which has a more rubbery disc and more growth cartilage than bone. Traction is thought to be the most common mechanism in birth paraplegia.[17] We have treated 11 patients with this condition. Concussion accounted for five injuries, contusion for four, and infarction for two (see below).

David Burke described seven children with permanent complete traumatic paraplegia with no radiographic signs of gross injury.[4] (Fractures of ribs were present in three, fractured transverse process in one, and slight forward subluxation of L2 and L3 in another). The paraplegia was spastic in five and was flaccid in two young children with high thoracic lesions who had been run over.

*Dr. George Weicz took the initiative to review these patients, and this chapter is based on his work.

Table 22-1. Classification of Spinal Injuries in 86 Children

SKELETAL INJURY WITHOUT CNS SIGNS		
Compression fractures	31	
Rotatory fixation C1–2	6	44
Miscellaneous subluxations	7	
SKELETAL INJURY WITH CNS SIGNS		
		31
CNS SIGNS WITHOUT OBVIOUS SKELETAL INJURY		
Concussion	5	
Contusion	4	11
Infarction	2	

Concussion

After a fall or blow, transient, incomplete neurologic signs without bladder involvement are present for a matter of hours up to 2 days. All are due to cervical injuries. Rest and observation are all that is required, because recovery is quick and complete.

Contusion

A contusion of the cord is defined as a lesion that results in some degree of permanent local destruction.

Contusions occurred at all levels and showed the spectrum of severity seen in adult paraplegics. All patients improved, but to varying degrees. All required correction of lower-limb spastic deformities, and one required surgical correction of scoliosis.

Infarction

A complete, permanent, flaccid paraplegia below the midthoracic region is the characteristic feature of infarction. In one patient, the onset was delayed for a day. Arterial damage was confirmed as the cause of the paraplegia in one patient. The blood supply of the thoracic cord depends on the arteries of Adamkiewicz, the spinal branches of the first and the eleventh intercostal arteries. Anastomosis between these vessels is said to be poor, and there is little supply from intervening intercostal arteries. If the eleventh intercostal artery is damaged, infarction of the cord up to the midthoracic level may follow. Because the whole cord is not functioning, the paraplegia will be flaccid, in contrast with the spastic paraplegia produced by a segmental lesion. The pathologic findings in this rare condition are well described by Ahmann and associates.[1]

CORD INJURY WITH VERTEBRAL FRACTURE OR DISLOCATION

We have seen 31 children with cord injury concomitant with fracture or dislocation, which range from birth injury to injuries sustained by 14-year-olds in car accidents or falls. I am not going to write a treatise on traumatic paraplegia; you can read many papers on this subject. But the pattern of childhood injuries shows some important differences from that in adults, and children have special long-term problems (Table 22-2).

Table 22-2. Fractures with Cord Damage in 31 Children

C 19	3 died early	
	6 complete	5 permanent
		1 useful recovery
	10 partial	6 normal
		4 useful recovery
T 10	1 died with multiple trauma	
	9 complete and permanent	
L 2	1 complete—recovered	
	1 partial—useful recovery	

PATTERN OF INJURY RELATED TO PROGNOSIS

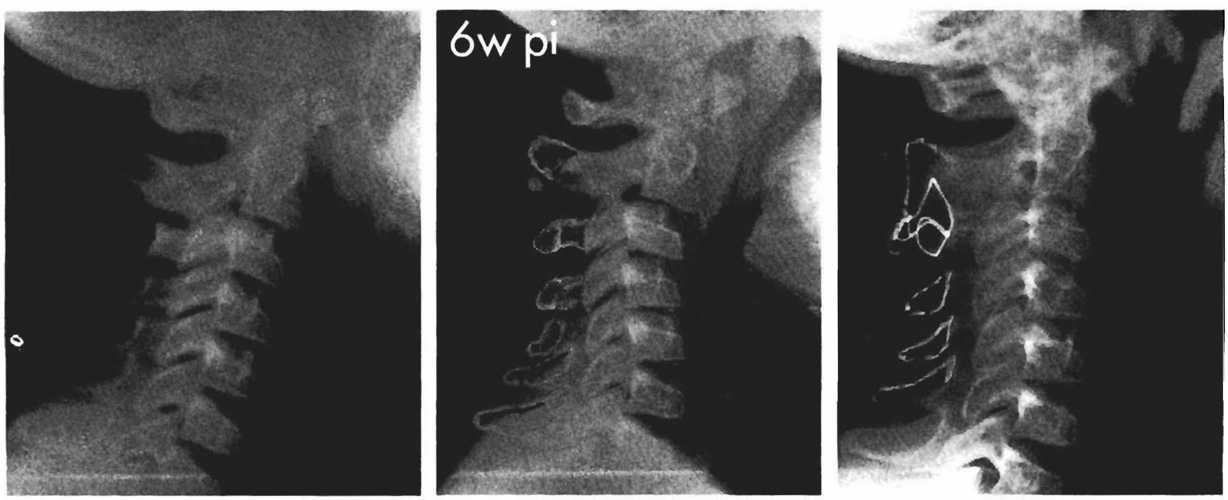
Thoracic Injuries

The prognosis for recovery in thoracic injuries is hopeless. The majority of injuries were fracture dislocations, and it may be assumed that the cord was transsected initially. Some of these children were nursed in bed, some had fusions, and some had laminectomies, but nothing made any difference. When the cases were reviewed some years after their injury, it was found that the patients were all alive, they were all at school or college, and all were in wheelchairs (Figs. 22-5, 22-6).

Cervical Injuries

By contrast with the thoracic injuries, the cervical injuries showed considerable variation in the extent of initial damage. Three children died; one was apneic after a forceps delivery, one was apneic after a C1–2 dislocation and fractured skull, and the third had multiple injuries. However, most of the lesions in patients who survived long enough to be admitted to the hospital were incomplete with a hemiplegia

Fig. 22-3. An occult fracture. Twelve-year-old Geoffrey was somersaulting off a box when he landed painfully on the back of his head. Immediate x-ray film was normal. After 3 weeks the avulsed cartilage of the spine of C2 had formed enough bone to reveal the injury of the posterior complex. Despite prolonged immobilization, the subluxation remained. Posterior fusion was undertaken to protect from a more severe injury in the future.



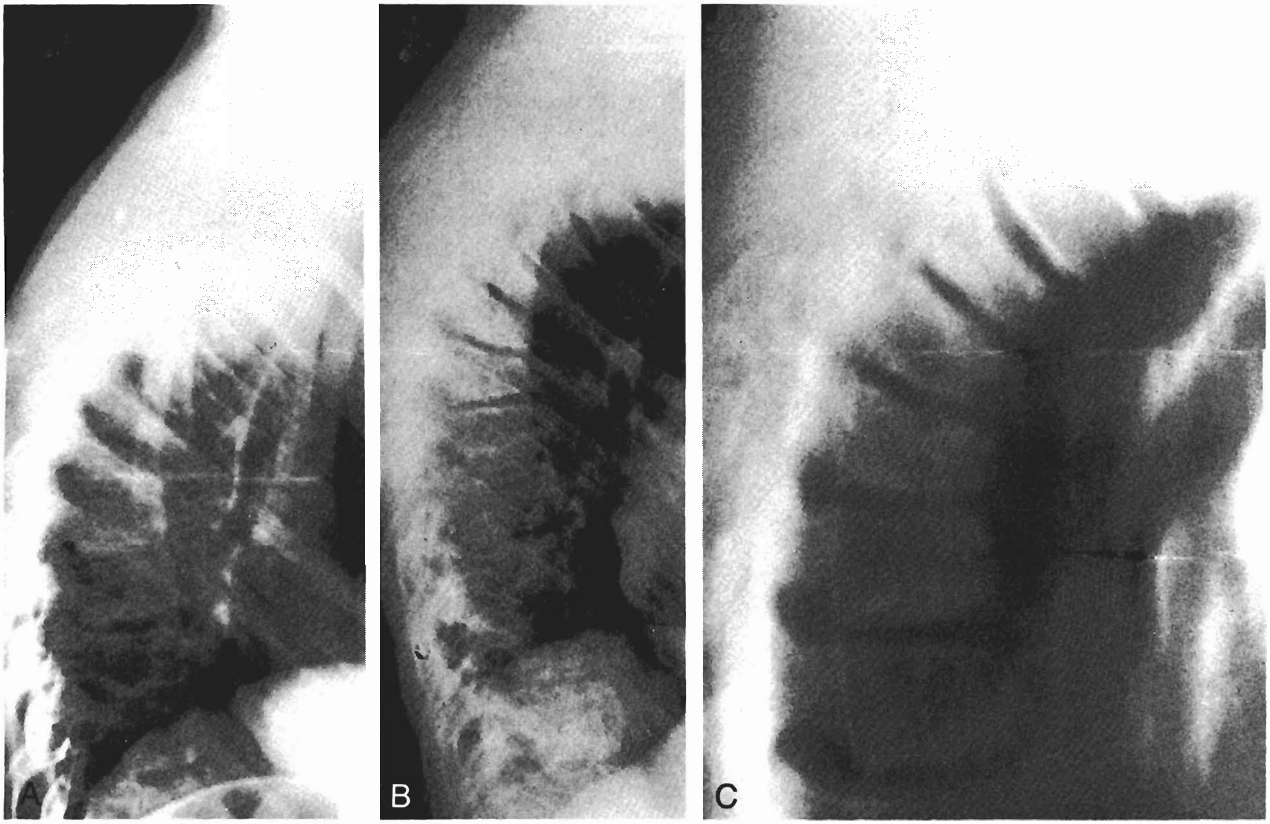


Fig. 22-4. High thoracic wedge fractures are easily missed. *(A)* This film, centered low, was passed as normal. *(B)* When it was repeated with better centering, the wedge fracture could be seen and confirmed on tomograms *(C)*.

Fig. 22-5. Gary fell out of a tree at the age of 14 years, sustaining a fracture–dislocation of T9 and T10 and a total paraplegia. The dislocation was reduced and a laminectomy performed. The spinal lesion remained complete, and he required a fusion to correct kyphosis. Eight years later he is attending college in a wheelchair.

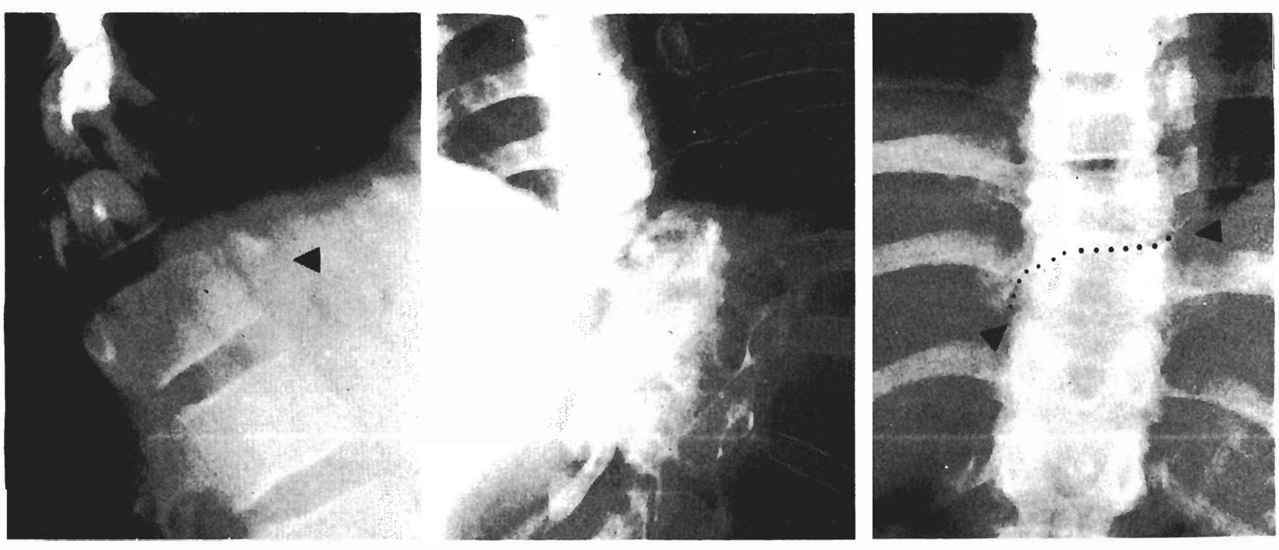
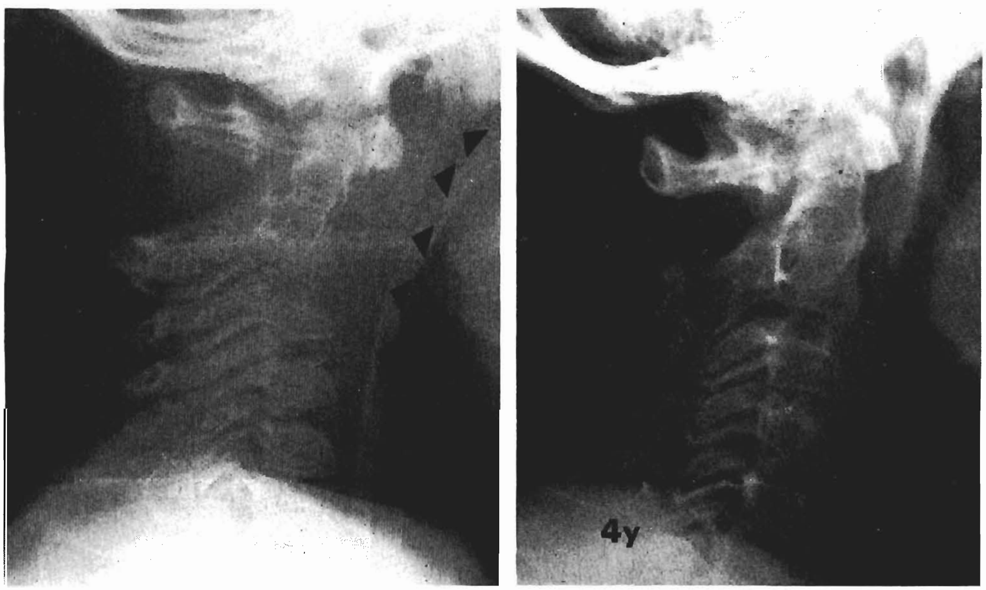


Fig. 22-6. Bursting fracture of T3. This girl sustained a grossly displaced fracture of the pelvis, and inability to move the legs was attributed to plexus lesions. The high thoracic spine shows up poorly on radiographs. Only when she was transferred to another hospital and reassessed was it realized that her legs were spastic, as distinct from stiff. Tomographs revealed the spinal fracture. She has recovered sufficiently to walk with aids after hip and ankle releases.

Fig. 22-7. Fracture of odontoid with retropharyngeal hematoma. Boy aged 5 years injured in a car accident. He had a complete right motor hemiplegia without sensory loss, which recovered to a great extent. He was treated in a Minerva cast. Retropharngeal widening is a poor sign in children. The space becomes very wide when a child is crying and breathing in with the mouth closed.



(rather than paraplegia or quadriplegia) occurring in 50% of the group (Figs. 22-7, 22-8).

Injury occurred at all levels in the cervical spine; the only striking feature was that locked facets, so common in adults, were not seen in children. Only one child in this group had an underlying congenital bone anomaly, but this is a recognized predisposing cause.

The majority of children were treated in traction until the fracture was stable, and then placed in a Minerva cast. Very few were fused. Fusion is required for atlanto-occipital and atlantoaxial instability in many dwarfing conditions and in Down's syndrome.

Lumbar Injuries

Both injuries were high lumbar lesions, and both showed recovery. One child who had a complete lumbar lesion recovered after laminectomy.

LONG-TERM PROBLEMS OF PLEGIC CHILDREN

In this group of spinal injuries, only one child has died. She died of pneumonia about 1 year after a complete C5 quadriplegia. The remaining children are active and are in educational programs.

Spinal Problems

In our series, about half the children with complete thoracic paraplegia required spinal fusion for deformity. Of 14 children, 5 were treated by Harrington instrumentation, and 2 more were treated by long fusions at the time of their injury (Figs. 22-9, 22-10).

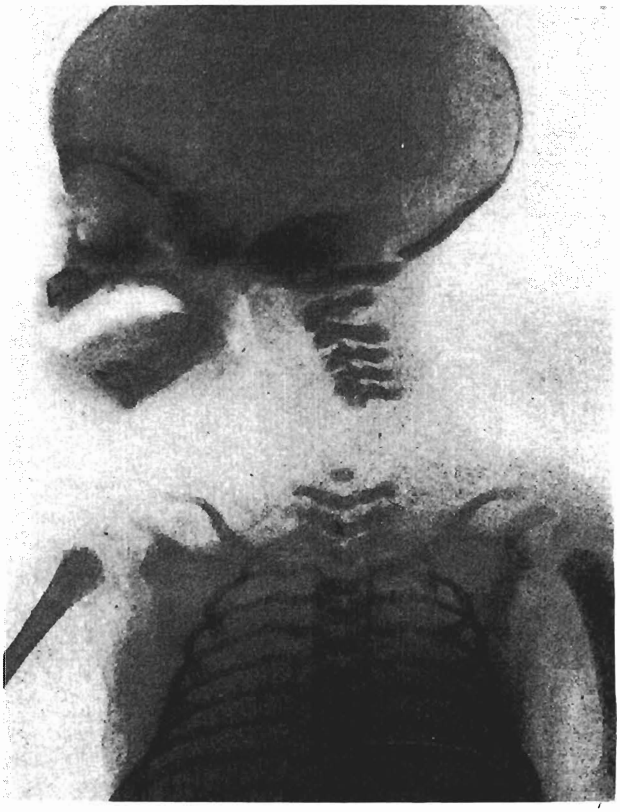
There are a number of papers on this subject.[2,3,12,13]. All draw attention to the frequency of scoliosis in children and adolescents. The risk factors for scoliosis are age at injury, spasticity, and level of lesion. Progressive angular kyphosis may damage cord function in partial lesions, and early fusion is indicated. In complete lesions the incidence of spinal deformity (lordosis, kyphosis, or scoliosis) is higher when: (1) the lesion is high, (2) there is muscle imbalance, (3) the onset of paraplegia was early in life, and (4) laminectomy has been carried out. Bracing buys time, and spinal fusion is usually required. The aim should be to abolish pelvic obliquity so that the risk of ischial pressure sores is reduced and to produce a stable, balanced spine. This is easier said than done.

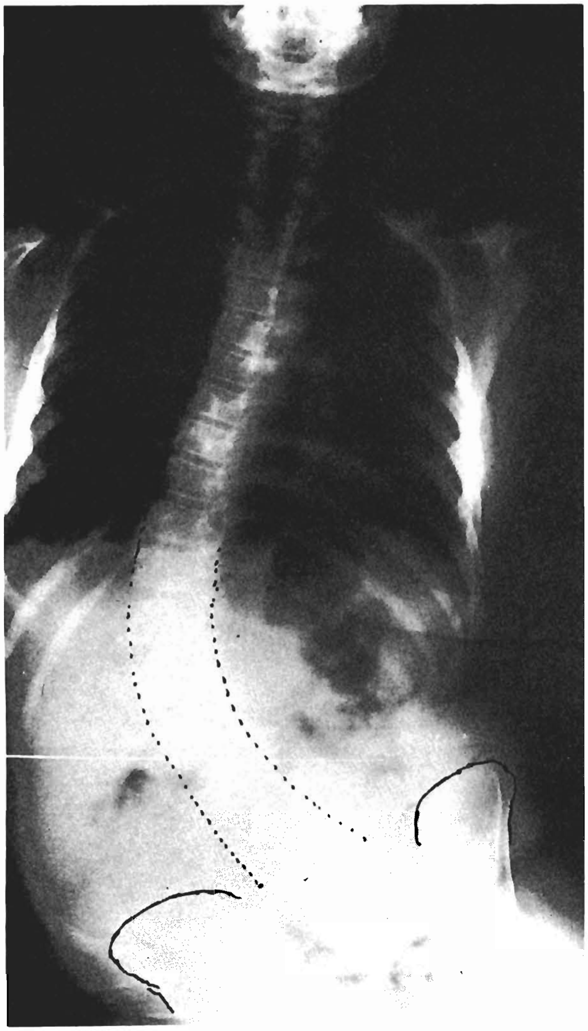
The fusion should always go down to the sacrum. It may be wise to correct pelvic obliquity with a Dwyer instrumentation and fusion, and then use a Harrington instrumentation and fusion to accomplish the lumbosacral fusion and hold the thoracic spine. This is a lot of surgery, but a review of our cases shows that there is no place for half measures. We are just beginning to use Luque segmental spinal instrumentation to correct the curves early. The system is more secure than the Harrington system.

Lower-Limb Problems

A smaller proportion of children required releases at the hip, knee, or ankle for spastic deformities (Fig. 22-11).

Fig. 22-8. A birth injury. (From Truesdell ED: Birth Fractures and Epiphyseal Dislocations. New York, Hoeber, 1917.)





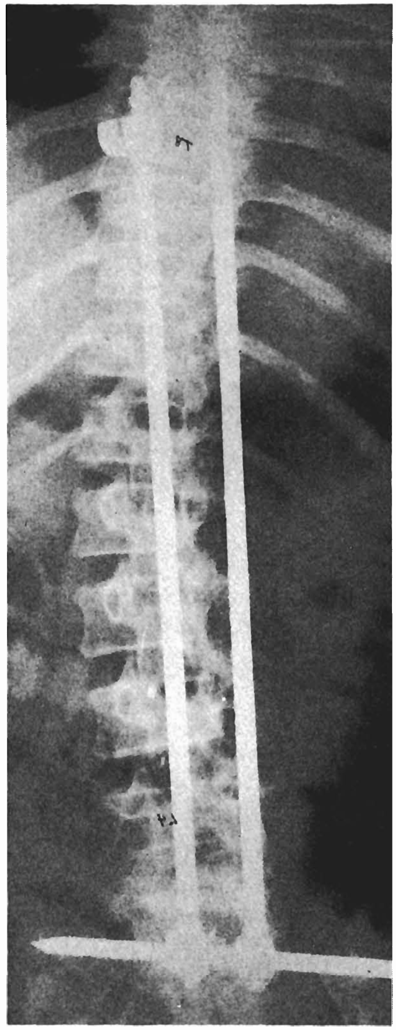


Fig. 22-10. At the age of 3 years this boy suffered a complete and permanent paraplegia owing to a fracture dislocation at T12–L1. This radiograph at age 6 years shows a scoliosis and an interesting head-within-a-head appearance of the femoral heads, representing disuse atrophy followed by activity. A Harrington fusion was carried out at the age of 7 years, which must be repeated because of pseudoarthrosis. He has also had release surgery for leg contractures. He is mostly in a wheelchair at the age of 16 years.

Fig. 22-9. This curve with pelvic obliquity was present 3 years after a complete thoracic paraplegia. Harrington fusion corrected this, though the patient's pelvic obliquity has recurred since because of pseudarthrosis. Correction of paraplegic scoliosis tends to be transient. Luque fusion is today's first choice.

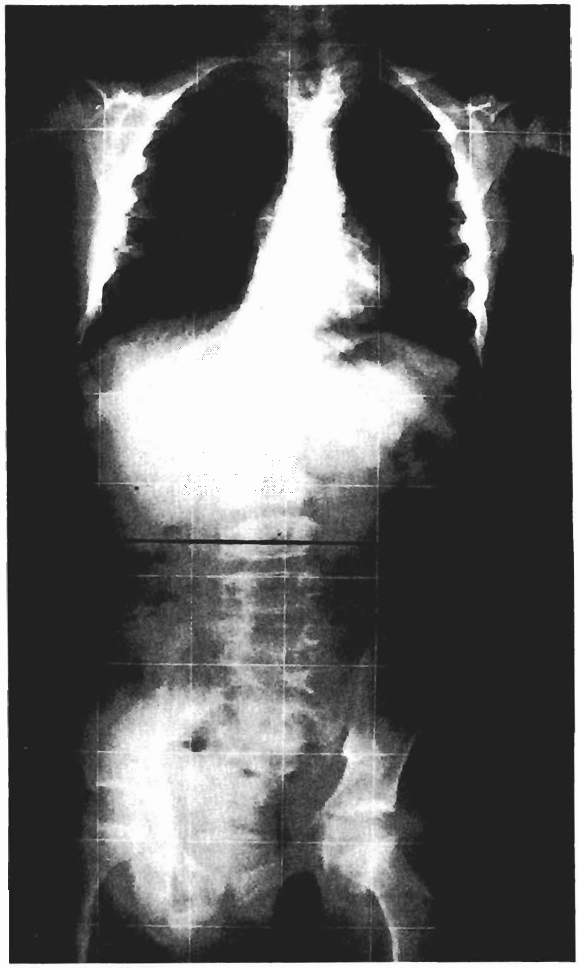


Fig. 22-11. Gunshot wound of C5 in a boy of 9 years. He had a partial cord lesion, which recovered to a partial left hemiplegia. He shows a scoliosis and has required tendon releases around the left ankle.

Urologic Problems

The urologic problems are formidable and require specialist care. None of our patients remained free of infection.

VERTEBRAL FRACTURES AND OTHER INJURIES

During this period, 45 fractures without neurologic signs were seen. The injuries were evenly distributed throughout the spine.

Cervical Spine

Children with pain in the neck after a fall are a common challenge to diagnosis. If they have a torticollis, the radiographs are difficult to understand. Furthermore, radiographs of the child's cervical spine are more difficult to interpret than those of the adult. Everyone should read a paper by Cattell and Filtser entitled "Pseudosubluxation and Other Normal Variations in the Cervical Spine in Children."[5] They note that normal children commonly show changes that could be mistaken for signs of injury (Fig. 22-12). Apparent subluxation of C2 and C3 occurs in

19% of normal children. The spine has no lordotic curve in about 15%. Epiphyseal plates may be mistaken for fracture. Remember that if a child receives a blow sufficient to damage the neck, he usually has a bruise or cut somewhere on his head.

The following injuries are commonly encountered.

Rotatory Fixation of the Atlantoaxial Joint (Fig. 22-13). Because the name suggests a chiropractic diagnosis, the very existence of this condition has been doubted. But experience is a great teacher. Wortzman and Dewar drew attention to the essential features of rotatory fixation in 1968.[18] Fielding and Hawkins described four types in 1977 and showed the value of computerized tomography in diagnosis in 1978.[7] It is so rare that I have not seen a case since writing the first edition of *Children's Fractures*.

Usually beginning with a minor accident, such as a blow to the head or a rear-end automobile collision, the child complains of pain and stiffness in the neck and occipital neuralgia. There is torticollis, which may be so slight as to be barely discernable.

Open-mouth anteroposterior (AP) radiographs show that the odontoid is asymmetrically placed between the lateral articular masses of the atlas. The diagnosis is confirmed by further open-mouth views taken with the head rotated 10 to 15 degrees to the right and left, which show no alteration of the asymmetry. This radiologic abnormality does not occur in normals, and it is not an artifact produced by torticollis. A CT scan shows the pathology clearly. It may be looked on as locking of one of the lateral joints between the atlas and axis, perhaps owing to a capsular tear and trapped synovial fringe.

If nothing is done, rotatory fixation tends to persist, though in the end most children will improve symptomatically, whether there is radiographically demonstrable improvement or not. A few patients with unremitting symptoms have required a Gallie fusion between C1 and C2 after it has been shown

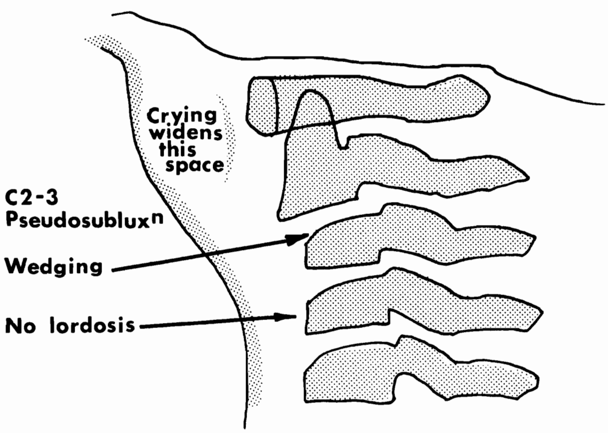
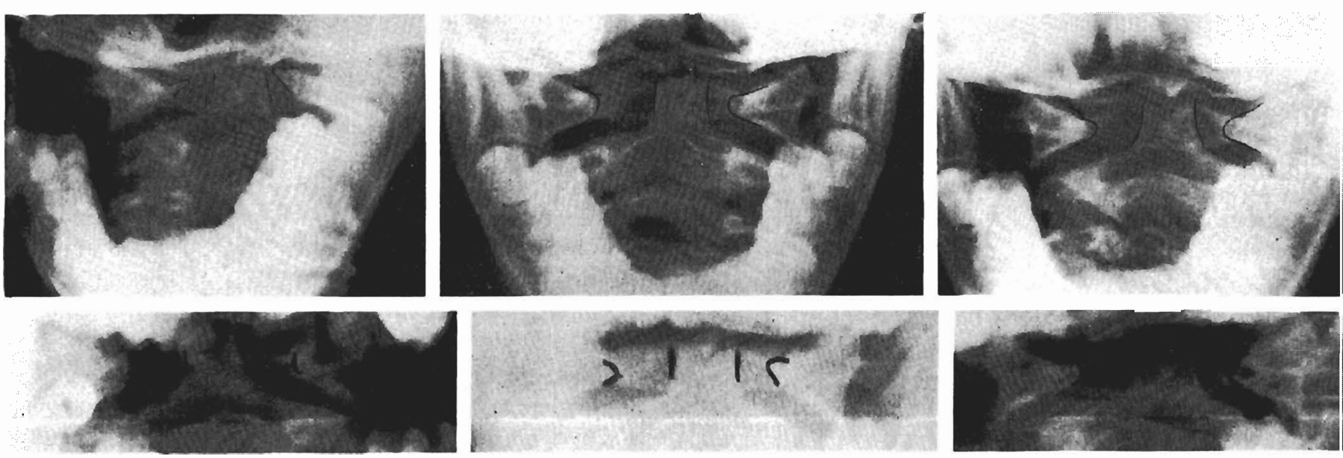


Fig. 22-12. Common variants in the normal child.

Fig. 22-13. Rotatory fixation: boy aged 7 years. The radiographs are taken looking 10 degrees to the right, looking straight ahead, and looking 10 degrees to the left. *(A)* The odontoid is displaced to the left in all views. *(B)* After 7 days in traction the odontoid is more central, and movement is taking place.



that their pain can be relieved by infiltration of the lateral atlantoaxial joints with local anesthetic under x-ray film control.

Treatment. When rotatory fixation is recognized early, the child should be admitted to the hospital and placed on continuous halter traction until the fixation has reduced on x-ray film examination. Traction for about a week is required, and this should be followed by protective ruffs for a few weeks.

Whiplash Injuries. Affecting principally asthenic, long-necked, teenage girls who have been involved in rear-end automobile collisions, the symptoms run a protracted course. Radiographs are normal. A collar and medication with diazepam seem to make little difference. The parents usually grow tired of your failure to effect a cure and move on to other doctors.

The following injuries are rare.

Subluxation or Dislocation C1 on C2. We have seen this condition only once in a child, perhaps because the ligaments are stronger than the bone. Hunter describes the nontraumatic variety in children.[11]

Jefferson's Fracture of the Lateral Mass of C1. This certainly occurs in children.

Fractures of C2. In distinction from adult injuries, the odontoid is rarely fractured. The majority of odontoid anomalies are congenital (Fig. 22-14). Fractures of the odontoid are uncommon; union can be obtained in skull traction. Obviously fusion is required for those that do not unite.[15,16]

Lower Cervical Spine Fractures. Compression fractures with dislocation may occur without cord injury. Fractures of the articular facets are also seen.

Treatment of Cervical Fractures. In our experience, traction, followed by Minerva cast, has given good results. Instability is unusual and fusion is seldom required.

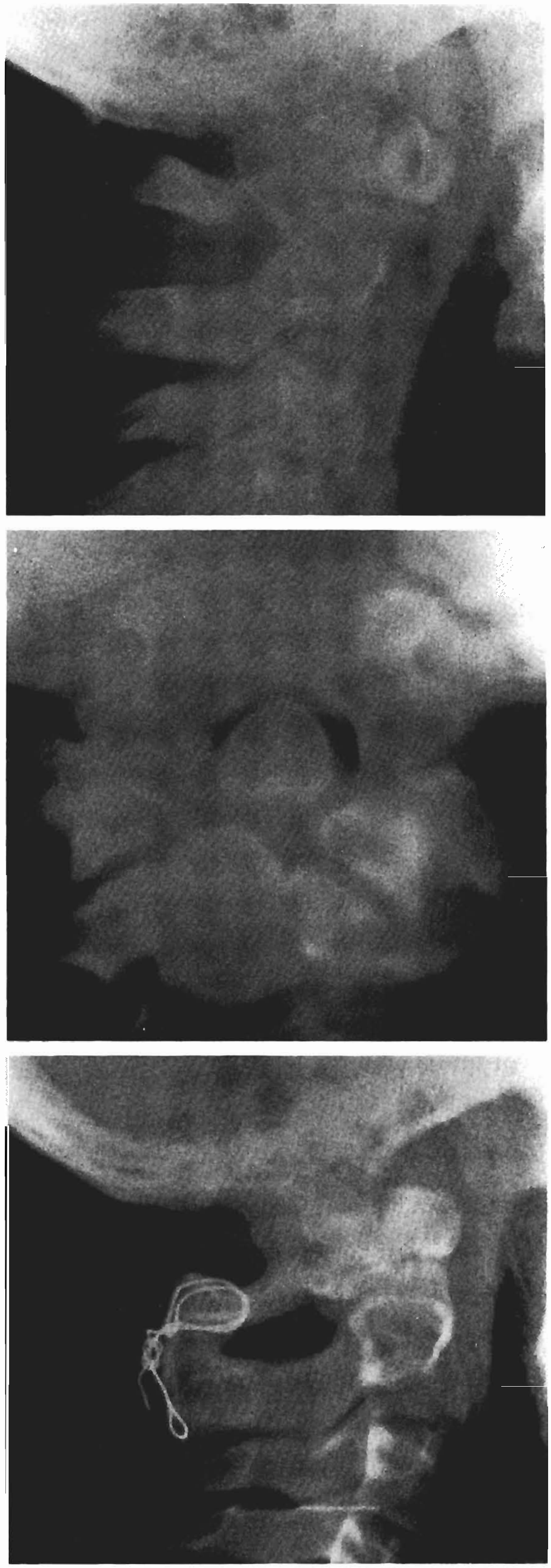


Fig. 22-14. Os odontoideum. This may represent nonunion of infantile injury. Usually discovered in the emergency department during radiography for a minor neck injury, fusion is indicated. Even after fusion, activities that impose a special strain on the neck should be restricted permanently.

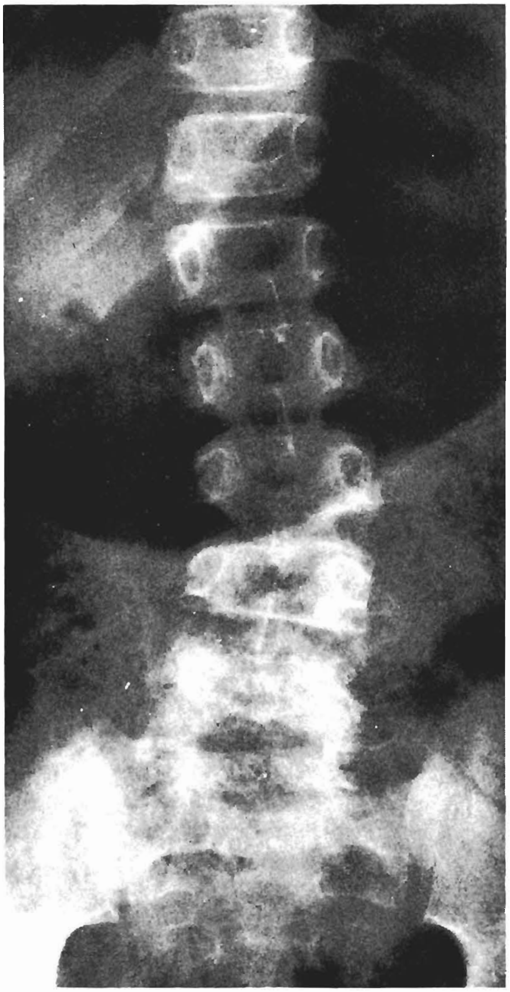


Fig. 22-15. Lateral wedge compression of L3 and L4, producing a persisting scoliosis. The extreme gastric dilatation occurring immediately after major trauma is well seen. Girl aged 6 years.

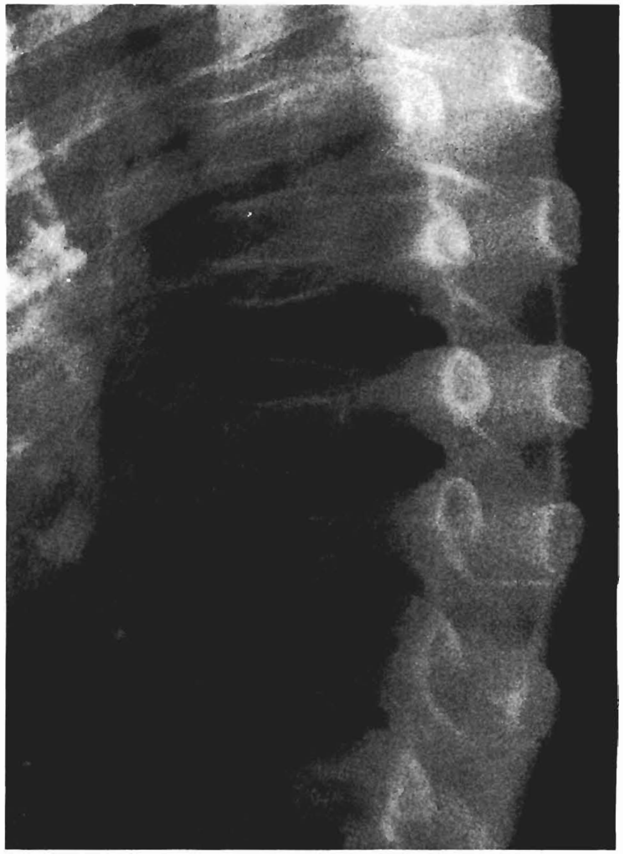


Fig. 22-16. Not every wedge fracture is straightforward. This child had leukemia.

Lumbar and Thoracic Spine

Minor wedge fractures are seen at all levels and require no more than bed rest for about 2 weeks. Relief of pain is usually rapid (Figs. 22-15, 22-16).

Recent seat-belt legislation has resulted in several Chance fractures with an without paraplegia. These youngsters would probably have died without seat belts. They sustained a flexion–distraction injury that is best treated by a short Harrington compression instrumentation (Fig. 22-17).

Fractures of the Sacrum and Coccyx

Direct violence will produce these injuries. They are difficult to recognize on radiographs. However, displacement of an intercoccygeal joint is recognizable on radiographs and causes pain on bimanual examination. The pain usually settles when a cushion (disguised as a canvas book bag) is placed on the school chair.

Sequelae

Backache. In a survey of 48 childhood spinal fractures by Horal and associates, the incidence of back pain was no greater than in the normal population.[10] Thirty-eight percent had occasional pain at the site of the fracture.

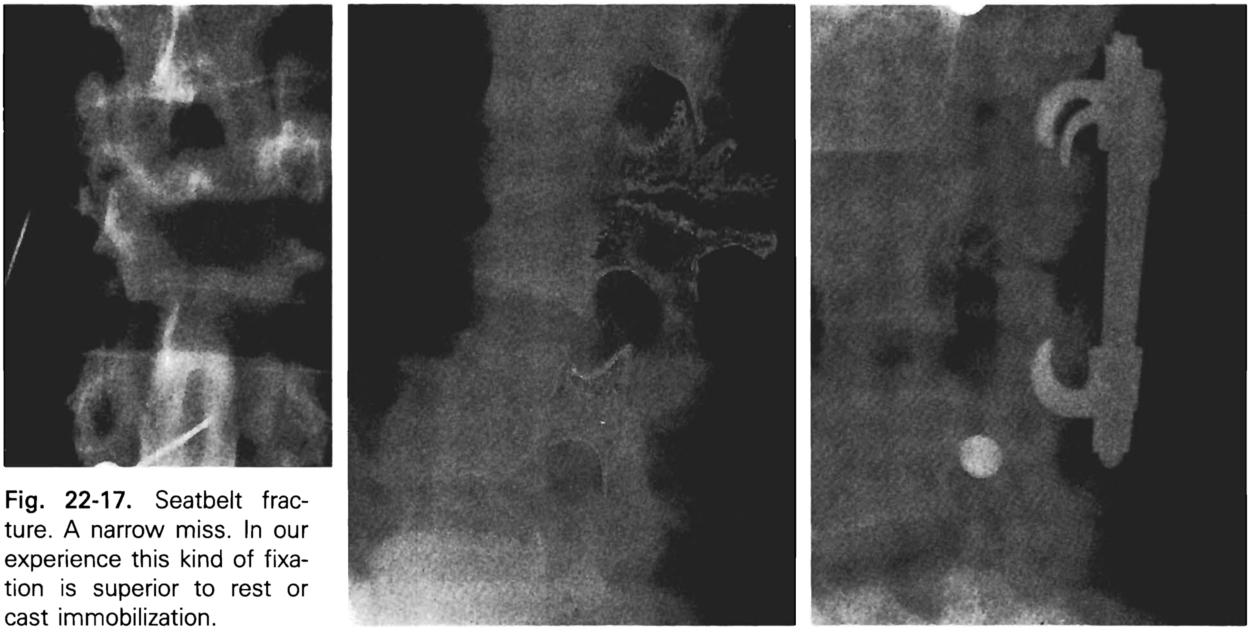


Fig. 22-17. Seatbelt fracture. A narrow miss. In our experience this kind of fixation is superior to rest or cast immobilization.

Radiologic. Time erases the signs in half the children. Fractures sustained under the age of 10 are more likely to become invisible than those in older children.[10] Congenital anterior hemivertebra can be mimicked by a previous child abuse.[6]

Nonunion. The evidence has strengthened in favor of a traumatic origin for os odontoideum and a fatigue origin for spondylolisthesis.

A BRIEF GUIDE TO THE CARE OF SPINAL INJURIES IN CHILDREN

Transportation

Transfer the patient on a spinal board, with sandbags to support the head. Helicopter evacuation to the regional spinal-injuries unit is becoming the standard for cord-injured patients.

Assessment

Detailed neurologic examination is a must. Finding some intact function in an otherwise apparently complete lesion will provide hope for recovery. In a partial lesion, increasing signs may require action, and improvements are very encouraging. Children with apparently purely vertebral lesions should be examined carefully for signs of root injury or minimal long tract signs.

Radiographs must be good enough to show the exact nature of the lesion. Order AP and lateral tomograms if they may help. A CT scan will demonstrate fractures not seen on plain radiographs and will define fractures more exactly than has ever been possible before. Decide, using Holdsworth's criteria, whether the fracture is stable or unstable. If unstable, the position must be held by traction or (rarely) by internal fixation. Because ligamentous rupture is rare in children, most fractures occur without rupture and will stabilize by bony healing. Instability produced by congenital anomalies usually requires fusion.

MYELOGRAPHY

Myelography has limited indications. It is only useful to disclose remediable cord compression that cannot be seen on plain radiographs. If there is an obvious dislocation, there is no point in doing a myelogram. Complete cervical and thoracic lesions are not helped by laminectomy, so myelography is unnecessary. Myelography is indicated for progressive deficits, or when cauda equina compression or a disc herniation is suspected.

Curative Measures

It is an unhappy fact that the cord is maximally injured at the moment of impact when the spine is maximally displaced. In experiments the injury initiates a chain of auto-destructive changes in the first few hours. This raises the prospect that the course of a spinal injury may be modified.

In clinical practice today the role of persistent bony compression is small.

Intensive Care

Acute spinal-cord injuries may require respiratory monitoring and support. Transfusion should be used if there is hypotension, which may damage the cord. During the first few days attention is given to fluid and electrolyte balance. Ileus needs attention. Abdominal injury is common in seat-belt injuries; ileum has even been trapped between vertebral bodies. Deep vein thrombosis is so common in teenagers that antiembolism stockings and anticoagulants should be used in all those above an arbitrary age of 10 years.[9]

Steroids are very effective in cerebral oedama, and this has encouraged their use in spinal injury, though without any convincing efficacy. Acute gastroduodenal hemorrhage is common when steroids are used for cervical lesions. Perhaps when steroids are used Cimetidine should be used prophylactically.

Spinal Management

The goals are:

1. To immobilize the spine so that further injury will be avoided
2. Immediate relief of persisting cord compression in certain cases of incomplete lesions.
3. To realign the spine to avoid deformity

Immobilization. The halo has largely replaced tongs because it is easily applied and can be attached to a halo vest to provide mobility. The halo will hold most cervical and upper-thoracic injuries. Lower-thoracic and lumbar injuries can be "controlled" with pillows in bed. Efficient methods of open reduction and internal fixation make surgery the method of choice.

Decompression. For centuries laminectomy has had appeal, because it has been the only alternative to doing nothing for what is, after all, the worst possible injury. Indiscriminate laminectomy is disappointing or harmful, except for the very occasional good indication.

Decompression is indicated for 1. persisting cauda equina and conus compression, because roots can repair in a way that the cord cannot; 2. incomplete cord lesions with persisting compression; and 3. progressive deficits.

Decompression may be secured by reducing the spine—traction, Harrington instrumentation—or by an anterior or posterior decompression. Morgan and associates were strongly opposed to laminectomy for incomplete lesions because half the patients were worse afterwards.[14] In our series none of the four children with complete thoracic paraplegia recovered after laminectomy. One complete lumbar lesion with lateral subluxation and wedging at L1, in a battered 10-month-old child, recovered completely after laminectomy and fusion.

After a neurosurgeon carries out a laminectomy he will step back and say, "OK, you stabilize it now." A Luque spinal segmentation instrumentation is the perfect answer.

Realignment. A permanent kyphus can be expected when there is posterior disruption or marked anterior wedging. Correction and bony healing are the best remedies.

Preventive Measures

Prevention of pressure necrosis of skin, prevention of osteoporotic fractures, prevention of contractures, and prevention of renal infection require the same vigilance as in adults.

Rehabilitation

Children with traumatic lesions are usually placed in rehabilitation with those who have meningomyelocele. By comparison, the former shine.

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APPENDIX 1/ Accident Prevention

The municipality opened a new adventure playground one weekend. Within a few hours, the orthopaedic resident had seen four fractures from the new giant rope swing. The resident called the police, who promptly closed the brand new playground. This caused much rumpus later, because the playground had been the apple of a politician's eye. But as a form of accident prevention, closing it was very effective.

A friend, Dr. Alex Kates, cared for two children suffering crushing, degloving injuries of the foot. They were on escalators, wearing rubber boots, when the boots caught in the gap between the moving tread and the stationary side. He started a campaign that resulted in a better design for escalators.

A year after I reported a boy who nearly twisted off his arm in a high-speed laundry-dryer, the Canadian Standards Association wrote a new standard that should prevent this type of injury.

Most children's fractures are trivial. They are easily treated and have no lasting effect. Accidents in general, however, cause half of childhood deaths. A campaign against accidents would have a substantial effect on childhood morbidity and mortality (Fig. APP-1). In many ways the surgeons who care for accidents have a responsibility for preventing accidents in the same way as the physicians who look after measles are enthusiastic about immunization.

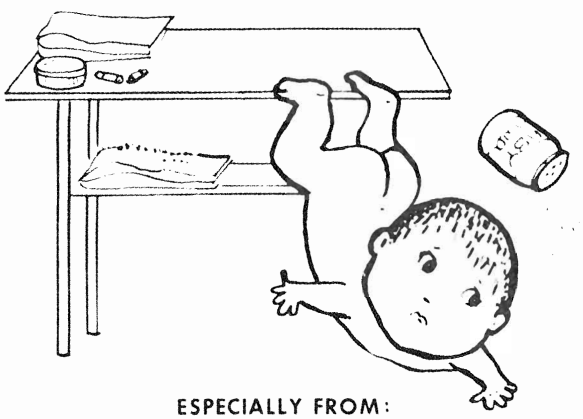
However, accident prevention is a many-sided problem without simple medical answers. The first step is to gather information; next comes the idea for preventing the accident; then this must be put into operation and evaluated. At our hospital this was done simply by the Medical Records Officer, Helen Haffey, who publishes the causes of all the accidents each year. Miss Haffey has collected many examples of common preventable accidents in a booklet entitled "Please Make My World Safe." Thousands of copies have been distributed (Fig. APP-2). Dr. Douglas Cohen of New South Wales, Australia, has been very active in promoting child safety through various campaigns. Our Easter Seal Society has just appointed a Prevention Officer who will be looking into the causes of accidents and who will develop accident-prevention programs.

Prevention programs are not easily carried through. Very often the data on which they are based are flimsy, and there is little proof that the programs will work. Many, such as seat-belt legislation, make people say that their civil rights are infringed. The program may be difficult to evaluate.

Haddon divides preventive program into active and passive categories.[1] In *active* prevention the individual must do something to help himself (*e.g.*, fasten a safety belt, put on a safety helmet, take "the pill"). In *passive* prevention the individual has nothing to do (*e.g.*, drinking flouridated water, driving a car with an airbag for crash safety). Obviously passive prevention achieves more compliance. There are few people to convince. Once decided, the program runs itself. Active prevention means that millions of people have to remind themselves about safety every day.

With improving disease control, the need for accident control in childhood becomes clearer. A few epidemiologic studies may whet your appetite for this field.

FALLS FROM FURNITURE



ESPECIALLY FROM:

BEDS
TABLES (USUALLY BABIES UNDER 1 YEAR)
CHAIRS OR HIGH CHAIRS
CHESTERFIELDS (USUALLY INFANTS UNDER 6 MOS)

HOW YOU CAN HELP

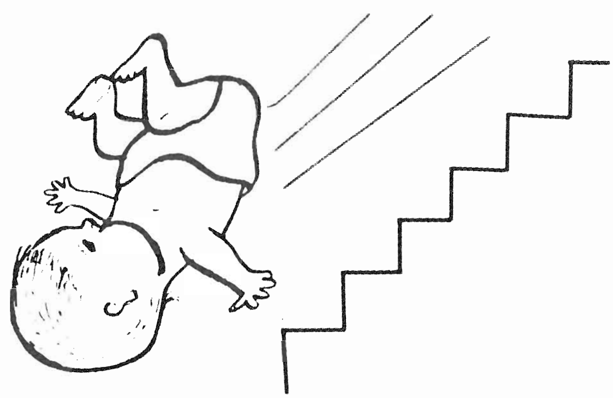
NEVER LEAVE A BABY ALONE ON A TABLE OR BED
IT TAKES ONLY A FEW SECONDS TO ROLL AND FALL OFF
DON'T ALLOW STANDING ON CHAIRS

MORE THAN 700 ARE TREATED EACH YEAR

Fig. App-1. Accidents don't just happen.

Fig. App-2. Pages from *Please Make My World Safe,* a parents' booklet. Reproduced by courtesy of Hospital for Sick Children, Toronto.

FALLS ON STAIRS



HOW YOU CAN HELP

NEVER LEAVE A CHILD IN A WALKER OR STROLLER NEAR THE STAIRS
CLOSE THE DOOR TO THE CELLAR STEPS
PUT GATES AT TOP AND BOTTOM OF THE STAIRS
KEEP CRAWLING INFANTS AWAY FROM STAIRS

MORE THAN 600 ARE TREATED EACH YEAR

Traffic Accidents

Although only about 20% of children's accidents are due to traffic, they are among the most serious. In one study children were asked four simple questions related to traffic rules; for example, what is a crosswalk? and what do the different colors on a traffic light mean? Not until the age of 11 to 15 years could 70% answer these questions correctly.

Skateboarding

Epidemics of injuries moved around the world in the wake of the skateboard. Many studies have been published. Protective clothing *and* skateboard parks are the best prevention.

Horseback Riding

The injury rate is low: about one accident every 1330 rides. The greatest risk to children is riding in a group without supervision. Most injuries are the result of falls. Severe injuries are the result of being dragged along by a stirrup. There is probably a greater place for stirrups that release when traction is applied. Current helmets do not provide much protection and should be redesigned.

Farm Injuries

Farm safety organizations are active. Auger injuries frequently result in amputations.[2]

Snowmobile Injuries

Few young children are injured by snowmobiles. Teenage drivers suffer most of the injuries. Some are injured because of speeding. Collision with cars on the highway are often fatal. Many leg injuries are the result of the leg getting trapped under the snowmobile as it turns over. Snowmobiles are not safe transportation. The injury rate per 1000 vehicles in Sweden is as follows: mopeds—4.45; automobiles—5.26; snowmobiles—17.7; and motorcycles—28.24.

Safety may be helped by creation of snowmobile trails away from cars, by wearing helmets and by speed reduction.

Snowblower Injuries

Every year we see mangled limbs caused by snowblowers. Children slip in front of the intake. These powerful machines, with poor safety features, used only a few times a year in poor weather, should be kept away from children.

Bicycle Injuries

The bike with a tenspeed is a close relative to the motorcycle. Today, two-thirds of cycle accidents produce craniocerebral injury. Four percent of admissions die. Some answers to this problem are described on page 353.

Lawn-Mower Injuries

Very serious injuries are produced by the rotating blades of a lawn mower. Missiles are flung out at 100 mph. Riding lawn mowers overturn.

Falls From Buildings

Hot weather and defective screens mean that children will fall from high-rise buildings. While adults tend to fall feet first, sustaining fractures of the heel and pelvis, children, with a larger head, fall head first. Fractures of the skull and upper limb are most common.[4] In New York City 20% of accidental deaths in children result from vertical falls.[3] We have legislated safety in high-rises, but still the deaths continue.

Water Sports

Diver's quadriplegia is the number-two cause of traumatic quadriplegia on the West Coast. Young men run into the ocean, take a running dive, and hit the bottom. Some have been drinking, and most misjudge the depth of the water.

Clearly, divers should check the depth of the water before diving. They should "jump before they dive." We are starting a poster campaign along these lines.

Knife and Gun Club

Interpersonal violence produces the most serious injuries in some regions. There are many approaches.

In Michigan, for example, a law was passed in 1977 whereby any person convicted of a felony while in possession of a fire arm automatically received a 2-year jail sentence without parole. At Detroit General Hospital gunshot wounds decreased by 50% and stab wounds remained little changed.

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APPENDIX 2/

Sports Medicine

The ancient Greeks introduced the concept of competitive sports; the human ideal was the complete person who used every ability. The Puritans considered all sports frivolous, almost destroying the idea; but today nearly everybody takes part in one sport or another, and this has lead to the development of sports medicine.

Sports medicine has four possible roles: (1) sports medicine clinics, (2) health surveillance of athletes, (3) studies in epidemiology, and (4) prevention of injuries.

SPORTS MEDICINE CLINIC

Athletes prefer special clinics because they do not want to feel freakish among the wise-cracking gerontocracy of the average Physiotherapy Department. Athletes are often addicted to their sport. They want to meet people who are knowledgeable and sympathetic about athletic injuries. They may hurt only when playing their sport, tempting a physician to say, "Perhaps you should give it up." This suggestion will fall on deaf ears. Athletes want advice on changing technique, substitute activities, and better equipment; they will be prepared to put in hours of work getting into shape once more. They will want to use the latest fad in treatment. They want to get back to their sport, and need to know when it is safe to do so. A goal-setting program fills this need: "When you can walk for 10 minutes without pain you can start to jog. Ten minutes of pain-free jogging means that it is safe to try running." Printed handouts dealing with common problems save a lot of explanations and improve compliance.

Sports medicine clinics should be organized at times that are convenient for sports people, and they require physiotherapists on the spot. A close relationship should be built up with sports clubs and schools.

Problems of two kinds come to sports medicine clinics—injuries and exertional pain. In one study of national track and field athletes between 10 and 15 years of age, it was found that 13% suffered injuries each year and that 20% suffered exertional pain conditions.

THE CARE OF COMMON INJURIES OF THE KNEE AND ANKLE

Knee-ligament injuries are common in adolescents and rare in younger children. An important part of physical examination of any acutely injured knee is the inclusion of the Lachman test, which has been very helpful in the diagnosis of anterior cruciate ligament injuries, which are perhaps the most common serious injury. Ligamentous injuries are differentiated from epiphyseal separations by stress x-ray films. In the younger child, a general anesthetic may be necessary to carry out a satisfactory examination. Arthroscopy is playing an increasing role in the diagnosis of acute hemarthrosis.

Management. Grade-1 ligament sprains of the medial and lateral ligaments are usually treated with a Jones bandage and partial weight bearing with crutches. After 5 to 10 days the knee is comfortable and physical therapy can be started to rehabilitate the hamstrings, quadriceps, and adductor muscles by means of isometric exercises.

Grade-2 and some Grade-3 medial collateral ligaments without evidence of anterior cruciate ligament instability can be treated in a cast brace, with the last 30 degrees of extension blocked. This protects the ligament without causing stiffness. Strengthening exercises can be carried out. A window can be cut in the cast to permit faradic stimulation.

The success of rehabilitation can be judged by muscle bulk and muscle strength. At the beginning of treatment, measure the thigh circumference 20 cm and 30 cm above the adductor tubercle on both sides. Ask the therapist to measure the maximum quadriceps and hamstring lift on the uninjured side. After treatment is completed, the patient should regain normal thigh circumference and weight-lifting capacity on the injured side before returning to contact (collision), jumping, or cutting sports. The patient's cardiovascular condition can be maintained by straight-ahead running on the level, by swimming, and by bicycling. Upper-extremity strength can be maintained by weight lifting for sports that require this, such as gymnastics, wrestling, hockey, and football.

When returning to a sport, the athlete should complete one full practice before being allowed to play any games. It is worthwhile emphasizing conditioning and home programs by constant reinforcement at each visit.

Ankle

Ankle injuries in children with open growth plates are usually treated with a below-knee walking cast. It is done because many have injured growth cartilage, and all find it easier to get to school with a cast on than to attempt partial weight bearing with crutches. After growth-plate closure, ankle sprains of Grade 1 and Grade 2 (without laxity on the anterior drawer and lateral tilt tests) can be treated with supported wrapping to reduce swelling and by crutches or a cane until weight bearing is comfortable. Icing and ultrasound may reduce symptoms and may make it possible to begin pain-free movement early. As soon as comfort returns, strengthening exercises for the tibialis anterior and peroneals become important.

Before returning to play there should be pain-free full movement, equal peroneal strength on manual testing of both ankles, and the absence of pain on stress. The patients should be able to jump on the spot and run in figures of eight to show that there is no residual instability. They should complete a full practice before returning to competition, and they should tape the ankle to avoid reinjury. Taping of ankles in athletes with recurrent injuries and in high-risk sports is popular; exercises on a balancing disc are helpful.

HEALTH SURVEILLANCE

Children should be fit for the sport in which they take part. If children with epilepsy want to swim, special precautions must be taken. You may be asked whether a child with vision in only one eye should play ice hockey. How long should a child with mononucleosis stay away from gym in order to avoid the risk of a ruptured spleen?

Few of these issues are orthopaedic problems, and family practitioners undertake most of the work. Many excellent guides have been prepared that deal with the techniques of examination, the conditions to consider, and the appropriate advice.

Parents often feel angry when children are prevented from taking part in sports because of a handicap. They are equally angry when their child is injured in school sports. Writing this chapter was interrupted by an afternoon spent in court while a parent was suing the School Board for a sports injury. Helen was good at the broad jump. On this occasion there was a little sand on the take-off spot so that she landed badly in the sand pit; she twisted her back. Intractable sciatica followed. At laminectomy she had a rare condition (described first by Keim)—a congenital absence of the posterior articular facets between L5 and S1 on one side. I had no doubt that the congenital anomaly rendered her vulnerable to her disc injury following minor trauma. The School Board lost the case on the grounds that they should have ensured that there was no sand on the take-off area. The fact that the girl had an almost undetectable anomaly was considered irrelevant. I was glad that I had not been asked to pronounce her fit before she jumped, because I might have been the defendant.

On the other hand, parents of children who have been declared unfit for sports may feel that their child's rights are infringed. Some local schools get around this by allowing parents to sign an indemnifying contract, but our school principals are not allowed to tell the parents that this mechanism exists. In the U.S.A., high school and college students who have lost an organ, limb, or appendage have been excluded from unsuitable contact sports, but this policy has been challenged.

As a guide to sports for people with disabilities or for those who are recovering from disabilities, a sports-classification table is included (Table App-1). It serves as a useful basis for discussing what is safe and what should be avoided.

EPIDEMIOLOGY

Many different organizations are collecting injury statistics—the Canadian Ski Patrol, hospital emergency departments, consumer associations, safety councils, The National Electronic Injury Surveillance System, medical associations, and sports associations. The largest is the National Athlete Injury Reporting System, in the U.S.A. These surveys make it possible to compare injury rates at various levels between different centers for different sports. Risk factors can be prepared and trends can be watched. The pattern of injury in each sport becomes obvious. Unexpected or bizarre problems come to light; for example, how many people know that scuba divers suffer eye injuries as a result of the elastic straps on their goggles? The wet goggles slip when they are stretched away from the face to clear them and rebound into the eye. Velcro straps are safer. Simple changes in many sports will make for safety. All injuries should be considered worthy of prevention, however unusual the injury.

Injury rates can be expressed in many ways.

Significant Injury Rate. A significant injury is defined as one that curtails athletic participation for

Table 1. Sports Classification

	COLLISION	CONTACT	NON CONTACT
STRENUOUS	Football Hockey Wrestling Rugby Boxing Judo	Team basketball Soccer Field hockey Squash Racket ball Team volleyball	Track and field Cross-country running Weight lifting Gymnastics Cycling Tennis Skiing Swimming Fencing Rowing
MODERATELY STRENUOUS	Trampoline	Recreation baseball Recreation basketball Recreation volleyball	Golf Table tennis Badminton Recreation swimming Scuba diving
MINIMALLY STRENUOUS	Skydiving British bulldog	Diving	Archery Riflery Bowling Recreation swimming Curling Sailing Skating

(Modified from Hirsch PJ, Hirsch SA: Check out for the would be athlete. Emergency Medicine 12:65, 1980.)

more than 7 days. The rate is expressed as the number of significant injuries per person per thousand athletic practices or games.

Significant Injury Rates—1977

Softball	0.6
Baseball	0.6
Field Hockey	0.9
Volleyball	1.0
Basketball	1.5
Soccer	2.0
Ice Hockey	2.3
Football	2.9
Wrestling	3.3

(Powell JW: Pros and cons of data-gathering mechanisms. In Vinger PF, Hoerner EF (eds): Sports Injuries. The Unthwarted Epidemic. Littleton, PSG Publishing, 1981)

Total Injury Rate. This describes the total number of injuries per person per thousand hours of participation.

Total Injury Rate

Swimming	0
Baseball	0.14
Soccer	0.29
Gym	0.85
Basketball	0.88
Football	1.72

(Chambers RB: Orthopaedic injuries in athletes (ages 6–17): Comparison of injuries occurring in 6 sports. Am J Sports Med 7:195, 1979.)

The Death Rate Per Year. It is an approximation based on 10 days of activity per year for most sports and 25 days for football.

These figures may provide guidance for people who have yet to decide which sport to participate in.

Death Rate Per Year

Technical mountain climbing	1:167
Hang gliding	1:560
Parachuting	1:570
Gliding	1:1710
Professional boxing	1:2200
Scuba diving	1:2400
Snowmobiling	1:7600
College football	1:33000
Racing skiing	1:40000

(Reif AF: Risks and gain. In Vinger PF, Hoerner EF (eds): Sports Injuries. The Unthwarted Epidemic. Littleton, PSG Publishing, 1981.)

The Incidence Rate for Overuse Disorders. Some of these disorders, such as Little-League elbow, are seen only in young athletes; others, such as heel pain or retropatellar pain, occur in nonathletes as well. In a Finnish study it was found that 20% of athletes had one or more episodes of overuse or exertional disorders.[1] Those who trained most had more problems. Two-thirds were specific athletic syndromes, and the remainder were common in nonathletic children of the same age.

PREVENTION

People participate in sports to become fit, not to become paraplegic and not to become a candidate for total knee replacement. Yet the frequency of major knee injury in sports, particularly football, makes sports a major cause of osteoarthritis of the knee. Should anything be done about this problem?

Epidemiologic studies in other sports have provided the best lead to prevention strategies. For example, skateboard injuries have declined as a result of protective clothing and the growth of skateboard parks.

Bicycle safety has been a subject of an excellent report by the American Academy of Pediatrics. Forty-seven percent of deaths on bikes occur between the ages of 5 and 14 years. Accidents are due to losing control after hitting a hole in the pavement or becoming flustered by traffic and to riding a bike of inappropriate size. Collisions with a vehicle often happen close to home and occur at intersections. The child may ignore a stop sign. Hence accidents may be prevented by education, bicycle flags, good upkeep, parents setting a good example, bike paths, helmets, and special clothes that do not flap into moving parts.

Skiing has become much safer as a result of improving equipment and of emphasis on lessons, but every winter brings a crop of injuries in first-time skiers. They rent skis, their bindings are not adjusted, and as they slide slowly down the beginner's slope, without the thought of a lesson, they are surprised to hear their tibia crack. It is so unnecessary. An effective antidote to this behaviour remains a test in ingenuity.

There are several common-sense principles for the prevention of injury:

1. **Conditioning.** Muscle strength, cardiovascular fitness, and endurance take time to build.
2. **Warming Up.** This reduces the likelihood of muscle strain or stumbling with injury to a joint.
3. **Instruction.** People should learn the correct way to do a thing from the start. Hazards should be appreciated.
4. **Suitable Equipment.** The equipment should be the right size and be well maintained. Appropriate storage is important.
5. **Psychologic.** Attitude is important. Sport is a substitute for the life-and-death struggle—not the struggle itself. Sports people should not play to injure others. They should not play when injured themselves. There is no place for playing dirty to win, for crazy parents, or for coaches with no thought for tomorrow.
6. **Rule Enforcement during play.** Good referees are not afraid to blow the whistle.

SPORTS FOR THE DISABLED

Wheelchair sports are now so widespread that there are clubs for most people who want to take part. Other disability groups form sports associations, and there are few sports that have not been modified for the disabled. Downhill skiing with modified equipment has been very popular. Kayaking for paraplegics is just beginning, and last year we had our first sailing program. A large arena for the disabled has been opened locally. Much of the effort that formerly went into supplying the basic needs of the handicapped is now going into providing recreational needs.

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APPENDIX 3 / Grief and Disaster

A doctor has to deal with grief every time a patient develops problems as a result of his care. Sometimes he may feel he has been negligent or made a wrong decision. At other times, a patient moves from one complication to another even more serious, in the course of the exemplary treatment of a trivial condition. The surgeon grieves for the patient, regrets the exhibition of his own stupidity, and perhaps has fears of litigation. These patients keep coming back, and the surgeon's grief can prevent any further useful intervention. The patient senses this change from optimism, bred of competence, to ineffectiveness. Complaints are stated more forcefully, in order to stir the doctor into activity again; but this only makes things worse. Indeed, the doctor's whole outlook on this particular problem may be permanently altered. For example, after missing one case of acute appendicitis he may feel compelled to remove the appendix from everyone with the vaguest suggestion of acute appendicitis, until he trusts his judgment once again. Many doctors show cyclical behavior in the treatment of disease.

At the moment, I can think of a number of patients I dread meeting because of the memories they bring back.

Why was I so stupid?

Why did I try to obtain a perfect rather than an adequate result, only to be left with a disaster?

Why did I treat this patient at all?

He had so many injuries, I thought that this one was the least of his problems.

I should have asked him back for a check radiograph and ignored that he lived a hundred miles away.

It didn't look 100% right, but I thought I would get away with it.

Grief is certainly a learning experience. But how do you live with this feeling? You can become a heavy drinker, become more secretive, become obsessional about every detail, seek a less demanding practice, have second opinions whenever you sniff danger, and create scenes every time one of your assistants makes an error.

My own practical solutions to the problem of professional grief are these: (1) Accept that persons in every occupation make errors, and we cannot expect to be immune. (2) Look at the patients of other surgeons. When I hear a paper at a meeting I am led to imagine that the author never makes a mistake. But statistics hide many faults, and quiet many a complaining tongue. Seeing somebody else's work, you will realize that you are not alone with disasters.

There is nothing more comforting than listening to the justifiable complaints of a patient mismanaged by a senior man you admire. (3) Get on with treating your patient again. Forget the reason for the problem long enough to make a decision about the next step. For example, if a patient has a supracondylar fracture that goes on to malunion because you misinterpreted a radiograph, there is nothing to be gained by looking at it every month and hoping that it will go away. Instead, you should book the child for corrective osteotomy in 3 months' time.

Behind this feeling of grief, you will also have very real fears of litigation. A doctor needs courage to admit even a trivial error because of the risk of painful and expensive consequences. This sesms unrealistic. Most industries and businesses have mechanisms for dealing with error. The whole system of guarantees on manufactured goods is designed to handle errors in an easy way, and more particularly to limit the liability of the company.

In Ontario, and in other places, legislation exists to provide modest recompense by simple means for the innocent victims of crime. It would seem timely to provide some comparable method of recompensing patients with iatrogenic problems by something less elaborate than suing the doctor or the hospital. For the patient without subsidized legal aid, the cost can be prohibitive. For the doctor, the commotion and opprobrium generated make litigation something to be avoided by all means. There is much to be said for making admission of error possible. The Workman's Compensation Board has done this for industrial accidents. Perhaps the Medical Protection Association and the Ministry of Health could do something in the same direction. Even the car-insurance industry has accepted a "no fault" plan because of the costs and difficulties of establishing liability. The main problem to be expected from such a plan is that it might soon be swamped with claims by patients who believe that every consequence of an illness is due to medical negligence. Until these legal innovations are made, the surgeon has to struggle with the sense of grief, and try to be honest.

APPENDIX 4

Writing a Medicolegal Report

You will probably write many reports. At first they will seem useful as a lucrative adjunct to your practice, but as time goes by you will meet many parents who can ill afford the cost of your report for an action that is unlikely to succeed. Reports are time-consuming to prepare, because very much more detail is required than you normally use for the purpose of making a diagnosis and recording and assessing treatment.

The quality of reports varies a great deal, yet lawyers very seldom send them back for improvement. Perhaps they don't read them. You can improve your reports by writing in a clear, unambiguous, accurate, and detailed fashion. Remember that you are writing as an unbiased expert, and you should not write an extravagant report for the plaintiff and a deprecating report for the defendant. "This dear little child was struck down by a speeding motorist"; "the unsupervised child of an unemployed workman ran out in front of a car without warning." Statements like these, in addition to putting you on one side or the other, have no place in a medical report. Your report should deal with the health of the child, not with hearsay evidence. Stick to facts.

Release Form. Before sending any report, be sure that you have a release note from the lawyers, signed by the child's guardian.

The Report

Lay the report out clearly, using headings as a guide to the organization. Try to distinguish clearly between factual observations and opinion. Try to indicate which observations have been made by you personally and which have been made by others.

Indentification. Identify the subject of the report by name, address, date of birth, and the date of the accident.

History of Accident. This history can be very brief, because you have only the secondhand impression of the events. It is the lawyer's job to investigate this, not yours. When you use other people's testimony, make this clear on the report by words such as: "His mother told me that. . . ."

Initial Examination. The hospital record will describe the time, date, and mode of arrival; include this. If you examined the child, write: "When I examined him, I found. . . ." If you are using the notes of somebody else, put this down clearly: "On arrival at the hospital, he was examined by Dr. So-and-so, who noted. . . ."

Put down the positive findings or diagnoses first, with mention of investigations used to support them. Then describe negative findings, such as, "he was not unconscious." If other specialists have examined the child at this time, list their names, and note the diagnoses they reached.

Treatment and Progress. Lawyers are not interested in minutiae. They want a broad picture from which to form an image of "pain and suffering." State the number of days traction was used, the number of days that intravenous fluid balance was maintained. Do not get involved with drug dosage or your own little dilemmas. You are not being sued.

Give the date that the cast was removed, the number of visits made, how long the child was on crutches.

Present State. If the lawyer wants a current examination, list the complaints and physical findings. Many lawyers do not ask for a special examination for medicolegal purposes, particularly if it is a year or more after the accident. It is my custom to leave out the heading "Present State" in this situation and to replace it with a phrase such as, "I have not examined the child since the 21st October 1971, and if complaints are made regarding permanent disability, the child should be brought to see me for an up-to-date examination."

Summary and Conclusions. Put down the diagnosis and list any current sequelae or complaints. Announce your prognosis, with the introduction: "In my opinion," for each particular complaint. When the child complains of symptoms outside of your particular specialty, you should not attempt to give a prognosis on these complaints; rather, refer the lawyer to the specialist who is familiar with the given body system.

Children rarely complain about the sequelae of injury. Parents are more concerned with the possibility of late effects. Unlike adults, who often seem to exaggerate the consequence of injury, children seldom do. Writing an opinion is very much easier. Special mention should be made about the possibility of a growth disturbance following injury. Few fractures affect growth, but lawyers have been trained to expect a definite statement. In Chapter 17, you will find advice on how to deal with leg-length discrepancy in report writing.

You should also mention the possibility of late osteoarthritis, although very little data is available. Whatever you put in your report would be hard to refute. Try to state if late problems are (1) probable (indicate the percentage of probability) or (2) possible (probable and possible have two distinct meanings). Indicate the treatment that may be required for any late problems together with the morbidity rate of that procedure.

When you send the report, be sure to keep a copy of it; read it carefully before posting, and initial any alterations that you make. A covering letter, offering to clarify any points that are not clear, together with an account of the cost of the report and of the cost of past and possible future medical treatment, should be enclosed.

Finally, remember that often parents will be given the report to read by their lawyer, and that the only occupational hazard to life that an orthopaedic surgeon faces is murder by the patient who feels that he has been wronged in a compensation suit.

APPENDIX 5 / The Role of Muscles in Fracture Patterns

Fractures happen so quickly that it is impossible to reconstruct the direction of forces responsible. A given type of injury is apparently capable of producing many different patterns of fracture. For example, a valgus force at the elbow may damage the radial neck, the medial epicondyle, or the medial condyle in children of a given age. But a judo expert would be able to ride such a force by yielding to it.

I think that many fractures associated with falls are produced by muscle holding the limb so rigidly that bone-breaking forces are generated. The evidence in favor of this hypothesis is as follows:

1. Muscle contraction alone is strong enough to produce a fracture. Athletes avulse apophyses. Grenade throwers get spiral fractures of the humerus. Patients receiving electroconvulsive therapy and those with uncontrollable convulsions sustain many fractures.
2. A limb with a rigidly immobilized joint, for example by arthrodesis, is more likely to fracture than a mobile limb. If muscles are holding a limb rigid during a fall, less energy can be absorbed before injury.
3. "He puts his arm out to save himself." If he puts his arm out from the body as fast as the ground is coming up, the velocity of impact is double what it would have been if he had done nothing. The risk of injury to the wrist has been increased while the risk of a head injury has been diminished. Certainly people do tense their muscles when they sense a fall (as been shown on electromyogram by Carlsoo and Johansson and by Watt and Jones).[1,3]
4. Wrestlers and paratroopers can be trained to avoid injury when they fall. Cats do it instinctively. Wrestlers, who are thrown from one side of the ring to the other, "go with the fall"; they do not resist it.

If it can be accepted that many fractures are the result of resisted falls, perhaps it could be accepted that the *site* of the fracture depends on which muscles are contracting. Tomkins has put forward the view that the radial head is dislocated in a Monteggia fracture by strong contraction of biceps when a hyperextension force is applied to the arm.[2] In the autopsy room (when muscles are ineffective) hyperextension produces a supracondylar fracture.

It may well be that the level at which a forearm fractures is determined by the extent of muscle activity. If triceps alone is contracting, a high fracture may be anticipated; when pronator teres is contracting, a fracture just distal to its insertion may be expected; and if the wrist flexors are active, a wrist fracture should occur. Similar hypotheses can be invoked to resolve the mechanism whereby similar forces produce fractures at many different sites. Muscle contraction may concentrate the force of the injury at a particular site.

A greenstick fracture is the result of force too short-lived to produce a complete fracture, and not the result of force too weak to produce a complete fracture, because a bone with a greenstick fracture is weaker than an intact bone. A greenstick fracture avoids becoming a complete fracture, either because the child has come to rest on the ground or because the muscles relax in the nick of time.

In conclusion, muscle action may produce fractures and may determine the site of injury.

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ADDITIONAL READING

Kelly JP: Fractures complicating electro-convulsive therapy and chronic epilepsy. J Bone Joint Surg 36B:70, 1954

APPENDIX 6 / Suggested Readings

This is a short list of suggested readings. Tachdjian has published an excellent bibliography in *Pediatric Orthopedics,* and there is little point in recording an exhaustive list again. I have recorded only the more recent publications at the end of each chapter because these will lead back to the older ones.

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