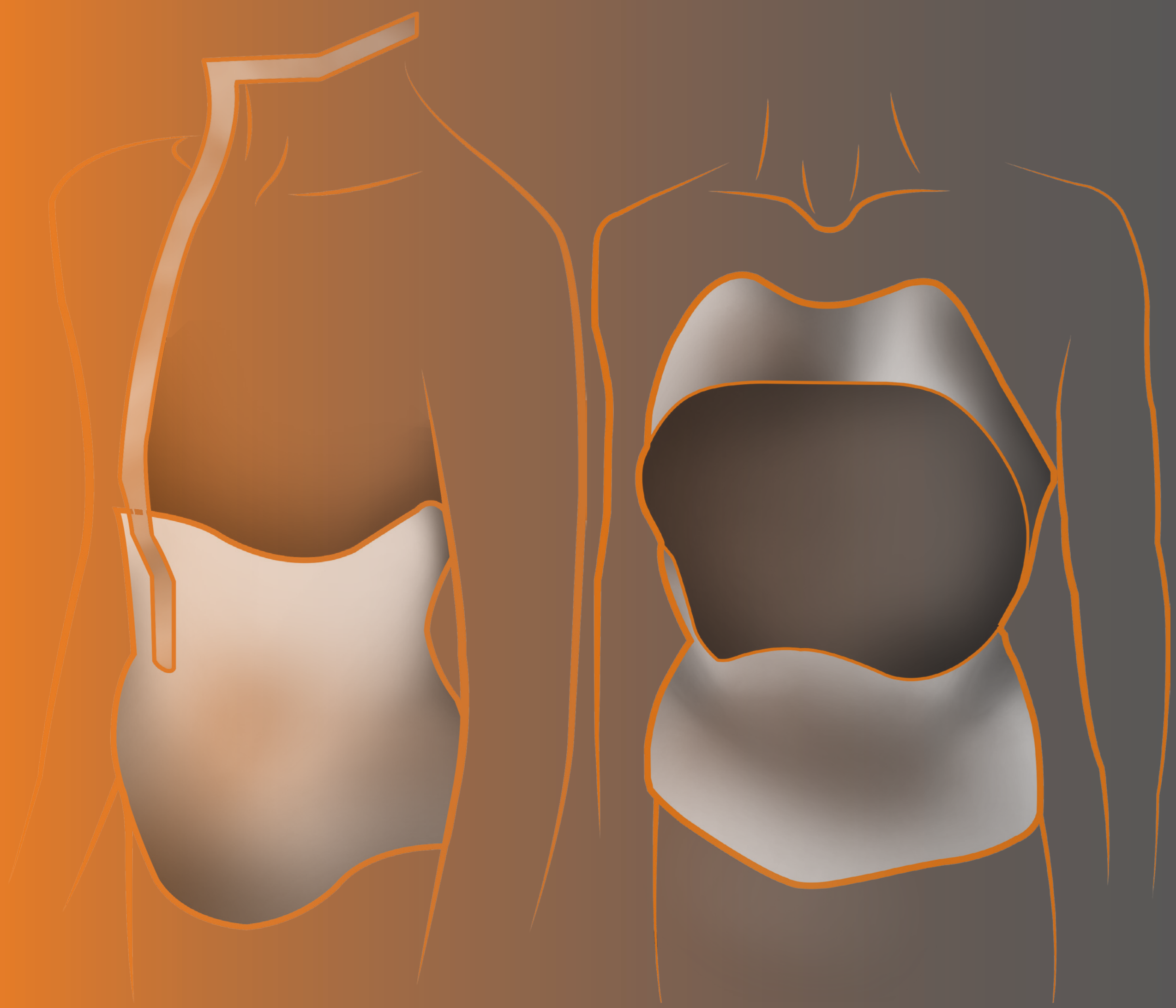
The Atlas of Spinal Orthotics



John R. Fisk
John E. Lonstein
Bryan S. Malas

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The Atlas of Spinal Orthotics

John R. Fisk, MD
Professor Emeritus
Southern Illinois University School of Medicine
Board Chairman
Exceed-Worldwide
Saint Helena Island, South Carolina

John E. Lonstein, M.D.
Clinical Adjunct Professor
Department of Orthopaedics
University of Minnesota
Staff Surgeon – Twin Cities Spine Center
Minneapolis, Minnesota
Gillette Children's Specialty Healthcare
St. Paul, Minnesota

Bryan S. Malas, MHPE, CO
Assistant Professor
Director, Department, Orthotics/Prosthetics
Moira Tobin Wickes Orthotics Program
Ann & Robert H. Lurie Children's Hospital of Chicago
Northwestern University Feinberg School of Medicine
Chicago, Illinois

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Atlas of Spinal Orthotics

Editors:

John R. Fisk - john@exceed-worldwide.org

John E. Lonstein - lonsteinj@aol.com

Bryan S. Malas - bmalas@luriechildrens.org

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Notice: Knowledge and best practices in this field are constantly changing. The chapter authors and the editors have tried to insure that evidence based medicine is referenced throughout this atlas. As individual experience and scientific reporting adds to the field of spinal orthotics, the reader is encouraged to follow best practices.

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By: Exceed Worldwide
PO Box 429
Hillsborough
BT28 9EX
UK

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equip, enable, empower

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Contributors

Riley Ahl
Twin Cities Spine Center
Minneapolis, Minnesota

Rafael Cruz Bundoc, MD
Professor 7
Department of Anatomy
College of Medicine
Department of Orthopedics
University of the Philippines
Philippine General Hospital
Manila, Philippines

J. Martin (Marty) Carlson, MS(Engr.), CPO, FAAOP
Tamarack Habilitation Technologies, Inc.
Blaine, Minnesota

Helen Cochrane, CPO(c) MSc
Boundless Biomechanical Bracing
Mississauga, Ontario

Trenton Cooper, DO
Gillette Children's Specialty Healthcare
St. Paul, Minnesota
University of Minnesota
Department of Orthopaedic Surgery,
Minneapolis, Minnesota

Jennifer Fawcett, CO
Winkley Orthotics and Prosthetics
Minneapolis, Minnesota

Elaine Figgins, BSc (Hons) PO
Associate Director for Allied Health Professions
Director of Nursing Midwifery and Allied Health Professions
Glasgow, Scotland

John R. Fisk, MD
Professor Emeritus
Southern Illinois University School of Medicine
Springfield, Illinois
Board Chairman
Exceed-Worldwide
Beaufort , South Carolina

Grace Garvey
Twin Cities Spine Center
Minneapolis, Minnesota

Timothy A Garvey, MD
Twin Cities Spine Center
Minneapolis, Minnesota

Thomas M. Gavin, CO
Research Orthotist
Musculoskeletal Biomechanics Laboratory
Palos Park, Illinois

Thomas J. Gilbert M.D., M.P.P.
Chief Clinical Officer
Center for Diagnostic Imaging
St. Louis Park, Minnesota

John J. Grayhack, M.D., M.S.
Associate Professor
Division of Orthopaedic Surgery
Feinberg School of Medicine, Northwestern University
Ann & Robert H. Lurie Children's Hospital of Chicago
Chicago, Illinois

Amanda Guevara PT, DPT
Department of Physical Therapy
University of Florida College of Public Health and Health Professions
Gainesville, Florida

Contributors

Tenner J. Guillaume, MD
Staff Spine Surgeon
Gillette Children's Specialty Healthcare
St. Paul, Minnesota

Nanjundappa S Harshavardhana, MS(Orth), FRCS(Orth)
Specialty Registrar in Tr & Orth
Department of Orthopaedics
Forth Valley Royal Hospital
Larbert, Scotland

Carol J Hentges, CO
Custom Care Orthotics, Inc.
Eagan, Minnesota

M. Timothy Hresko, MD
Associate Professor
Department of Orthopedic Surgery
Harvard Medical School
Boston Children's Hospital
Boston, Massachusetts

Tyler J. Jenkins, M.D.
Department of Orthopaedic Surgery
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Erik C. B. King, M.D., M. S.
Associate Professor
Division of Orthopaedic Surgery
Ann & Robert H. Lurie Children's Hospital of Chicago
Department of Orthopaedic Surgery
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Steven E. Koop, M.D.
Associate Professor of Orthopaedic Surgery
University of Minnesota Medical School
Medical Director
Gillette Children's Specialty Healthcare
Saint Paul, Minnesota

Mark Lee, MD
Connecticut Children's Medical
Hartford, Connecticut

Robert S Lin, MEd, CPO, FAAOP
Director of Clinical Standards
Hanger Clinic
Cromwell, Connecticut

John E. Lonstein, M.D.
Clinical Adjunct Professor
Department of Orthopaedics
University of Minnesota
Staff Surgeon – Twin Cities Spine Center
Minneapolis, Minnesota
Gillette Children's Specialty Healthcare
St. Paul, Minnesota

Bryan Malas, MHPE, CO
Assistant Professor
Department, Orthotics/Prosthetics
Moira Tobin Wickes Orthotics Program
Ann & Robert H. Lurie Children's Hospital of Chicago
Northwestern Feinberg School of Medicine
Chicago, Illinois

Kevin P. Meade, PhD
Professor
MMAE Department
Illinois Institute of Technology
Chicago, Illinois

Contributors

Tom F. Novacheck, MD
Director
James R Gage Center for Gait and Motion Analysis
Gillette Children's Specialty Healthcare
St. Paul, Minnesota
Adjunct Associate Professor
Department of Orthopaedic Surgery
University of Minnesota
Minneapolis, Minnesota

Avinash G. Patwardhan, PhD
Professor
Department of Orthopaedic Surgery and Rehabilitation
Loyola University School of Medicine
Maywood, Illinois
Director
Musculoskeletal Biomechanics laboratory
Veterans Administration Hospital
Hines, Illinois

Mark Payette, CO, ATP
Tamarack Habilitation Technologies, Inc.
Blaine, Minnesota

Robert L. Rhodes, BA, MPA, CO(e)
Assistant Professor (Retired)
Eastern Michigan University Washtenaw Community College
Saline, Michigan

James O. Sanders, MD
Professor of Orthopaedics and Pediatrics
University of Rochester and the Golisano Children's Hospital
Rochester, New York

Claudia Senesac PT, PhD, PCS
Clinical Associate Professor
Department of Physical Therapy
University of Florida College of Public Health and Health Professions
Gainesville, Florida

Sandra Sexton BSc (Hons)
Director, Rehabskills Ltd.
Wishaw, Scotland

Eiman Shafa, MD
Clinical Fellow
Twin Cities Spine Center
Minneapolis, Minnesota

Walter Truong, MD
Assistant Professor
Gillette Children's Specialty Healthcare
St. Paul, Minnesota
Department of Orthopaedic Surgery
University of Minnesota
Minneapolis, Minnesota

Leonard Voronov, MD, PhD
Adjunct Instructor
Department of Orthopaedic Surgery and Rehabilitation
Loyola University Chicago
Maywood, Illinois
Clinical Research Scientist
Musculoskeletal Biomechanics Laboratory
Edward Hines Jr. VA Hospital
Hines, Illinois

Contributors

Man-sang WONG, CPO(HK), PhD
Associate Professor
Interdisciplinary Division of Biomedical Engineering
The Hong Kong Polytechnic University
Hung Hom, Kowloon, Hong Kong

James H. Wynne, CPO, FAAOP
Vice-President - Director of Education
Boston Brace - National Orthotic Prosthetic
Company
Avon, Massachusetts

Michael R. Zindrick, MD
Clinical Associate Professor
Department of Orthopaedic Surgery and
Rehabilitation
Loyola University Chicago
Maywood, Illinois
Hinsdale Orthopaedics Associates
Hinsdale, Illinois

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Introduction

The International Society for Prosthetics and Orthotics (ISPO) sets standards and provides educational resources for the care of persons with physical disabilities. To date it has not held a Consensus Conference nor conducted a Short Course on the topic of the orthotic treatment of spinal pathologies. The treatment of these conditions requires a qualified clinical team consisting of well-trained orthotists, physicians, therapists, nurses, social workers and educators. Until recently such teams were not available in many underserved regions of the world nor even in those countries where qualified P&O schools exist. There is evidence that this circumstance is changing and that the time has come for expanding the skills of orthotists in the field of spinal orthotics.

At a recent symposium at the American Academy of Orthotists and Prosthetists experts in the field of Spinal Orthotics addressed the question of what the content of a curriculum on spinal orthotics should contain. One of the conclusions of this discussion was that there does not exist in one place a collection of materials addressing comprehensive spinal orthotic care. This group also recognized that students seeking to expand their skills into this sub-specialty field would need a resource that provides fundamental principles of spinal orthotic management. The editors of this text have attempted to bring together chapters that address that need. An ISPO Consensus Conference is not required, as a consensus has already been met for most of this material.

Contributions have been solicited from recognized experts in the field that have of cared for people with spinal conditions requiring orthoses. All of the chapters have been peer reviewed by the editors for content and accuracy. By no means is this an exhaustive collection of all of the materials in the field, rather it is intended that it will to serve as a resource to those seeking to the expand their knowledge.

Approaches to patient care in the field of spinal orthotics is not without controversy. The editors have attempted to bring together authoritative material that reflects agreed upon and previously published information. Where proprietary devices and varying protocols exist, this text has attempted to present that material in a generic manner. Accepted standardized terminology has been used throughout.

Exceed Worldwide is one of the foremost organizations involved in O&P education in the developing world. They have agreed to sponsor this work by providing a site for its publication. In addition our thanks go to Rudolf Becker, III, President of Becker Orthopedic for a generous donation in remembrance of his parents. This contribution has helped to defray some of the costs of formatting this online resource.

We have chosen to publish in the public domain as we want this information available to the widest audience. We expect that individual chapters will be reproduced for use in the classroom. We do not however expect or approve the reproduction of the whole text for commercial gain. We welcome suggestions for updating and corrections.

It is our hope that this resource will be of value to the reader and challenge or increase their ability to provide appropriate care to their patients and families they serve.

The Editors

Section 1:
Perspective

1

Spinal Orthotic Education in Less Resourced Settings

Helen Cochrane

INTRODUCTION

The World Health Organization (WHO) reports that 100 million people are currently in need of prosthetic/orthotic services, however, global estimates suggest that only 1 in 10 of those in need, currently have access.[1] WHO further reports that the problem of accessing orthotic (and prosthetic) services is more acute in low and middle-income countries where non-government organizations (NGOs) without certified providers deliver services that often results in poor quality and fit.[1]

The field of orthotics is a speciality within the field of health care technology of which spinal orthotics is a subset for providing specific devices for the spine.[2] This area of services provision represents a highly specialized field of knowledge and skills within professional orthotic service providers. This chapter describes the history, education, experience, barriers and opportunities to optimize service delivery in less resourced settings for managing those needing spinal orthoses.

HISTORY OF EDUCATION

The first known use of spinal orthoses was by Ambrose Pare (1510-1590), when a metal corset was fabricated by an armorer.[3] Early orthotic service providers were artisan blacksmiths, armorers, and patients themselves who created devices out of metal, leather and wood. Since that time in well-resourced settings, orthotics has developed into a health profession followed closely by prosthetics and physical therapy. All three disciplines are considered to have experienced major professional advances associated with World War I & II as well as the outbreak of polio in the 1950's.[4]

The evolution of the profession is reviewed in The Advance in Orthotics by George Murdoch (ed). in 1976.[5] In a section on training requirements for orthotists, he noted that polio provided the impetus for people to specialize in making braces, which lead to the evolution of the profession. Initially there was little change in the educational process above an apprentice model.[6] In an effort to address this deficiency, in July 1968 an International Regional Seminar on Standards for Training of Prosthetists and Orthotists was held in Denmark, by that government and the United Nations. In 1970 a similar meeting was held in the United States involving the American Board for Certification of Prosthetists and Orthotists and the University Committee for Orthotic and Prosthetic Education (a part of the National Academy of Sciences). While these meetings improved availability of qualified faculty, other challenges persisted, namely;

- Educational institutions were reluctant to expand the scope of programs with small numbers of students and limiting resources,
- There was a higher cost of tuition for these specialized programs and limited government resources.[6]
- Orthotic training was reported to be variable in type, quantity and quality resulting in a di

versity of skills.[7]

Paul and Kennedi[8] identified the orthotist as a member of the clinical team, requiring mutual professional respect and effective communication. They added to the recommendations of the Denny Report[9] for a formal 4-year education program for Prosthetists, and suggested that programs add to their syllabuses to meet the needs for training of orthotists.

Wille,[10] in his discussion of the needs in low-income countries, reported that with rapidly emerging rehabilitation services, governments were keen to have good orthotic services as quickly as possible. He noted that often, as the immediate need for services became apparent, basic training programs were frequently combined with service provision.

In an effort to meet the need for prosthetic and orthotic services, training programs were broken down into several different modules focusing on specific areas. Future orthotic technicians were given concentrated training in one section only.[10]

Wille further indicated that although some individuals had opportunities to reach the level of a qualified orthotist, through upgrading their professional knowledge; the profession often began with orthotic technicians forming the basic structure from which the profession grew. These informal pathways and apprenticeship routes, not traditionally used for training health experts, lead to problems of professional recognition and consequently poor employment conditions. This discouraged individuals with good educational backgrounds from being attracted to the field.[10]

While it was recognized that a 3-4 year university training program would be desirable, a specialized training system presented a practical alternative route for entry into the field and the resultant establishment of services.

Murdoch[5] concluded in his discussions of education by summarising the immediacy of the problem. He identified the great need in terms of the number of individuals requiring treatment, and the expense associated with providing that education. He suggested that many governments already had large investments in providing inadequate services, and suggested that an emphasis on education could be made cost effective.

In most well resourced settings the profession has continued to develop since 1976. In less resourced settings, while some education and service delivery has developed, in many instances these outcomes have not been realized. It is common for the challenges identified in 1976 to persist in less resourced settings. Lack of resources, variability in the capacities, poor recruitment and retention continue to impact the profession and its beneficiaries.

CURRENT STATE OF EDUCATION

In the current circumstance, orthotic educational programs are typically delivered in conjunction with prosthetic training in post secondary educational settings. Programs are established using a range of models including traditional education and blended learning curricula. In well-resourced settings it is typical for comprehensive clinical programs to include; prosthetic/orthotic theory and practice, as well as academic requirements for advance decision-making. They typically culminate in a minimum university degree or higher (4-6 years).

In less-resourced settings (where comprehensive clinical programs do exist) they are usually of shorter duration (2-3 years) and focus on routine clinical service delivery. In these settings, modular courses (1.5-2 years) that provide focused training in a specified area of practice may also be available.

A relatively small number of training programs are known to exist for the initial training of technicians. The term technician is often used to describe a range of services providers in prosthetics/orthotics occupations. In international standards and occupational classification, the term technician refers specifically to providers of technical implementation only. Individuals who are trained as technicians should not be involved in clinical applications. Although this level of training is critical for the optimization of resources, technicians are still often trained in apprenticeship models in many underserved areas.

Job titles are known to be highly variable across regions with more than twenty different titles identified in a recent international assessment in less resourced countries.[11] In establishing specialist teams to deliver spinal management the education and competencies of team members should include individuals with appropriate clinical and technical knowledge as well as skills regardless of nomenclature.

Because educational programs have been seen to be highly variable, in an effort to improve the consistency of the education and service delivery, WHO and the International Society for Prosthetics and Orthotics (ISPO) established International Standards for Education in 1991. These standards have been adopted by 38 schools in 26 countries[12] and enjoy a growing interest with educational programs around the world. ISPO provides a list of internationally recognized programs that is updated regularly.[13] Programs that have met these international standards present a good starting place for building collaboration, finding qualified graduates, mapping access to service and ensuring that service provider competencies are aligned with global expectations.

The WHO/ISPO standards include three categories of training;[14]

- Category I – Professional Prosthetists/Orthotists who have typically been trained in higher education settings and have a broad range of relevant competencies, including the breadth and scope of clinical and technical services, evidence-based practice and leadership,
- Category II – Associate Prosthetist/Orthotists who have been trained in tertiary education settings to deliver clinical and technical services. This may include programs that train providers within a limited scope of practice such as modular programs, where training is pro vided in either lower limb prosthetics or orthotics, or a combined upper limb and spinal de vices module,
- Category III – Prosthetic/Orthotic Technicians who have been trained in the fabrication of de vices, but who do not provide clinical treatment.

Programs that have met the international standard for education of prosthetic/orthotic occupations document that their graduates have achieved appropriate academic and professional competencies. While these standards include training in spinal orthoses, typically these skills represent only a small percentage of the overall curriculum. Programs focus instead on curricula related to the lower limb, as this area is most prevalent in a typical orthotic caseload. In many cases, students will have at most one or two opportunities for practical exposure to spinal management by the time they graduate.

EXPERIENCE

After graduation, orthotists likely will have had limited exposure to spinal management. In a national practice analysis of orthotists in the United States and Canada, practitioners reported that they spent respectively 16% and 10% of their time providing care for spinal cases.[15,16] This suggests that even in well-established settings a relatively small number of spinal cases may be seen or that cases are seen by a small number of specialized orthotists.

In less resourced settings, despite relatively limited exposure during their education, graduates are required to manage these cases. In studies of clinical graduates from recognized programs in twelve less resourced countries, most graduates reported that spinal orthotics were a part of their caseload and that these cases represented a comparatively small proportion of their overall caseload. Only a small number of graduates reported that spinal management was an area where they felt confident. Some cited it as an area they felt could have been better covered during their education. Many graduates further indicated that continued education in this area would be of benefit to them. The investigators indicated spinal management was an area for development in each setting surveyed.[17-21] These findings suggest that the demand for competencies in the orthotic management of spinal conditions exists, and that there is agreement that further learning opportunities are needed to ensure optimal outcomes. This finding also suggests that graduates of recognized programs understand the complexity of these cases and acknowledge the importance of formal education and experience in ensuring the best outcome for patients.

Mentoring of qualified graduates is an important element of developing clinical skills. This is especially true when managing spinal cases. Few structured mentoring programs exist in less resourced regions and they are considered an important step to improve the quality of services. The ISPO recommends that standardised programs for mentoring should be developed and promoted.[11]

Ideally, mentors would be available on site to participate and advise in clinical decision-making. At a minimum an experienced orthotist could support the development of clinical skills through technology-based solutions (e.g. online interactions). Intra or inter-professional collaboration to peer review cases may help improve clinical outcomes.

BARRIERS

Barriers that exist for orthotic services in less resourced settings as a whole are more problematic for the management of spinal conditions. Spinal orthoses require an experienced multidisciplinary team to assess individuals; plan, deliver, and monitor appropriate treatment, as well as technical resources to implement treatment plans. A multidisciplinary team (including doctor, orthotist, physical and occupational therapist along with the patient and their support network) is considered an appropriate model for such teams.[4] [See chapter 2]

In many settings a full team may not be available. They are often incomplete, poorly co-ordinated and/or burdened by high demand for limited resources. It is important to ensure that at a minimum key members are involved. In particular, orthotists working with doctors are critical in prescribing, fitting and monitoring orthotic management.[22] Even if well-formed teams do exist, an awareness of and access to services may be limited. Diagnosis is often delayed, school screening programs are almost non-existent, and restricted resources may impact the range of possible treatment plans.

It is common in regions with scarce resources for individuals with clinical presentations beyond the scope of appropriate orthotic treatment to be referred for orthotic care. This is often the result of a limitation in surgical capability; including (but not limited to) lack of surgical equipment, instrumentation, shortage of qualified surgeons and financial barriers. The 10 year-old boy in Figure 1 presented with short rigid curves and was referred for bracing as surgical facilities were lacking. Unfortunately in this case orthotic management will not help, is potentially harmful and a waste of resources. The boy in Figure 2 was refereed for the repair of his device that had been supplied by an untrained provider. Both the nature and magnitude of the curve indicate that orthotic intervention was not appropriate, in spite of that the boy had been wearing the metal and leather orthoses for sometime.

Fig 1

Fig 2

Inappropriate referrals increase demand on already strained resources and places the individual at risk, since no benefit could be expected from inappropriate orthoses. Teams should use evidence-based criteria for implementing treatment plans and refer to appropriate services only when criteria for orthotic intervention are met.

In a review of service provision for individuals with scoliosis referred to the Sri Lanka School for Prosthetics and Orthotics, the multidisciplinary team found that after an evidence-based screening process of 130 referrals, 30% of individuals had a curve greater than 50 degrees and 60% had a Risser sign of 3 or higher.[23] The team also noted that only one physician was known to provide surgical services for scoliosis cases in Sri Lanka. One important barrier to surgery identified was that some associated costs were direct costs to the patient, which were considered prohibitive for the majority.[23] Their findings suggest that a large proportion of these referrals would not benefit from orthotic intervention, and that referral may only have been made because of constraints in other more appropriate services.

Even when referrals are appropriate, the difficulty of assessing the outcome of spinal orthotic management can be challenging even for the most qualified and experienced professionals. Monitoring the effectiveness of treatment, assessing complications, providing psychosocial support and education of patients requires the collaboration and communication of a well-trained team.[24] It is common in less resourced settings for technicians with little or no education in orthotics, to provide clinical and technical services. Providers without training often work in isolation and have limited resources. They may especially lack the knowledge and skills to appropriately fit and assess the outcomes of spinal devices.

Corrective devices that aim to prevent future deformity can be uncomfortable. In less resourced regions poorly trained providers or those with limited experience may rely on the self-reported comfort rather than using the more appropriate objective measures such as comparison of radiographs of the unbraced and brace condition. Outcome measures are rarely used in these settings, and few measure clinical outcomes. Therefore the importance cannot be over stated of having an objective clinical team assess the outcome of spinal bracing and which is key to a successful treatment plan.

Technical limitations may also be a barrier in less resourced settings. Access to materials and equipment, including commercially prefabricated or modular spinal orthotic systems, and quality radiographs may be lacking.

Prefabricated spinal orthoses are a common method of optimizing resources in the delivery of services in many well-resourced settings. In the practice analysis of American Orthotists, custom-fit prefabricated spinal orthoses were reported to be used in 40% of spinal cases.[15] These systems are effective in expediting service delivery when they are available; however in less resources regions they may be either unavailable or cost prohibitive. In recent impact assessments of orthotic graduates in four Asian and two West African countries, financial resources and access to materials where found to be a barrier to overall delivery of services in spite of access to trained Orthotists.[18-20] Appropriate orthoses must be custom made in these regions, which represents a significant commitment in time and materials and further highlights the need to ensure resources are allocated to appropriate cases.

OPPORTUNITIES

As each device must be custom made, knowledge and skills are key to appropriate outcomes. Graduates of recognized programs should possess competencies that allow for foundational sciences to be combined with orthotic theory and practice, then translated into relevant competencies to manage appropriate cases.

While materials are often constrained, opportunities exist if services are planned and appropriately allocated. In the assessment of graduates in these regions, researchers identified that high-temperature thermoplastics were used in all clinical settings where these graduates of recognized programs practice.[18-20] This suggests that custom-made high-quality orthoses are possible. Figure 3 shows workshops in different countries that exemplify technical resources available in many areas where graduates of ISPO/WHO recognized programs work. Figure 4 shows a graduate of a recognized program adjusting a custom made orthosis. Figure 5 includes some examples of custom made thermoplastic orthoses provided in one less resourced settings. These images show, both the technical potential and the need to carefully screen patients before an orthoses is prescribed. Appropriate knowledge and skills are required in prescription, design and fitting of custom-made spinal orthoses and should be coupled with the clinical skills of an experienced orthotist, and/or in collaboration with an appropriate mentor.


Fig 3


Fig 4


Fig 5

In all regions that were included in recent surveys of graduates, participants reported that they had access to experienced professionals to seek advice for complex cases. While the specific experience of mentors was not reported, a range of professionals appears to be included in these relationships. They can help graduates of recognized programs enhance their skills and improve decision making.

Professionals from whom graduates sought support included more experienced practitioners within the discipline, therapists and doctors.[17-21] This suggests that inexperienced graduates from recognised programs can, and do seek advice from appropriate resources, and that relationships can be cultivated to enhance their clinical outcomes.

Information technology also provides a range of opportunities for professional development, clinical collaboration and mentoring. Access to the Internet is steadily increasing.[25] In less resourced settings most graduates of recognized programs report that they have at least some access to the Internet and use it for keeping up to date with professional information.[17-19,21] This represents an important opportunity for continuing education, resource sharing, communication and collaboration.

Key stakeholders have developed materials to help plan, develop and advocate for prosthetic/orthotics services.[12] These resources can be effective in helping to identify local, regional and international experts and agencies which in turn support the development of multidisciplinary teams, enhancing existing teams and advocating for services. In establishing teams for this specialized area of care it is of importance to review existing resources, work with professionals who possess the highest level of training and experience and seek to access resources to help develop or improve services.

SUMMARY

There exists a high demand and large unmet need for appropriate spinal management services. Where education and training have been unable to evolve beyond the artisan approach, using rudimentary materials and processes in the hands of inadequately trained individuals, the outcome for patients is expected to be poor. Fortunately in many less resourced regions education is advancing and provides good opportunities for the development of well-formed clinical teams.

It is necessary for providers of spinal orthoses to accurately assess patients and diagnostic imaging, and to translate findings into the design, fit and monitoring of the orthosis. In the case of spinal orthotics, superficial review of the device is not sufficient for determining effectiveness. Providers of spinal orthoses should possess knowledge of the evidence-base, clinical sciences and materials to ensure that the design and implementation are appropriate.

Ideally, orthotists with a post secondary school orthotic education should provide orthotic management of the spine. In light of a relatively limited spinal orthoses curriculum content, experience should be considered an important element in developing competencies necessary to manage these often-complex cases. It is advisable that less experienced orthotists work with an experienced orthotists in a mentor-mentee relationship, before transitioning to independent service delivery.

Inappropriate referrals absorb precious resources (clinical time, materials etc.) and typically result in poor outcomes for patients. Referring physicians should aware of the most appropriate clinical pathway. Multidisciplinary teams involved in spinal management should objectively screen each referral to ensure that suitable individuals receive the most appropriate services, and optimize the correct use of resources.

Skills and competencies of the service provider of spinal orthoses must be established at a level that reflects the complexity of the pathological spine. Referring doctors should carefully consider the education and experience of the team and/or service provider to mitigate the potential for detrimental effects associated with inappropriate, poor quality or poorly fit devices.

A wealth of opportunities exists for well-planned services that manage resources and provide patients with optimal outcomes. Accessing these opportunities require strategic planning, communication, collaboration and begin with appropriate referral to educated experienced teams.

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2

Team Care

Sandra Sexton and Elaine Figgins

INTRODUCTION

This chapter discusses teamwork in healthcare and then explores the published scientific literature on team care of spinal conditions to understand what aspects of the team approach are important to delivering effective orthotic management of the patient with a spine problem.

The concept of team working is widely considered to be the most appropriate way of delivering health care. A useful definition of teamwork in the health care context is "a dynamic process involving two or more health professionals with complementary backgrounds and skills, sharing common health goals and exercising concerted physical and mental effort in assessing, planning, or evaluating patient care. This is accomplished through interdependent collaboration, open communication and shared decision-making. This in turn generates value–added patient, organizational and staff outcomes".[1]

Team working offers benefits to the patient, health professional and healthcare organisation: patient benefits include improved care, outcomes and satisfaction; reduced clinical repetition; health professional benefits include job satisfaction, recognition, motivation and improved mental health; and healthcare organization benefits include having a committed cross-cultural workforce, cost control and improved staff retention. This is shown in Table 1, which summarises the findings of a concept analysis of teamwork undertaken by a team of researchers who derived the earlier definition. It can be surmised, therefore, that a team of professionals is better placed to deliver health services than lone practitioners.

Table 1

Table 1: Antecedents, attributes and consequences of teamwork.

Both clinical and non-clinical personnel are integral to effective health provision with a team approach. Reception, administration, clinical, technical and support staff have an influence on patient experiences and the overall quality of service. Indeed, non-clinical personnel are usually the people who have the first interactions with the patient at the very outset of their journey on the care pathway even before the first appointment. These communications and experiences are known to influence patient expectations and outcomes. The terms multidisciplinary and more recently interdisciplinary have been used to describe health service teams with a combined clinical and non-clinical workforce.[2]

Different terms are used to describe how clinical personnel work together. These include uni-professional, multi-professional, inter-professional and trans-professional teams. Each team is defined uniquely:

Uni-Professional Teams

Uni-professional teams refer to groupings all within one occupation. They have a clearly defined scope of practice according to their profession. In a hospital setting a uni-professional team may be coordinated to work with other disciplines; for example, physiotherapists or orthotists who comprise a hospital department or service unit. Such uni-professional teams are required to be fluid so that their individual team members are able to work with other disciplines depending on the needs of the patient. Thus members of uni-professional teams should contribute to different generic or specialist inter-professional teams to deliver specific care pathways. In less resourced or less coordinated settings, the possibilities for individuals to contribute to different patient care pathways can be severely restricted, thus leading to silo working, professional isolation and less effective care.

Multi-Professional Teams

Multi-professional teams refer to groups of professionals with different occupations who work in a somewhat autonomous way with separate tasks and roles. Team members meet together to plan care and discuss case studies. Members then individually assess and treat a patient for a distinct treatment intervention before referring that patient onto another team member of a different profession for a different treatment.

Inter-Professional Teams

Inter-professional teams are comprised of professionals of different occupations who work closely on a shared goal through shared assessment and have a clearer identity as a team. Inter-professional teams have the capacity to offer solutions to complex problems by combining intervention strategies that are multifaceted. Inter-professional interventions in chronic care have been shown through systematic review to include: implementation of shared tools (systems); reorganization of the composition of the team with new team positions being established; reorganization and alignment of team meetings based on the International Classification of Functioning criteria (rather than medical condition organisation); team training and workshops; and team performance feedback.[3]

Trans-Professional Teams

Trans-professional teams practice task sharing and have competencies that enable them to easily interchange tasks.

Ten characteristics of a good interdisciplinary team were illustrated by a study of teams working in community rehabilitation and intermediate care.[2] Their findings, as shown in Table 2 provide useful information for services interested in developing and strengthening their interdisciplinary teams.

Table 2: Characteristics of a good interdisciplinary team.

The ten characteristics shown in Table 2 underpin effective interdisciplinary teamwork and can be readily adopted for use by personnel working with different kinds of patients, including those presenting with spinal problems.

Table 2

SPINE CARE TEAMS

Of all the modes of delivery, the model of interdisciplinary team-work aligns most closely with the needs of the patient with a spinal condition. This is because of the complex structure of the spine and the associated rehabilitation challenges that a loss or change in structure can impact on the life of the patient. Therefore, more interconnected solutions are needed.

Considering the earlier definition of a team, where professional membership should consist of at least two persons, spine teams should also adopt this model. It is preferable for these teams to have more professionals from different nursing, allied health and medical professions to ensure that the appropriate mix of competencies in assessment and treatment are present. The ideal spinal care team should at least contain a physician, a therapist (physical or occupational) and an orthotist, with additional team composition varying depending on the needs of the patient, their age, the nature of their specific condition and the level of functional loss.

The following examples of the team care of patients with different spinal conditions have been selected from published peer reviewed scientific journals because they give interesting insights about spine care team composition, roles, and responsibilities. These are by no means exhaustive, but they clearly illustrate that the right kinds of interdisciplinary team interventions can influence quality improvement in spinal services.

Back Pain

Patients are often motivated to seek medical advice for spinal conditions because of manifestations of pain that impact their quality of life and limit participation in everyday activities. This puts tremendous pressure on health systems due to the sheer volume of referrals from primary and secondary health and care services to tertiary health services with expectations for treatment by specialist spinal care teams. This often then leads to bottlenecks in the health system with waiting lists for patients accessing spinal specialists. Without service redesign, this pressure is likely to increase as the number of people experiencing low back pain rises in proportion to the growth of our aging populations along with the rise of obesity rates, both are significant risk factors for low back pain.

Spinal teams have a role to play in leading service redesign and improving care pathways to help manage this situation. Having faced just this problem, a recent Canadian study[4] conducted a practice analysis using purposive sampling and interviews with 17 representatives of colleges and regulatory bodies. They proposed that allied health professions have a greater role to play in reducing waiting times by being involved in an inter-professional triage team forming a “centralized intake” model. Team personnel involved in this study included family physicians, nurses, chiropractors, occupational therapists, physiotherapists, athletic therapists and others.

In a further publication,[5] a spinal team from the University of Iowa gave a description of their interdisciplinary spinal service for people reporting with back or spine pain. They discuss that effective triage was important, not only for patients requiring surgery, but was essential in identifying patients who do not need surgery to manage their expectations and to initiate any conservative treatment plans. The essential elements of their practice were described; that their team had a common mission; whether a surgical or non-surgical treatment plan was prescribed; they appreciated the close proximity of their team members; and they valued communication in regular meetings, usually weekly. It was clear that their team was led by a physical medicine and rehabilitation physician with team composition including three orthopaedic spine surgeons, three physical medicine and rehabilitation physicians, five physical therapists, a vocational counsellor, a medical social worker, a health psychologist as well as multiple program and secretarial staff.

A randomised controlled study of 20 patients with chronic back pain by a team from a Physical Medicine and Rehabilitation unit in Italy[6] compared two interventions one of which was a team approach: a multidisciplinary program of motor training and cognitive behavioural therapy with physical therapy exercises alone. They described their multidisciplinary team as comprising two physicians, a psychologist, an occupational therapist and two physiotherapists. Despite the small sample size, their findings were promising. Questionnaires and walking tests were completed before treatment and follow up was done at 8 weeks and 3 months after the treatment ended. They showed that the multidisciplinary motor training and cognitive behavioural therapy was more effective in addressing disability, pain, quality of life, gait parameters and global perceived effect. They also showed improvements in the 6-minute walk test and spatiotemporal parameters of gait.

When considering team composition for treatment of low back pain it should be noted that the balance of evidence in the literature indicates that orthotic management is not routinely recommended for treatment of this condition. [See chapter 23] Despite this, orthotists may receive referrals to treat low back pain when working in a uni-professional way in an orthotic outpatient service. This referral pattern has been reported to occur in both high income and low-income countries. This may mean patients do not benefit from the referral to an orthotic service, their expectations may not be met and there is an ultimate waste of resources (administrative and clinician time). In poorer quality services that do not practice evidence-based prescriptions, patients may be offered costly but ineffective spinal orthotic provision. Actions taken by the orthotist to remedy this situation should be accomplished by taking a complete patient history, practicing evidence based physical assessment, provision of self-management advice and referral onto a low back pain service team. In addition, the orthotist should inform the referrer of their decision not to treat with a spinal orthosis justifying their decision to help improve future referral pathways thus ensuring more appropriate and timely triage and/or potential treatment.

Orthotic Management Of Scoliosis

Established international guidance on the treatment of scoliosis is available from the Scientific Society of Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT). They have published SOSORT guidelines on the 'Orthopaedic and Rehabilitation treatment of idiopathic scoliosis during growth.[7] The guidelines were derived from a systematic review of the literature and Delphi process involving spine experts. They provide recommendations for treatment interventions and clear detail about the team role that involves inter-professional working with a medical doctor, orthotist and physiotherapist as core team members. The recommendations are grouped in six domains, namely: experience/competence, behaviours, prescription, construction, brace check and follow up. The two domains experience/competence and behaviours give the most information about the inter-professional team. The SOSORT experience/

competence requirements for the medical doctor and prosthetist/orthotist are summarised in Table 3. The authors of the guideline described this as an ideal situation, but they did not publish any results of this approach.

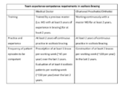

Table 3

Table 3: Team experience-competence requirements in scoliosis bracing.

The behaviours expected of this inter-professional team of the medical doctor (MD), prosthetist/ orthotist (CPO) and physiotherapist (PT) are observed across 3 SOSORT recommendations and align with some of the ten characteristics of a good interdisciplinary team shown earlier in Table 2.

RECOMMENDED BEHAVIORS

- To ensure optimum results, the MD, CPO and PT must work together as an inter-professional team. This can be accomplished, even if they are not currently located in the same workplace, through continuous exchange of information, team meetings, and verification of braces in front of single patients.

- Commitment, time and counseling to increase compliance: MDs, CPOs and PTs have to give thorough advice and counseling to each single patient and family each time it is needed (at each contact for MDs and CPOs) provided they give as a team the same messages previously agreed upon.

- All the phases of brace construction have to be followed for each single brace;
    1. Prescription by a well trained and experienced MD
    2. Construction by a well trained and experienced CPO
    3. Checked by the MD in cooperation with the CPO, and possibly the PT
    4. Correction by the CPO according to MD indications
    5. Follow-up by the CPO, MD and PT.[7]

Since the original publication of the SOSORT guidelines a number of subsequent research studies have been published that give additional information about the role and influence of the inter-professional team in achieving positive outcomes for patients with scoliosis.

A strongly aggregated team approach was shown to improve patient outcomes in a study from 2011 involving 38 patients with scoliosis or kyphosis treated by a specific team involving a physician, orthotist and physiotherapist.[8] In one group the physiotherapist was placed as a team coordinator with clear treatment protocols guidance: in another group, only a weaker, loose team structure was in place. Two outcome measures were used at a minimum of 6 months after treatment began: the Scoliosis Research Society 22 Questionnaire (SR-22); and a newly designed twenty-five item 25 questionnaire on adherence to treatment. Pain, quality of life and compliance with treatment was shown to be better in the strongly aggregated team and it is proposed that allied health professionals have a greater coordinating role to play in improving the quality of service provision. One must consider however that this was a small sample size.

One significant factor influenced by spine team dynamics is compliance. If we consider that scoliosis treatment is most commonly for an adolescent patient population we can surmise that this particular age group could be influenced positively or negatively to engage with a treatment program and can be affected by both interactions with and advice from the spine team professionals.

A number of researchers have explored compliance with treatment and outcomes. Compliance was found to be a significant variable in 2014 when 522 patients with idiopathic scoliosis from a Department of Orthopaedics and Traumatology in Italy which investigated bracing and compliance.[9] The outcome of their study was that increased compliance in wearing a spinal brace prescribed from 18 to 22 hours per day reduced the likelihood of scoliotic curve progression, but the influence of the team beyond clinical and technical interventions was not clear.

A Norwegian study of the treatment of 495 people with idiopathic scoliosis with custom bracing and supply of information about brace wear 23 hours a day published in 2012, involved a spine surgeon, experienced orthotists and a nurse.[10] This showed that brace wear of more than 20 hours a day reduced the likelihood of curve progression. Contributing factors to compliance included: the enthusiasm of the spine surgeon and orthotist; when bracing began; types of brace; and patient and parental motivations. Professional attitudes and relationships appear highly important in achieving compliance and positive outcomes.

Compliance monitoring was specifically considered as part of a comprehensive review of the literature in 2013 about idiopathic scoliosis and described three phases of intervention (diagnosis, custom brace fitting and a two year follow up).[11] The review considered not only the team as being physicians and orthotists, but also patient "buy in". They discuss the efficacy of bracing and made an interesting point that compliance monitoring in itself can influence compliance.

More recently in 2016, a study of 222 participants with idiopathic scoliosis from the United States of America investigated interventions of bracing, compliance counselling and counselling about monitoring within an inter-professional team of a physician and orthotist .[12] The study found that increased compliance reduced the likelihood of curve progression. Significantly, they also found that compliance counselling plus counselling based on monitoring improved the compliance time of brace wearing ($p=0.002$). This emphasized the need for good communication and clear messages between professionals and patients. Inter-professional team working is not only about the treatment itself, but also about professional involvement of each member in the treatment plan and follow up.

Spinal Cord Injury

Team working in spinal cord injury gives us insights into longer term lifestyle issues and associated solutions that could inform team working for other spinal conditions, especially as spinal cord injury teams tend to bring in professionals working across both health and social care.

Obesity poses a risk to people with spinal cord injury because of the mechanisms that lead to pressure sores. Weight reduction is therefore important to reduce deep tissue injury, improve function and enablement. A team of professionals comprising physicians, nurses, psychologists, social workers, physical therapists, occupational therapists and dieticians considered a weight management program involving weight management discussions and the provision of written materials.[13] They found that facilitators to weight loss included leadership support, resource allocation and provider involvement. Barriers to weight management included staff and resource shortages and structural environmental challenges.

Another study on spinal cord injury focussed on vocational rehabilitation. The inter-professional team consisted of a vocational rehabilitation specialist, doctor and medical team with outcomes measured in terms of whether employment was obtained or not. The team was able to address barriers to employment such as transportation and physical access to the workplace.[14]

CONCLUSION

From the point of view of a person seeking help for a spinal condition, their main objective is to find a solution to address their problem of pain or mobility issues. How this solution is offered from one person or a team of people is not their priority, their focus is on a positive outcome. However, an interdisciplinary model of care is an appropriate model for spine teams because this offers the patient with a spine condition the best opportunity of their needs being matched to appropriate treatment interventions in a timely manner.

The ten characteristics of a good interdisciplinary team[2] can be used as guidance to create and improve spine care teams. These characteristics along with lessons learned about spine team care from published evidence about the treatment of one spine condition are often transferable lessons which resonate across treatment for different spine conditions. When considering the patient journey and the steps needed for orthotic management of the spine, the same four steps of service provision are present regardless of condition:

Step 1: Referral and appointment
Step 2: Assessment and prescription
Step 3: Product preparation, fitting and user training
Step 4: Follow up and maintenance

An inter-professional spine team has the possibility of positively influencing treatment and patient experiences at each step of the patient journey along the service care pathway.

Step 1: Referral and appointment

Patients referred for spinal treatment may face waiting times for appointments with spinal specialists. The spine care team has a role to play in educating and informing referrers in their locale about appropriate procedures as well as inclusion and exclusion criteria, so that the correct kinds of patients are referred for treatment.

The spine care interdisciplinary team can help control waiting lists by agreeing and implementing a referral triage system to prioritise a patient's appointments depending on their referred condition and the associated risks of deterioration with time.

Administration personnel should ensure that the date of receipt of a referral and time to first appointment is noted in a service database and that this information is used as part of regular quality improvement reviews. The patient should be registered with a spine care service and if a medical record is not already created in the appropriate database, it should be done at this point. A clear communication about the appointment should be made to the patient with the information that they are to be assessed by a spine care team, noting team members and their roles.

Step 2: Assessment and prescription

An interdisciplinary team has a very strong role in ensuring that each patient's needs and preferences are understood at the first assessment. Leadership and governance of the spine care team in assessment and prescription is paramount to effective care. For complex spinal cases this is particularly important because these cases rely on the team approach for problem solving and generating an evidence-based treatment protocol. An appropriate combined skill mix, experience and competence among physician, orthotist and therapist is needed, especially for more complex cases. Each team member contributes his or her assessment and analysis to the medical record for each patient. Close liaison and familiarity with other teams for assessment tests and investigations, such as the radiography team, also helps to ensure that the right assessment procedures are followed. Treatment goals should be agreed between the spine care team and the patient. A baseline assessment should be carried out against these goals.

In the context of less resourced settings, the proportion of complex cases actually rises. People with spinal conditions in developing countries tend to have more complex presentations at first assessment. This is due to the neglect of their condition related to poverty, poor health systems, low awareness about the services available and the limited or reduced opportunities to seek treatment. Significant barriers to care often exist. Despite patients' more complex situation, service provision is limited and the workforce employed in these services may not have the advanced competencies needed to design and deliver the care required. There usually is a lack of orthotists and their associates. For this reason, the right care needs to be provided to the right patient at the right time to prevent a waste of resources.

Given the scarce availability of medical doctors and prosthetists/orthotists in many countries and the competing demands of patients with a range of spinal conditions, the possibility of achieving teams with the right expertise is often hard to implement. Despite these challenges it is possible to build evidence based practice at the assessment stage, utilising proven clinical assessment techniques. Evidenced base prescription of appropriate orthoses is also needed for more effective and efficient care. Easy access to information about effective practices is tremendously important and this Atlas of Spinal Orthotics will greatly contribute to increasing knowledge.

Step 3: Product preparation, fitting and user training

The orthotist and the orthotic technician are closely involved in fulfilling the prescription for a spinal orthosis. An exact specification instruction is needed by the orthotist and this can include analysis of radiographic images, shape capture for model making and other anthropometric measurements. Further specification is agreed in liaison with an orthotic technician who then sources and/or forms, assembles and finishes the prescribed orthosis ready for fitting stage. These processes are best controlled within a quality management system.

Fitting is required to be carried out by the orthotist in collaboration with the patient. The orthotist then works in partnership with the orthotic technician to customise and complete the definitive device.

Team Care

For patients attending the service for re-provision or care and maintenance for protracted periods of time, (for example over a two-year period for idiopathic scoliosis patients) their individual device preferences and needs become more familiar to the team. This familiarity should lead to more satisfied patients as care is more often personalised. Patients should be allocated the same key orthotist/orthotic team personnel throughout their treatment and if possible, the patient should be able to select their key orthotist.

User training can be done with different team members and with assistant personnel, so long as the key messages are the same for all. Most often user training is done by the orthotist and/or therapist. We have already found that compliance in the use of spinal orthosis is a strong determinant of success in scoliosis bracing, and this premise of following a correct treatment plan supported by appropriate information sharing and compliance counselling can be applied to any spinal orthosis.

Step 4: Follow up and maintenance

Follow-up is not only important to reinforce messages of compliance, but is absolutely essential if the spine care team is to learn and develop from their past case experiences. Counselling patients about the follow-up plan and intention to monitor their care is a motivator for the patient to comply with treatment and attend follow-up appointments. Monitoring of the effectiveness of treatment should be done against the previously agreed treatment goals. These outcomes should be carefully and systematically recorded in the medical record in a format agreed with the spine team. Follow-up and maintenance of treatment and orthoses can be supported by an orthotic technician and appropriately trained associate or assistant orthotic personnel.

Finally, clinical audits should be used to measure the effectiveness of spine team care on a regular planned basis. Data collected when monitoring outcomes for individual patients should be combined with data from similar patients, analysed and reported. Involving members of the interdisciplinary team and patient representatives in planning this analysis will help to make this more meaningful. Ethically, only data that will be analysed should be collected. A report of the findings should be shared and discussed among the entire interdisciplinary spine care team and patient representatives. Such clinical audit reports can be used as part of a quality improvement cycle for a service and to refine the organisation and structure of the interdisciplinary spine team itself.

In summary, we can consider team care generally; improving attitudes and "team climate" have been found to improve patient safety. Team climate can be defined as "shared perceptions of the team's work procedures and practices".[15] Therefore, a multidisciplinary team approach to patient spinal orthotic care which involves the right mix of expertise and services is, required to ensure that patients are provided with the most appropriate, safe treatment in the most appropriate setting when they need it.

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3

A Short History of Spinal Orthoses

Robert L Rhodes

HISTORICAL VIGNETTE

In 2012, a body discovered buried under a parking lot in Leicester, UK, was identified as that of King Richard III, the last English monarch to die in battle. Forensic studies showed that earlier history had in fact been correct - King Richard III was a "hunchback". These studies confirmed the true nature of his spinal deformity was the result of adolescent onset idiopathic scoliosis with a curve magnitude of 70 degrees.[1] Initially, it was thought that this might limit his prowess in battle, but appears now that his status as warrior will remain intact.[2] An evaluation of the scoliosis, published in The Lancet, concluded: "A curve of 70–90° would not have caused impaired exercise tolerance from reduced lung capacity."[3] The question remained, however, how would he function while wearing a 30 kg suit of plate armor? To answer this question, a study was undertaken in which a man of similar stature and curve magnitude (scoliosis) was taught to ride and subsequently fit with a replica suit of armor. The armor was fabricated with "waisting," the typical armorer's technique of tightening the armor around the anatomical waist to transfer some of the superincumbent load to the hips (Fig 1). Rather than limit the rider, this technique was found to increase support and strengthen the upper body."[4] Likely unknown to the armorer at the time was the application this principle would have in later years for orthopaedic surgeons and orthotists managing spinal deformities with orthoses. This bit of forensics and historic re-creation gives an idea of the interplay that has existed between armor and orthoses throughout history and is a good reminder that solutions for today's orthotic challenges may very well be found in the past.


Fig 1

A PRIMITIVE ORTHOSIS?

The logical starting point for the history of spinal orthotics is the Orthopaedic Appliances Atlas published in 1952. This work -although dated - is considered the first comprehensive textbook in the modern era of orthotics and an important entry point and window into the past. Through this lens it is apparent that circumferential management, regardless of material type, formed the basis for early armor and spinal orthotic designs. In the Atlas, a drawing is presented of an "orthopaedic corset of tree bark..." (Fig. 2) dated around 900 CE.[5] This item was first mentioned as a corset in a Journal of the American Medical Association (JAMA) article, in 1918.[6] It was described as "... an interesting appliance of bark made to fit the torso and provided with eyelets as though to lace it together in front. It closely resembles the modern orthopedic corsets used in the treatments of lesions of the spine, and may have been used by the cliff dwellers for this purpose or for fractures of the ribs." This early orthopaedic corset made of tree bark is an example of a circumferential design and man's ability to address an orthopedic need with the natural resources that are regionally available.


Fig 2

Another example of the use of bark is displayed and part of The History Colorado collection and in this particular case is described as "Armor"(Fig 3). A later evaluation by Carlson and Armelagos (1965) identified this same artifact as a "cradleboard hood."[7] More recently, it has been established that the item was originally described as a "bark vessel," and was only later classified as "primitive armor." In the end, whether or not these items were used for medical treatment or protection, the benefits of circumferential designs appear to have stood the test of time. Today's ballistic/flak vest (for protection) and polymer TLSOs are examples of circumferential designs that really can be considered as mere adaptions of bark.


Fig 3

THE RENAISSANCE

The use of plate armor was considerable during the Medieval, Middle Ages and into the Renaissance Age as a practical solution for protection during battle. As weaponry advanced so did the style, weight and type of armor worn by infantry and horseman alike. Particularly important and in addition to the practical side of armor was the aesthetic value placed on each design. This was evident by the influence the armorers had on the intricate engravings used for the frontispiece of the 1952 atlas[5] (Fig 4) compared with the suit of armor shown above. The parallel design and aesthetic advancements to armor were not exclusive to the battlefield, but were occurring in the orthopaedic community as well, but under a different name. The corset, one of the earliest descriptions of an orthosis, was used by Paré to manage what he referred to as a twisted body.


Fig 4

In the 16th century, Ambrose Paré described the practices of a surgeon: "...he repairs those things which are defective, either from infancy, or afterwards by accident, as much as Art and Nature will suffer... who fits a doublet bum basted [i.e. padded] or made with iron plates to make the body straight...."perforated so as not to be too heavy, and padded so that they will not cause excoriation ...and should be often changed."[8] In this effort to describe the function of a surgeon Paré was also able to demonstrate not only the purpose and function of the orthosis, but the importance of increasing comfort, patient follow-up and adjustment of the orthosis for the growing patient. Paré made a "corset for the correction of a twisted body" and advised that it should be changed both in shape and size as the patient grows or improves, "for otherwise instead of doing good one would cause harm."[9]

Thomas, credits Lorenz Heister, (1683-1758), a German anatomist and surgeon, as having created the first true spinal orthosis.[5] "This crude device, known as 'The Iron Cross,' consisted of a flat, straight metal upright extending from the pelvis to the occiput, with a shorter crosspiece just below the shoulders. A metal upright was attached to the top of the upright for a head support. The device was fastened to the trunk by thongs about the waist and under each axilla." [5]

THE INDUSTRIAL REVOLUTION

Some sixty years after the death of Heister, western civilization had advanced into the industrial age and with it came variations of Heister's orthosis and a myriad of newer designs. While the actual number of designs around the world at that time, were unknown, there were enough to compel Samuel Cooper to write a commentary on spinal orthoses. In, "A Dictionary of Practical Surgery," (1818) he writes"...the iron-cross proposed by Heister, the corselet described by Brasdor... and the leather strap recommended by Brunnighaussen, are only modifications of the figure of 8 bandage, and are not at all better."[10] With the increased number of orthotic designs came the growing and often times grey area between support and correction. While the actual function of the orthosis was in debate, the desired outcome of treatment was not. There appeared to be more agreement in what to do and what was desired rather then how the orthosis was able to accomplish this feat. Prior to the industrial revolution, Nicolas André, in "Orthopaedia," (1743) described management of "The Bunch-Back [sic], the Hollow-Back, and Crooked-Back."

"...the Bunch, as well of the Sternum, as of the Back, may be corrected in Children, by pressing it gently with the Hands; for this gentle Compression, when it is frequently repeated, gradually disposes the Bones, whether of the spine or Sternum, to recover their natural situation... The use of Whalebone Bodice gently to compress the part that bunches out is of great service here."[11] He later adds, "If the Spine be crooked in the form of an "S", the best method you can take to mend it, is to have recourse to whalebone bodice, stuffed in such a manner that the stuffed parts shall exactly answer to those Protuberances which ought to be repressed, and these Bodice must be renewed every three Months at least."[11]

Whenever a new design of orthosis was published, there seemed to be a challenge to practitioners to change or modify the existing orthoses. This back and forth debate continued and was further described in a paper by Chelius. After describing Heister's Iron Cross and its modifications, Chelius, in A System of Surgery, (1847),[13] adds:

" Here also belongs Le Wacher's machine" which consist of stays laced in front and having a plate attached to its hind part. An iron rod passes into a groove upon this plate, which ascends straight up the middle of the neck and thence curves over the head to the forehead. In the notch at the upper end of rod is hung an apparatus, which is fastened around the head and beneath the chin of the patient. Pelug has improved this machine by attaching Instead of the head apparatus at the end of the iron rod that reaches only to the upper part of the neckband, by which the chin and occiput can be held up.

Sheldrake altered Levecher's machine; he took away the stays and fastened the iron rod on a plate that descended from the middle of the back and is fitted closely to the rump bone. Delacroix also altered this machine making its point of support on the pelvis. Guerin has proposed an apparatus for the simultaneous extension (extension sigmoid) of the vertebral column in contrary directions of the curvature."[12]

STRAP AND BUCKLE DOCTORS

Fig 5

The century from 1850 to 1950 was the age of "Strap and Buckle Doctors" with numerous designs for orthotic systems. Lovett, in the American Journal of Orthopedic Surgery (1913), observed, "The theorist and the apparatus maker went mad and every form of device appeared. Braces and corsets, infinitely complicated, worse than useless, appeared by the dozen."[13] Others seem unnecessarily cruel, though well intended such as the Spitzy-Vischer[14] (Fig 5).

The marriage of medicine and mechanics that gave rise to the professions of orthotics and prosthetics was happening, albeit slowly. Charles Fayett Taylor, credited with the TLSO design that bears his name, realized early on that the instrument maker (orthotist) required skills and knowledge beyond simply making the device. Anything less and the orthosis would likely be ineffective. This is captured in his writing from

1863, "...the physician contenting himself by sending the patient to an instrument maker, for one of the many apparatuses found in the shops, and too often leaving the whole matter of kind, form and fit to the selection of the mechanic.

Now this transferring of responsibility from one's own shoulders to the blacksmith might be well enough, if this person were a pathologist and anatomist as well as a mechanic, but as unfortunately this is never the case, the only alternative would seem to be for the doctor to control the mechanical part of the of the treatment himself... Simply to apply an instrument, even a good one, is not enough; it should have a definite object and be mechanically, anatomically, and physiologically adapted to each particular case; if it fail in any of these it will be ineffectual."[15] Taylor's ability to diagnose, assess the geometric deformity and determine the best design application was further recognized by Newton M. Schaeffer, a student of Taylor's. In his writings Schaeffer described his mentor in the following manner:

"Taylor's method of diagnosis, his alert adaptation of mechanical means to pathological ends, his great originality in devising apparatus for all kinds of deforming diseases and conditions; his quick appreciation and interpretation of symptoms, all this was a revelation."[16] Taylor's attention to detail insured that the design provided the appropriate biomechanical force application based on the diagnosis, but it was designed with careful consideration for the comfort of the patient. This attention to detail was captured in his writings that allowed the contemporaries of his day to replicate this design for similar patient populations (Fig 6).

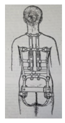
Fig 6

As described by Taylor, "There is no painful pressure downward on the abdomen and hips; but a broad band passes around the trunk low down -- so low in front that it almost touches the thigh in sitting. It passes above the pubis and entirely below the abdomen; so that the abdomen is sustained upward instead of being, as in most instruments, pressed downward. There are two pieces or levers passing up the back: not over the spine but each side of it, so that it is firmly held from lateral deviations. At the top is a cross piece in the form of two T's with the small ends united... At the point of the instrument opposite the point of disease-- the point where we make our fulcrum--the pads are placed... Every particle of pressure on the hips and shoulder straps is just so much force tending to straighten the spinal column... The instrument is provided with several hinges--stop hinges in front, but free to move backward.... The action of the instrument is simple, effectual and easy for the patient."[17]

Due to the detailed description of the design and the positive clinical outcomes, the design and variations of the design continue to be used in today's clinic landscape. Hyper-kyphosis secondary to osteoporosis, tuberculosis, and post-operative management of Pectus Excavatum represent several clinical presentations where the Taylor design (TLSO Sagittal Control) continues to be used today. As if to say, the design was not an end unto itself, Taylor's writing frequently bring the focus back to where it should be and that is with the patient. The danger with any spinal orthosis is that the practice can turn to being device driven. Taylor recognized early on that it is the patient's clinical presentation that should drive the device rather than the other way around. Taylor elucidates this philosophy of patient management in this regard, "My practice is to allow the patient the most unrestricted liberty, and when thus protected from shocks and pressure by the instrument, I have never known the least harm to flow from this entire freedom of action; on the contrary, the greatest good."[17]

Despite Taylor's attention to detail, little is mentioned about the para-spinal bars, a key component of his spinal design. The para-spinal bars that we associate with the "Taylor" orthosis, the ones that curve sagittally in the superior thoracic area, do not appear in the writings of either Charles Fayette Taylor nor those of his son, Henry Ling Taylor. They do, however, appear in an illustration in Dr. Lewis Sayer's Spine Disease and Spinal Curvature, in 1877 (Fig7). Sayer states that the brace was "...obtained in Cincinnati (does not remember the name of the maker), but patients had difficulty wearing the orthosis on account of the pain and difficulty of breathing."[18] Dr. Sayer was a proponent of suspending the patient and applying a plaster-of-paris body jacket and allowing it to harden with the patient in the suspended position. He quotes a John R. Myrick, Capt. 3rd Artillery, USA, "In my opinion, the advantages of the "jacket" over the "Taylor" or any other "brace" consist in the uniform support of the jacket to the whole of the upper portion of the body, its inflexibility and the freedom allowed to the shoulders. The straps of the 'brace' depress the shoulders, giving an unnatural appearance to that part of the body, and appear to me calculated to effect a permanent injury."[18] Sayer's treatment method was a viable alternative to the Taylor orthosis and offered a lower profile design. However, the total contact nature of the plaster-of-paris design brought with it the problem of heat retention and increased incidence of skin maceration. The use of plaster-of-paris and suspension, conceptually, are still used today with the Risser frame. Whether serial casting for Infantile Scoliosis or the TLSO Wilmington Method, both can attribute their roots to the concepts described by Sayers.


Fig 7

Continued discussion about the Taylor design ensued in 1909 when Dr. H.L. Taylor (not to be confused with the original designer of the Taylor, Charles Fayette Taylor) threw his hat into the discussion forum. While critical of the device, H.L. Taylor seemed to offer a more balanced assessment of the spinal orthosis. Here he states, "The simplest and most directly acting spinal splint is probably C.F. Taylor's, which has been much modified in various hands, but scarcely improved. This apparatus is a spinal lever, consisting of two uprights, one and a quarter inches apart, riveted to a pelvic band..."[19]

Historical evidence seems to confirm that the Taylor design and subsequent variations were not limited to North America, but occurred in Europe as well. Both domestically and abroad, the fundamental components of this orthosis included a pelvic band and para-spinal bars. This was confirmed by an engraving from a B. Dreher, Rottweil, Germany, 1906 catalogue (Fig 8) that shows the parallel bars as does a picture from the Henry Saur, Surgical Bandage Manufacturer, a catalogue (Fig 9) of the same era. The Saur picture does show a slight flare to the horizontal cross bar and this bar is placed more superiorly than in more modern designs. The para-spinal bars shown in Dr. Sayer's book, eventually became the norm but, one can only assume, that as they were full length, they came to be attributed to Taylor.

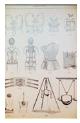
Fig 8


Fig 9

A contemporary of Taylor and equally important in the modern history of spinal orthotics was James A. Knight. In 1863 Dr. Knight opened a hospital in his home. It was the first orthopedic hospital in the United States and was known as the Hospital for the Ruptured and Crippled. He converted his conservatory to a "Brace Shop."[20] This became the first hospital to have an in-house orthotics facility. Knight and Taylor disagreed in their basic philosophies. His contemporaries saw Knight as ultra-conservative. He was of the opinion that there were so few cases that actually needed surgery, as they could be managed by "bandaging and bracing," that there was no operating theatre in the hospital. This led to Taylor being instrumental in the founding of The New York Orthopedic Dispensary in 1866.[16]

Specific to the spinal orthosis design that bears his name, Knight expanded the design to better address the coronal plane. Knight describes an orthosis that has lateral bars in addition to posterior bars like Taylor's (Fig 10). These are positioned to encircle two-thirds of the body and are thus placed more anteriorly than the current practice of placing them at the mid-axillary trochanteric line.[21] Here begins the first terminology standards, to use the term loosely: Orthoses with long posterior bars were called "Taylor" and those with lateral bars were called "Knight" Inevitably, these two designs were combined to produce what is still referred to as a "Knight Taylor Brace" in orthotic jargon.

Fig 10

In England, James Gillingham, of Chard, Somerset, who referred to himself as a "Surgical Mechanician", dominated prosthetic design.[22] Alhough his primary focus centered on prosthetics, his design capabilities extended to include orthoses as well. An advertisement appearing in 1870 mentions "Gillingham's instrument for single or lateral curvature of the spine," He states that he uses Sayre's method of suspension and describes the orthosis: "A pelvic band is secured just above the hips, and further supported by joint lacings over the crest of the ilium. To the belt is secured two lateral crutches to come well up in front, a back piece with padded shoulder plates, supported by [a] strap, in addition to which is the abdomen stay secured to the lateral uprights. The tendency of this support is to rest the spine and reduce the curve."[23] This description sounds much like the Knight-Taylor design, but the engraving shows that it is quite different (Fig 11). The thoracic band does not reach as far as the mid-axillary trochanteric lines and there is no attachment of the paraspinal bar (or bars) other than to the pelvic band. The axillary crutches are asymmetrical, with the largest dimension anterior and possibly functioning like infra-clavicular pads.[23]

Fig 11

Gillingham's other illustration (Fig 12) also includes axillary crutches but has a unique posterior. The para-spinal bar bifurcates superiorly beginning at about the waist forming a "Y" shape. Inferiorly this is attached to a rack and key so that it will "give pressure and rest on the transverse process of the spine, at the same time leaving the distressed and sensitive angle free from pressure."[23] The orthosis is also shown with a "jury-mast" attached (Fig 13).[23] The jury mast was so named because "jury" as an adjective, means "temporary," and this component, at least in Gillingham's design, appears to have been removable. James Newcomb, in his, The Epitome of Medicine, (1893), states: "...the active traction afforded by the jury-mast and halter is more comfort and effective than the simple fixation of the metal head supports. A disadvantage of the jury mast is, that it is [a] very noticeable and rather offensive support." He goes on to add that," An inoffensive chin rest may be used where the jury mast would not be tolerated."[24]

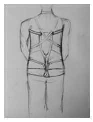

Fig 12

Fig13

Another prolific English orthopedist was Hugh Owen Thomas, known today as "The Father of Orthopedics." His seminal work, *Fractures, Dislocations, Deformities and Diseases of the Lower Extremities*, does not specifically address spinal orthoses but discusses them only when they serve as an extension of lower limb systems.[25] His sole contribution to spinal orthotics was the Thomas collar.

On the contiguous European continent, German innovators dominated orthotic design. Foremost among them was Frederich von Hessing. He was trained as a joiner and organ maker but soon turned to

"Mechanical surgery."[26] Von Hessing was one of the last self-taught orthopedists, yet he became a master of his craft and was known as "a miracle doctor" to his patients. It is said, "The art of brace making attained its fullest development during the latter part of the 19th century under the leadership of von Hessing and his contemporaries."[5] He utilized molded leather orthoses reinforced with a metal superstructure. Other than this technique, his most lasting contribution was what came to be known as the "Hessing Ring," (Fig 14). This proved to be the most effective means of stabilizing an orthosis on the pelvis before the introduction of modern polymers.


Fig 14

THE TWENTIETH CENTURY

Systematic research in orthotics began in 1927 with the establishment of The Pope Foundation, by Henry Pope.[27] This was still the era of polio and the focus of research was on lower limb orthoses. The early 20th century saw little innovation in new spinal designs, but numerous variations on existing designs. The first comprehensive study of spinal orthoses was by Paul L. Norton and Thornton Brown in 1957.[28] Several orthoses were evaluated with intervertebral motion measured using Kirschner wires. "None of the braces tested did more than limit interspace flexion."[28] They found that a new design was necessary. This did not have para-spinal bars but had trochanteric extensions to gain more control of the lumbo-sacral area by extending the lateral lever arms. The idea was to keep forces located over boney prominences so the patient would experience "somewhat uncomfortable pressure" when "forward bending or slumping."[28] Responding to this article, Dr. Paul Williams observed, "They have contributed a great deal if they can rid us of the many ineffective braces that I am inclined to speak of as 'nuisance' braces. Such braces push the patient in one place and push him out in another, but their only effectiveness lies in the fact that the patient eventually gives up and decides to hold still."[28]

A 1962 article, while discussing the "Taylor brace" adds parenthetically, "modifications include the Arnold, Magnuson, Bennett, and Steinler braces."[29] These eponymic "braces" created problems for prescribing physicians and orthotists alike, for there was no standard as to what constituted a "Bennett Brace," for example, or a "Magnuson Brace." The Bennett was presented in an article in 1936.[30] Bennett describes it as modification of the Knight spinal brace and utilizes Hessing rings for stabilization on the pelvis. In the Atlanta area in the 1970's a "Bennett brace" was a standard "Knight" design with a modified corset front. The two inferior corset straps were joined to form a "Y" and attached to the corset front by a single buckle on each side. This was somewhat like the Hessing rings on the original but obviously did not have the same stabilization effect.

A "Magnuson Brace" in the Washington, DC area referred to what was known in the Atlanta area as a "Walter Reed Brace." This had the infra clavicular pads of the Magnuson design but was stabilized on the pelvis by Hessing rings. The story at the time was that Robert Kelly, Chairman of Orthopaedics at Emory University, had developed it. Supposedly, Kelly was so impressed by Walter Reed selflessly using himself for experiments in determining the vector for yellow fever that he, Kelly, decided that if he ever designed or discovered anything himself, he would name it after Reed.

The proliferation of names and designs continued to increase. A 1962 nation wide study by Natress and Litt found that as many as 13 names were used to describe a single orthosis.[27] Several other spinal orthoses were developed in the first half of the 20th century, most notably the ones we now know as the Williams Flexion Brace, the Jewett Hyper-extension Brace, and the Milwaukee Brace. The "Williams" was developed by Paul C. Williams in 1937 and was originally termed "The Lordosis Brace" [31] and provided a dynamic stimulus to induce lumbar flexion. This was accomplished by having the lateral bars articulate with a thoracic band, which, in turn, articulated with an oblique bar that was rigidly attached to a pelvic band. A flexible anterior corset and/or pad allowed the necessary movement of the body. This orthosis was found to be particularly effective in the management of spondylolysthesis and symptomatic spina bifida oculta. The Williams Flexion Brace became very popular. Some of its adherents thought that it could be improved by fitting it "upside down."[32] Physicians writing orders for this orthosis would specify on the prescription, "Fit right-side up," or "Fit upside down." Hauser had applied this principle of inducing lumbar flexion to casting techniques in 1945[33] and later by Frank M. Rainey, to what came to be known as the "Rainey Flexion Jacket."[34]

The orthosis known as the "Jewett Hyperextension Brace" was developed by R. Arnold Griswold of Louisville, KY, and is similar to one developed by A.E. Hoadley in 1895.[35] Presented in a 1936 issue of JBJS, Griswold states, "The brace was developed in an attempt to apply mechanically effective counter pressure to the spine at both ends of the trunk against a posterior fulcrum at the peak of the kyphos[sic]." It "was designed for the convalescent support of compression fractures of the lumbar and upper dorsal spine" and was pre-fabricated and adjustable. "... "bars are adjustable in length, so that the joint may be raised or lowered ... in order that the brace may be adjustable enough to fit patients within a reasonable range of size."[36]

Eugene Jewett utilized this principle for what he described as "A Light Hyperextension Back Brace." 37 This orthosis was constructed over a plaster of Paris model. Jewett's opinion was, "Of course, Griswold's brace can be used without having any plaster of Paris cast made, and in that respect it is much more adaptable. However, it is the writer's opinion that in most cases it is better to make a brace from a plaster jacket, [i.e. mold], in order to be sure that all parts fit absolutely correctly."[37] It is ironic that the orthosis that we now identify as "a Jewett" is designed and utilized using Griswold's principles.

The Milwaukee Orthosis, commonly known as "The Milwaukee Brace," was developed in 1945 "... to provide more efficient and comfortable passive correction and fixation following surgery."[38] This was its routine use until 1954. There had been previous orthoses that were used for non-operative management of scoliosis, but they were mostly ineffective in providing correction and simply provided support to the torso, hopefully preventing progression of the curve. Orthotic designs that did attempt correction often had cranks, gears, levers, or weights or they had similar components providing passive corrective forces. The regimen for use of both of these types of orthoses required the orthosis to be removed at night, "...[the time] when they were most needed."[38]

The orthosis most often cited, as being a precursor to the Milwaukee was that attributed to Spitzy. (Fig 5) This design had conical projections under the occiput and chin that provided what has been termed "a stimulus to withdraw." In other words, it caused pain. Consequently, the patient would be actively avoiding these components and this act of "stretching" would provide distraction to the spine. The genius of the Milwaukee design was that it was able to obtain the same function but without the pain. It achieves this by providing a biomechanical environment in which the patient affects his or her own correction.

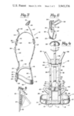
Fig 15

The Milwaukee Brace, despite its effectiveness, did have its drawbacks: It is difficult to fabricate, uncomfortable to wear, and has an undesirable appearance. These problems have been addressed in different ways. The Kuehnegger Orthosis[39] (Fig 15) was developed in the Netherlands in the 1970's. It utilized the same principles as the Milwaukee, but was modular and easily fabricated. It was popular in Europe, but never caught on in the US.

The orthotic design that ultimately supplanted the Milwaukee for most applications, was the Boston System. The system began "...with the Milwaukee Brace concept but the necessity to take a cast, pour, and rectify a positive model [was] eliminated in an estimated 95 percent of the cases by use of prefabricated plastic pelvic girdles."[40] The insight that the focus of corrective scoliosis management was not to make the orthosis fit the patient, but was rather the other way around, i.e. making the patient fit the orthosis. Bill Miller, C.O. of The Children's Hospital of Boston applied this concept to the pelvic girdle of the Milwaukee, with an expanded trim line and the elimination of the metal superstructure to become what we now know as The Boston Brace.[41]

The Boston Brace or one of its derivatives has become the standard non-operative treatment for scoliosis. Despite the improved aesthetics, the cosmetic appearance still remained problematic for many patients. Ralph Hooper developed another orthosis, the Charleston Bending Brace, in 1978. It utilized the principles of over correction[42] and nighttime (part-time) wear. Since it was only worn at night, the cosmetic problem was moot. "Originally, the new orthosis was used to treat patients in which other types of orthotic management had failed; patients who continued to show progressive curvatures, but whose skeletal maturity obviated full-time brace wear, and patients who had refused other treatment options. In these cases, time-modified brace wear seemed preferable to complete non-compliance, for obvious reasons."[43]


Fig 16

Attempts to manage scoliosis with minimal componentry had been tried previously (Fig 16) and reappeared in 1998 as the SpineCor orthosis. Developed in Montreal by Charles Rivard and Cristine Coillard, the SpineCor is described as "a dynamic non-rigid bracing system for the treatment of scoliosis." Its regimen calls for orthotic management to begin when a 15 degrees curve is present. Initial results showed a curve progression of 5 degrees or less in 93% of patients, but some physicians have been hesitant to use this orthosis, not wanting to begin orthotic management with such a small curve.[44]

Another minimalist orthosis, the TriaC was developed in The Netherlands by A.G. Veldhuizen, and is recommended for lumbar curves only.[45] Its name derives from 3 "C's", Comfort, Control, and Cosmesis.[46] And though not specified, improved compliance is implied as it has been for the SpineCor system.

A BRIEF RETROSPECTIVE

The three major innovations of the late 20th century that affected orthotic management of the spine had little to do with spinal orthoses per se. First was the new orthotics terminology and technical analysis form presented in Artificial Limbs in 1970.[47] This was the culmination of work of a subcommittee of the American Academy of Orthopaedic Surgeons seeking to remove eponymic terminology as the primary descriptor for an orthosis. Instead, the orthosis would be described by its location and biomechanical function.

"The prime objective was to develop terminologies based on logical systems which could also accept new devices with which a physician can communicate to the orthotist the functions desired for a device. Secondary objectives derived from this communication would be that such a system would provide a logical system for the teaching of physicians, therapists, orthotists and prosthetists, for the development of fee-paying schedules, and would provide an authority list for information retrieval systems."[48] This terminology had the secondary result of changing the focus of the profession away from an item delivery system into an evaluation and process system that resulted in item delivery.

Second was the development of new materials. The only ways to fabricate a custom molded body jacket, at the turn of the twentieth century, was by molding leather or a resin impregnated felt over a casting of the patient. This was an arduous and time-consuming process. In addition, molding the felt required using acetone, a highly flammable solvent. This became unnecessary when OrthoplastTM [49] was used for the pelvic girdle of the Milwaukee Orthosis in 1966.[50] OrthoplastTM is a type of balata and is moldable with heat, typically in hot water. Other thermal forming and thermal setting polymers followed along with reinforcing materials such as Kevlar® and carbon fiber.

Third was the application of computer technology to orthotics. In spinal orthotics, computers have streamlined central fabrication and in many instances obviated the need for a mold to be taken for a custom orthosis.

THE REST OF THE TWENTY-FIRST CENTURY

Material and computer technologies will continue to advance allowing greater ease of custom fabrication and allowing greater focus and time to be spent on patient evaluation and management. The field as a whole will continue to be impacted by advances in surgery and bioscience. For instance, Axial Biotech developed ScoliScore, a genetic test that indicates the potential for progression of a scoliotic curve. [51] This may eliminate orthotic management as an option for some patients with mild to moderate curves. And new applications for orthotic principles will surely arise; as for example did techniques for management of fractures, of plagiocephaly, and of the diabetic foot in the last half of the twentieth century.

* The various archaic terms for "orthosis," i.e., machine, instrument, brace, etc. have been left as they are for historical accuracy.

** At this time a lower-limb prosthesis was often called a "jury-leg."

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Section 2:
Basic Science Principles

4

Growth and Maturity in Musculoskeletal Care

James Sanders

Normal growth is highly coordinated from the single celled zygote to a full sized adult individual following predictable patterns of growth in height, weight, development of reproductive and secondary sexual characteristics, changes in mass and distribution of muscle and fat, and changes in bony structure. Height growth is very rapid during the initial year of life, and then gradually slows until reaching a steady velocity of about 5cm/year from age four to five until adolescence excepting a small mid-childhood growth spurt around age eight. With puberty, there is a very rapid growth acceleration followed by a decrease until maturity. The adolescent growth spurt typically begins around age 10 for girls, age 12 for boys and spans about four years, beginning about two years before and extending three years beyond the growth peak (Fig 1). In children with similar environments, normal pubertal timing can vary as much as four years.[1] Throughout postnatal growth, the physis is the primary generator of musculoskeletal growth. Muscles, ligaments, nerves, and blood vessels all have their own mechanisms of longitudinal growth, but each grows in response to the skeletal stimulus resulting in well-coordinated growth of the limbs, chest, and spine. Skeletal growth can be inhibited by abnormalities like muscle contractures or nerve palsies placing, forces on the physis or from intrinsic physeal problems such as in skeletal dysplasias.

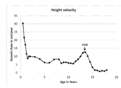

Fig 1

HORMONAL MECHANISMS OF GROWTH

Babies must be sufficiently small to pass through the maternal pelvis and birth canal, and dimensions needed for healthy delivery likely determine normal birth size, but this is also influenced by maternal health, nutrition, and placental health. Early infantile growth is quite rapid and is primarily driven by nutrition.[2] Malnourished children will have diminished stature which can usually be regained via “catch up growth” when the problem resolves. Childhood growth, from roughly 3 years until puberty is mostly hormonally driven from growth hormone (GH), insulin like growth factor-1 (IGF-1), and thyroid hormone.[2,3,4] The pubertal phase marks a discontinuity from the childhood growth.

Humans have two basic pubertal stages, adrenarche and gonadarche, which are regulated by separate but related systems, the hypothalamic-pituitary-gonadal axis (HPG), and the hypothalamic-pituitary-adrenal axis (HPA),[5] with the former most important for musculoskeletal growth. Both growth hormone (GH) and the sex steroids, particularly estrogen, are necessary for the normal adolescent growth spurt in both boys and girls. GnRH (gonadotropin releasing hormone, identical to luteinizing hormone releasing hormone, LHRH) release is suppressed between infancy and puberty. The mechanism of GnRH suppression and its subsequent release are only partially understood but include environmental and CNS mediated mechanisms. Environmental factors include various diseases or high levels of exercise affecting the amount of body fat and subsequent leptin levels, and possibly some environmental chemical causing either premature or delayed puberty.[6-11] With GnRH resuming its pulsatile release at the beginning of the adolescent growth spurt,[6] estrogen secretion is stimulated from the ovaries in girls and from the testicular testosterone's peripheral aromatization in boys. Estrogen is the critical stimulus of the physis causing the linear growth spurt.[5,10,12-15] The estrogen increase causes initial breast development in girls and rapid foot growth in boys and girls, the first physical signs of the adolescent growth spurt. The initial estrogen increase stimulates further growth hormone (GH) release;[10,16,17] although, there is some experimental evidence from rhesus monkeys, one of the few animals having an adolescent growth spurt like humans, that the GH increase can start without sex steroid initiation.[19] GH acts both directly and indirectly through production of Insulin-like Growth Factor-1 (IGF-1) to stimulate physeal growth. The growth rate then peaks about two years later and then slows to cessation after another two years. The two standard deviation range for North American girls' growth peak is 9.7 to 13.3 years.[18] Estrogen also appears to be the primary factor causing physeal closure at the end of skeletal growth in both males and females via estrogen receptor α (ER-α).[2] Lower doses of estrogen during early puberty stimulate growth, whereas higher doses in later puberty lead to growth cessation. Androgens appear to have a direct stimulating effect on the growth plate without any effect upon the GH-IGF-I axis.

THE GROWTH SPURT AND PEAK HEIGHT VELOCITY

The maximum height growth rate is called the growth spurt and the Peak Height Velocity (PHV). Chronological timing of the PHV has been called both the age at peak height velocity and the peak growth age (PGA). For simplicity, we will use the term PHV to indicate the timing of the peak height velocity rather than the velocity itself. Maturity may be measured in time intervals from the PHV such that PHV + 0.5 year represents 6 months after the PHV, and PHV -1.0 year as 1 year before the PHV. The PHV and its timing are under tight genetic and lesser environmental control.[19] Most studies show peak velocities in girls of about 8cm/yr. with a standard deviation of 1cm/yr., and in boys of about 9cm/yr. with a slightly larger standard deviation,[19-23] and standard reference curves have been developed.[18,22-24] Because the PHV is the major marker of growth, we will spend some time noting other events and their relationship to it.

<u>Muscle, Fat, And Skeletal Mass Development</u>

The development of normal muscle mass and strength, bone density and strength, and fat mass a distribution is under hormonal and genetic influence.[25,26] Muscle, fat and skeletal mass accretion differ between boys and girls, and are strongly related to physical activity with increasing exercise increasing bone and muscle mass and decreasing fat mass.[27-35] Higher impact sports also create higher bone mineral densities in the areas undergoing the impact[36,37] and also create higher bone mineral density in general. In general, these tissues have similar accretion velocity curves to height for both boys and girls[38] decelerating rapidly from birth through age 5 with a small spurt at age 6 to 7, a larger growth spurt near the time of PHV and then a decrease until maturity.

<u>Maturity Determination</u>

Maturity is multidimensional, but the dimension most important for musculoskeletal care is longitudinal growth upon which other important dimensions including muscle strength, weight and skeletal strength and dimensions depend. Height maturity is reflected best in the timing of the PHV. The most definitive way to determine PHV is by measuring the height velocity at sequential office visits, but this is difficult at best with diurnal variation of up to 1.4 cm.[39] Short-term growth is non-linear and has periods of both rapid and of little activity[40] creating strange velocity calculations, and a single misreported height can make PHV assessment difficult.[41] Patients needing evaluation and treatment rarely have prior serial accurate height measurements available, and other maturity indicators become important.

Secondary Sexual Characteristics

Secondary sexual characteristics are tightly connected with their growth spurt particularly in girls since estrogen is the common cause of both the growth spurt and secondary sexual characteristics. The correlation is not as tight in boys as in girls because of the importance of estrogen.

Tanner divided secondary sexual characteristic development into clinically useful stages for breasts and pubic hair development in girl and the scrotum and pubic hair in boys.[42] The pubertal or Tanner stages are highly, though not exactly, correlated with the growth spurt and the PHV.[24] Girls' rapid breast development tends to coincide with the acceleration of growth.[23] Girls typically reach their PHV between stages 2 and 3 for breast development and stages 2 to 3 for pubic hair development while boys reach theirs between stages 3 and 5 for testicular and pubic hair growth. Unfortunately, patient self-assessment is unlikely to provide accurate information,[43,44] and most orthopedists are uncomfortable doing this assessment in conjunction with a musculoskeletal evaluation making secondary sexual characteristic determination problematic in practice. Other secondary characteristics not included in Tanner's staging but helpful in identifying advancing maturity in their presence and lesser maturity in their absence includes sweat gland maturation, menarche, voice change, axillary hair, and course facial hair.

Menarche is a readily identifiable maturity indicator associated with the beginning of the cyclic estrogen-progesterone production in females. While menarche is usually a reliable sign that growth velocity is past the PHV and decreasing,[23,24] the early menstrual periods are often irregular, and menarche's timing relative to the PHV is much too variable for accurate assessments.

Skeletal Maturity

Skeletal radiographic appearance is the prime maturity measurement for most specialists. Skeletal maturity determination is based on bones growing and physes maturing in orderly sequences. "Skeletal age" is a misnomer and the concept of skeletal maturity as a developmental stage or maturity level is preferable to a non-existent a linear "age". The radiographic appearance of the skeleton is dependent upon both the overall hormonal maturation state and the inherent genetic control of each local physis. Any skeletal region with consistent physeal markers is amenable to determining a skeletal age. Several longitudinal studies of children's growth were initiated in the early twentieth century by obtaining serial radiographs and anthropomorphic measurements throughout growth. The most important of these for orthopaedists is the Bolton-Brush collection started by T. Wingate Todd of Western Reserve University in Cleveland, Ohio. In addition to growth data, the study collected longitudinal radiographs on upper middle class children, many children of university faculty, from the Cleveland area in the 1930's and 40's. Skeletal ages were determined by correlating the children's hand radiographs with their ages and taking the middle (mode) radiograph as represented in the Greulich and Pyle atlas.[45] The study itself and the original atlas by Todd had only the yearly radiographs during adolescence while the later Greulich and Pyle atlas picked some intermediate stages for the "six month" intervals during adolescence. There are other methods of assessing the hand and wrist such as the Tanner-Whitehouse III[46] and the Fels[47] methods also based on longitudinal studies. Other skeletal regions described for estimating maturity including the foot, knee[48,51] cervical spine,[49-60] and the calcaneal apophysis.[61] Spinal deformity surgeons commonly use the Risser sign[62-64] of iliac apophyseal ossification.

The Greulich and Pyle atlas is an example of the "atlas method" of determining skeletal maturity. "The individual bone method", which includes the Oxford score[65] of the hip and pelvis, the Tanner-Whitehouse method using the hand and wrist, and the Sauvegrain method[66,67] using the elbow develops scores from individual ossification center appearances which are totaled for a maturity score. These can then be correlated via a table or graph with the maturity.

Important Skeletal Maturity Nuances For Orthopaedic Surgeons

Skeletal age determinations are based upon normal children. Therefore, for clinicians facing a child with other medical or developmental issues or a skeletal dysplasia may find the skeletal age inaccurate.[68,69] The most common error in skeletal age determination is mal-positioning. In the hand, slight flexion of any digits makes interpretation difficult, and rotation can cause the same problem in the elbow. A number of investigators have questioned the validity of using skeletal age atlases in children of varying cultures, diseases, and epochs without substantial revisions for each particular group.[70-90] However, if the concept of skeletal maturity is used rather than skeletal age, most of these differences disappear.

The Hand:

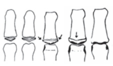

Fig 2

Knowing the various stages of hand's changes is not difficult and is important for accurate maturity determination regardless of which system is used. The various stages of the digits during adolescence are shown in (Fig 2) going from uncovered, to covered, to capped, to fusing, to fused. The ulnar side of the hand (the fourth and fifth digits) is the last to have fully covered epiphyses, the proximal epiphyses cap their respective metaphyses slightly before the distal epiphyses, the distal phalanges close before the proximal and middle phalanges, the digits close before the metacarpals, and the distal radius closes last of all. We have developed a reliable classification system based upon these patterns corresponding closely to the PHV (Fig 3).

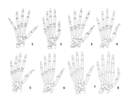

Fig 3

Risser sign:

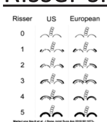

Fig 4

The Risser sign is a commonly used as a maturity indicator in scoliosis based on the radiographic excursion of iliac apophyseal ossification (Fig 4).[62,63,64] The Risser sign's advantages are its ready appearance on standard AP views of the spine and that it typically proceeds in orderly fashion. However, because of concerns of breast irradiation, most scoliosis films are now PA rather than AP. Unfortunately, because of radiographic parallax, it is much less visible on PA radiographs. If the patient also has a lateral radiograph, then the ossification can sometimes be more clearly seen on the lateral. The Risser sign appears after the PHV,[91] does not correlate well with skeletal age and correlates differently in boys than in girls. Girls typically have little remaining growth at Risser 4 while boys may still have significant growth and may continue to have significant curve progression between Risser 4 and 5. The utility of the Risser sign can be improved by including the pelvis, which has a large number of physeal and apophyseal ossification centers, on the radiographs. However, this utility must be balanced with the increased gonadal irradiation. The triradiate cartilage is currently the most useful of these as it typically fuses before initial iliac apophyseal ossification begins and also correlates closely with the PHV.[92,93]

Elbow:

The Elbow has a number of ossification centers visible during the adolescent growth spurt making it useful during puberty.[66,67,94] DiMeglio and colleagues have looked at the Sauvegrain method[67] during puberty and found it reliable with potential advantages to the Greulich and Pyle with more potential stages during adolescence. Charles, et al.,[95] have developed a system based on just the olecranon which has reliable stages during adolescence (Fig 5). We[96] compared Sauvegrain scores in both boys and girls and found it highly related to their PHV.

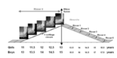

Fig 5

Other Skeletal Markers

Obviously, there are other potentially useful skeletal sites besides the hand, elbow, and pelvis including the spine with a number of markers particularly ossification of the rib heads and the ring apophysis,[71-73,97] the cervical spine's appearance,[49-63] the knee[48,98] the foot,[99-101] and the shoulder which are rarely used for accurate maturity determination. We have recently described the appearance of the calcaneal apophysis that is also useful around the adolescent growth spurt,[61] (Fig 6) and along with the Oxford scores from the pelvis sign, correspond to their timing around the PHV.

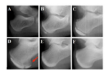

Fig 6

RELATIONSHIP SKELETAL MATURITY TO THE PHV

The PHV was unrecognized as such an important maturity marker when the Greulich and Pyle atlas was completed. A number of investigations[58-60,70,93,96,102-108] found a tight collection between skeletal maturity and PHV. In terms of appearance, hand phalangeal capping[109] and closure of the lateral condyle of the elbow[110] are both closely related to the PHV. We have found that using more than one skeletal maturity region can help identify proximity to the PHV better than any region separately.[61] While evidence is limited, it appears there is less coupling of the pre-growth spurt skeletal maturity than skeletal maturity once the growth spurt has stopped. This has been interpreted in the adolescent growth spurt being able to start at any level of skeletal maturity, but once the growth spurt starts, skeletal maturity quickly becomes tied to peripheral hormonal levels.[105,111] Overall, particularly for orthopaedists, skeletal maturity appears the best reliable and readily available method of maturity determination compared to hormonal and skeletal metabolic markers and secondary sexual characteristics. Recently developed systems for the elbow and hand provide reliability formerly lacking.

Individual Segment Growth

Most studies looking at the various segments date from early in the 20th century, though a few are later. Despite a strong relationship between the various body segments, the individual body areas have their own specific growth patterns. The overall pattern is of rapid spine and extremity growth from birth to age five, more rapid extremity growth between five and adolescence. The spine gains about 10 cm in length between birth and age 5,[112] which probably accounts for the often rapid progression of congenital and infantile curves during this time, but then only gains about 5cm in length between ages five and adolescence. During the adolescent growth spurt, the spine is the primary location of accelerated growth[46] gaining about 10 cm during this period and accounting for 80% of the growth during that phase.[113] The lower extremities have a more constant rate of growth and less conspicuous growth spurt. But, it is a mistake to assume the limbs do not have a growth acceleration and deceleration phase. The growth spurt of the limbs is slightly prior to the spine's growth spurt[114,115] and the percentage of segment growth from each physis changes over time. Once extremity growth ceases, the spine still has significant growth remaining. As the longitudinal growth of the spine slows, there is an increase in iliac crest width, inter-acromial distance, and lastly chest depth and diameter.[116]

Our primary sources of spinal growth are from cross sectional data using very small samples of normal children.[112,117-124] DiMeglio's publications are the most utilized currently to compare spinal deformity patients with those having normal spine growth.[110,112,113,125-127] The data from his thesis unfortunately are not accessible to review, and it is unclear whether the studies were longitudinal or cross sectional and provide no information on ranges and distributions. The other existing studies addressing spinal length by direct radiographic spinal measurement are cross sectional.[117-124,128-130] The problem with relying on cross sectional studies is that it limits our understanding of individual spinal growth at specific time points and hides differences between individual children. This is particularly true for times when different children have substantially differing growth. The adolescent growth spurt in particular constitutes a major disruption from prior growth and occurs at different ages in different adolescents. When studied with cross sectional data, the growth spurt is only seen as wider data scatter with only slight changes in averages because cross sectional data blunts the growth spurt by averaging across all the subjects. In spinal deformity, the adolescent growth spurt is typically the time of marked change in spinal curvature, making it very important in any growth modulation strategy. Fusion surgery prior to the growth spurt often results in continued deformity with poor appearance of the trunk and the need for further surgery. The crucial issue in evaluating growth during adolescence is where the child is within their growth spurt. A child at mid-growth spurt will have remaining growth behavior very similar to other children at mid-growth spurt who may be two years older or younger, but they will have very different growth from a child of the same age who is much early or later in their growth spurt.

DiMeglio indicates that from age five to puberty, two-thirds of the height growth is from the lower extremities (sub-ischial) with one-third from the spine, but that this ratio is reversed during the adolescent growth spurt.[110,113] Thoracic length and circumference do not grow simultaneously, especially during puberty. At age 10 years, the thoracic circumference is at 74% of its final size, whereas the sitting height is almost at 80% of its final length. Globally, the volume of the thorax triples from the age of 4 years until the end of puberty in girls and until 16 years in boys with a doubling between ages of 10 years and skeletal maturity.[131,132] The development of the male thorax continues after the age of 16 years. This results in a relative elongation of the rib cage until the end of growth in young men. In our own findings from longitudinal data, children from mid-childhood to the beginning of the growth spurt grow from T1-S1 at 1.5cm/year. This increases to 2.5 cm/year during the growth spurt and then markedly slows. These rapid changes can make brace fitting difficult and are also indicative of the marked changes, which can occur with the spine during the growth spurt.

SUMMARY

While this chapter can only touch on the many aspects of human growth and development related to spinal orthotics, these issues remain central to properly assessing and treating pediatric orthopaedic conditions. Future work in skeletal maturity assessment and growth modification will likely make these issues more important to hold and correct spinal problems in growing children.

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5

Biomechanics Of The Spine And Of Spinal Orthoses

Thomas M Gavin, Avinash G Patwardhan, Robert Lin

The primary biomechanical functions of the spinal column are to support the loads induced during activities of daily living while allowing physiologic mobility. In normal individuals, the spine performs these functions without causing injuries to bony, soft tissue, or neurological structures. This chapter presents a framework for understanding these biomechanical functions of the spine by first discussing the stability of the osteo-ligamentous spinal column and the role played by the muscles, then progressing to the stability of a healthy spinal segment, followed by a discussion of the effects of injuries, degeneration, and surgical procedures on the load sharing between the components of a spinal segment. Finally, the chapter presents a brief discussion of the biomechanics of spinal fusion implants as well as orthoses used for stabilizing an unstable spine. A more detailed description of the role of spinal orthoses and their mechanisms of action for individual spine pathologies are presented elsewhere in this Atlas.

PHYSIOLOGIC LOADS

Mechanical loading of the spine is an important factor in the etiology of spinal disorders and in the outcome of orthotic treatments for spinal disorders. The loads on the human spine are produced by (i) gravitational forces due to the mass of body segments, (ii) external forces and moments induced by physical activity, and (iii) muscle tension.[1] These loads are shared by the osteo-ligamentous tissues and muscles of the spine. Tensile forces in the paraspinal muscles, which exert a compressive load on the spine, balance the moments created by gravitational and external loads (Fig. 1). Since these muscles have a small moment arm from the spinal segment, they amplify the compressive load on the osteo-ligamentous spine.

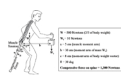


Fig 1

The human spine is subjected to large compressive preloads during activities of daily living.[2] The internal compressive forces on the ligamentous spine have been estimated for different physical tasks using kinematic and electro-myographic (EMG) data in conjunction with three-dimensional biomechanical modeling. The compressive force on the human lumbar spine is estimated to range from 200-300 newtons (N) during supine and recumbent postures and to 1400 N during relaxed standing with the trunk flexed 30 degrees.[3] The compressive force may be substantially larger when holding a weight in the hands in the static standing posture, and even more so during dynamic lifting.[4] The human cervical spine also withstands substantial compressive preloads. The cervical preload approaches three times the weight of the head due to muscle co-activation forces in balancing the head in the neutral posture. The compressive preload on the cervical spine increases during flexion, extension and other activities of daily living, and is estimated to reach 1200 N in activities involving maximal isometric muscle efforts.[5,6] Normally the spine sustains these loads without causing injuries to bony, soft tissue, or neurological structures.

STABILITY OF THE SPINAL COLUMN

Load Bearing Ability of the Osteo-ligamentous Spine

In the absence of muscle forces, the osteo-ligamentous spine cannot support vertical compressive loads of in vivo magnitude. Experiments in which a vertical load was applied at the cephalic end of the cervical, thoracolumbar, or lumbar spine specimens caused buckling of the spines at load levels well below those seen in vivo. The stability of the spine, characterized by a critical load (maximum load carrying capacity, or Euler buckling load of spinal column), was determined by these experiments. When the load exceeded the critical value, the spine, constrained to move only in the frontal plane in these experiments, became unstable and buckled. The cervical spine buckled at a vertical load of approximately 10 N, the thoracolumbar spine at 20 N, and the lumbar spine at 88 N, all well below the compressive loads expected in vivo during activities of daily living. When a compressive load is applied in a vertical direction to a multi-segment spine specimen, segmental bending moments and shear forces are induced due to the inherent curvature of the spine. This load application causes large changes in the specimen's posture at relatively small loads. Further loading can cause damage to the soft tissue or bony structures.

Role of Muscles

Some investigators have modeled the muscles as springs in order to explain their role in preventing a buckling instability of the spinal column. Simulation of active muscle forces in experiments on the ligamentous spine is difficult due to the large number of muscles and the uncertainty in load sharing among the various muscles during different activities. The simulated muscle actions must provide stability to the ligamentous spine to carry compressive loads while simultaneously permitting mobility needed to perform the activities of daily living.[7]

Recent analysis using muscle models of the trunk support the argument that the individual spinal segments, often referred to as functional spinal units (FSU's), are subjected to nearly pure compressive loads in vivo.[8] Attempts to determine joint loads based on the assumption of a vertical load on the spine have resulted in serious over-prediction of shear forces on the FSU. The calculations of spine modeling, taking into consideration the activity of paraspinal and abdominal muscles, demonstrate that in weight holding tasks the compressive force on the lumbosacral disc increased with increasing trunk inclination and the amount of weight lifted, while the maximum anterior-posterior shear force remained small (about 20-25% of the compressive force). The obliquity of the para spinal musclesallows them to share anterior shear forces resulting from a lifting load. When these muscles are activated to contribute a balancing extensor moment, they help to offset the anterior shear force on the lumbar FSU.[9]

Stability of the Spinal Column under a Follower Load

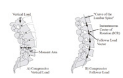


Fig 2

It could be reasoned that co-activation of trunk muscles could alter the direction of the internal compressive force vector such that its path followed the lordotic and kyphotic curves of the spine, passing through the instantaneous center of rotation of each segment (Fig. 2). This would minimize the segmental bending moments and shear forces induced by the compressive load, thereby allowing the ligamentous spine to support loads that would otherwise cause buckling and providing a greater margin of safety against both instability and tissue injury. The load vector described above is called a "follower load."

Experiments on human cadaveric specimens of lumbar (L1-L5), thoracolumbar (T2-sacrum), and cervical spines (C2-C7) as well as mathematical models have demonstrated that (i) the ligamentous spine with multiple motion segments can withstand physiologic compressive loads without tissue injury or instability if the compressive load vector is applied along a follower load path approximating the curve of the ligamentous spine, (ii) the ligamentous spine subjected to compressive preloads of in vivo magnitude along the follower load path permits physiologic mobility under flexion-extension moments, and (iii) the follower preload simulates the resultant vector of muscles that allow the spine to support physiologic compressive loads. Intradiscal pressures in human cadaveric lumbar spines under a follower preload are comparable to those measured in vivo, and the spinal stability is increased without compromising its mobility in flexion-extension and lateral bending. A superimposed follower preload renders the in vitro loading of the ligamentous spine with pure moments more physiologic.

The follower load concept suggests a new hypothesis for the role of muscle co-activation in providing in vivo spine stability. Co-activation of trunk muscles (e.g., the lumbar multifidus, longissimus pars lumborum, iliocostalis pars lumborum) could alter the direction of the internal force resultant such that its path follows the curve of the spine (follower load path), thereby allowing the ligamentous spine to support compressive loads that would otherwise cause buckling of the column. Muscle dysfunction can induce abnormal shear forces at the lumbar FSU, leading to segmental instability in the presence of disc degeneration. On the other hand, a compressive follower preload produced by coordinated muscle action could stabilize shear instability in a degenerative FSU.[10] This suggests a role for muscle conditioning and therapy in treating degenerative spine conditions.

STABILITY OF THE FUNCTIONAL SPINAL UNIT

Three-Joint Complex

A spinal motion segment is the smallest functional unit of the osteo-ligamentous spine and exhibits the generic characteristics of the spine. The FSU consists of two vertebral bodies connected by an intervertebral disc, facet joints, and ligaments (except at the C1-C2 segment where there is no intervertebral disc). The FSU could be viewed as a three-joint complex consisting of the disc (a cartilaginous joint) and two facets joints (synovial joints).[2] A dynamic relationship exists between the intervertebral disc and facet joints in sharing physiologic loads.

The intervertebral disc carries substantial loads due to gravitational and muscle forces. It is the major anterior load-bearing element in axial compression and flexion. In the young healthy spine, load transmission from vertebrae to vertebrae occurs primarily through the disc's nucleus pulposus. As a load is applied to the healthy disc, forces are distributed equally in all directions from within the nucleus, placing the annulus fibers in tension.[11] The collagen fibers of the annulus fibrosis (annulus) are well suited to resisting tension along the fiber direction. The pressure in the nucleus pulposus stretches the fibers in the annulus, and the resistance of the fibers to tensile loading allows the annulus to contribute to load sharing. The annulus fibrosis is well suited to resisting torsion due to the characteristic orientation of fibers in the each layer. The intervertebral disc provides most of the motion segment's stiffness in compression, whereas ligaments and facets contribute significantly in resisting bending moments and axial torsion.

Facet joints provide a posterior load path and have an important role in determining the limits of motion in the FSU. Biomechanical studies demonstrated that facets in the lumbar spine carry 10% to 20% of the compressive load when a person is in standing upright position.[12] The proportion of the total load shared by the disc increases with flexion. Load transmission through the articular facet surfaces as well as through the tips of the inferior facets in extension relieves some of the load on the intervertebral disc. The maintenance of cervical and lumbar lordosis helps to reduce the load on the disc, whereas flexion increases disc loading. The contribution of the facet joints to the stability of an FSU is also dependent on the capsular ligament and the level within the spine. For example, thoracic facets have a limited capsular reinforcement, which facilitates axial rotation, in contrast to the lumbar spine where the facet capsule is well developed to stabilize the spine against rotation and lateral bending.

Segmental Instability

Injuries, degeneration, and surgical procedures can significantly alter the normal load sharing between the components of an FSU, and can cause abnormal motion response under physiologic loads. Instability is quantified as a loss of stiffness or an increase in flexibility of an FSU. Stiffness of an FSU is a measure of how much load is required to produce a given motion. Flexibility is the inverse of stiffness; it is a measure of the motion produced by a given load. The FSU is unstable if the stiffness is too small or flexibility is too large. It is helpful to think about FSU instability in terms of macro- and micro-instabilities.

Macro-Instability

Macro-instability implies gross disruption of the spinal column such as that caused by a fracture leading to disruption in load transmission from one vertebra to another. Macro-instability can lead to a progression of the deformity at the injury site and a resultant neurologic deficit. Examples of macro-instability include instability caused by injuries of the thoracolumbar spine such as compression fracture, fracture-dislocation, traumatic spondylolisthesis, burst fracture, as well as tumors, infections, and iatrogenic causes. Thinking about the spine as a structure made of three load-bearing columns is helpful in appreciating the severity of clinical and biomechanical macro-instability.[13] The anterior column is formed by the anterior longitudinal ligament, anterior annulus fibrosis, and anterior part of the vertebral body. The middle column is formed by the posterior longitudinal ligament, posterior annulus fibrosis and posterior wall of the vertebral body. The posterior column is formed by the posterior arch, supraspinous and interspinous ligaments, facet joints, and ligamentum flavum. A compression fracture involves failure of the anterior column with the middle column being totally intact. The burst fracture involves failure of both the anterior and middle columns. The seat-belt-type injuries represent failure of the middle and posterior columns. Finally, the fracture dislocation injury represents failure of all three load-bearing columns.

The loss of load-carrying capacity of the spine is influenced by the number of columns disrupted. Disruption of a single column such as the anterior column due to a compression fracture results in a minimal loss of load carrying capacity. The instability associated with a two-column disruption such as that caused by a burst fracture or a flexion-distraction seat-belt injury is more severe. Burst fractures cause significant instability (loss of stiffness relative to intact segment) in flexion, lateral bending, and axial rotation. That is, the injured segments undergo excessively large motion as compared to the intact or uninjured segment for the same amount of load. If in addition to the two-column burst fracture, the facets are disrupted, a significantly larger loss of stiffness may be seen in axial rotation. A fracture-dislocation is an example of a three-column disruption, and is at the high end of the macro-instability spectrum.

Micro-Instability

The instability associated with degenerative disorders of the lumbar spine can be viewed as micro-instability. Failure or degeneration of any one element of the three-joint complex can alter the normal load sharing between these elements, leading to symptoms of back and leg pain.[14] It may also set into motion a chain reaction (degenerative cascade) leading to degeneration and pain at other elements of the FSU.

Disc degeneration is thought to precede all other changes within the aging FSU. Degenerative changes in a disc are associated with a loss of proteoglycans in the nucleus that, in turn, leads to a decrease in the ability of the nucleus to generate fluid pressure. With disc dehydration and narrowing of the disc space, the annular fibers of the disc are no longer subjected to the same tensile stresses, as they would be in a healthy disc with the hydrated nucleus.[15] Instead the annulus in a degenerated disc is more likely to bear the axial load under direct compression from the vertebra above. Early degenerative changes in the disc render the FSU more flexible.[16] Facet degeneration is most commonly a result of the segmental instability. As narrowing of the disc space occurs due to degeneration, the facets begin to undergo subluxation until the tips of the inferior facets impinge on the lamina below, causing the facets to increase their share of load transmission. Typically, the patient suffering from facet degeneration will have symptoms aggravated by an extension maneuver since facet loading increases in extension. Increased peak pressures within the facet joint may give rise to degeneration of the joint cartilage; a thinning of the cartilage may cause capsular ligament laxity and allow abnormal motion or hypermobility of the facets joints.[17] Cartilage degeneration seems to further increase the segmental movements that already were increased with disc degeneration. The final stage of the degenerative cascade is associated with joint stiffness. The abnormal pressure and focal degeneration give rise to formation of bony hypertrophy and osteophytes leading to a decrease in segmental mobility. Occasionally, an uneven collapse of the disc space may cause acute angular deformities within the three-joint complex; and the patient may present with both neurogenic as well as low back pain complaints.

During the process of three-joint complex degeneration, surgical intervention may be necessary to alleviate disabling symptoms. The combination of the surgical procedure (such as discectomy, facetectomy, foraminotomy, and laminectomy) and the phase of degeneration will affect the biomechanical stability of the FSU and the clinical outcome. Biomechanical studies on human cadaveric spines showed that disruption of the ligamentum flavum and postero-lateral annular integrity and removal of the nucleus content, simulating partial discectomy for disc herniations, significantly increase primary motions in flexion, axial rotation, and lateral bending.[18] Significant changes to the FSU motion occur with the removal of the nucleus pulposus as opposed to the removal of the annulus. Hemi-laminotomy and partial discectomy increases angular motion over that seen in the intact FSU. Unilateral hemi-facetectomy has little effect on the angular motion in flexion-extension and lateral bending, but may cause a small increase in axial rotation. Subsequent discectomy significantly increases the angular motion in flexion-extension without a preload (Fig. 3); however, a physiologic compressive preload of 400 N tends to reduce the instability produced after discectomy. Discectomy also significantly increases angular motion in axial rotation in the absence of a compressive preload. Hemi-laminotomy with partial discectomy is the gold standard for the surgical treatment of symptomatic radiculopathy caused by a herniated disc. Although discectomy is quite effective in relieving radicular symptoms, persistent mechanical low back pain is not uncommon. The back pain may relate to disc degeneration and the ensuing altered kinematics at the involved segment, which may be exacerbated by surgical treatment. However, the true source of back pain remains unknown in many cases. The non-physiologic motions may lead to altered stresses across the motion segment stabilizers including the facet joints as well as the supporting musculo-ligamentous structures, which could potentially contribute to post-discectomy mechanical back pain.

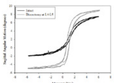


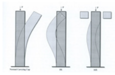
Fig 3

Procedures performed for pathologies in the late degenerative phase, such as decompressing laminectomy or facetectomy for degenerative spondylolisthesis may also lead to instability. Significant instability may result from bilateral hemi-facetectomy. Unilateral or bilateral total facetectomy was shown to produce an increase in the segmental motion of 65% in flexion, 78% in extension, 15% in lateral bending and 126% in rotation. These procedures may require post-decompression stabilization.

MECHANISMS OF ACTION OF SPINAL ORTHOSES

Orthoses for the management of deformities of the spine date to antiquity. Galen, the physician to the gladiators, wrote on a method of bracing and exercise of the deformed spine as a method to manage these deformities. What changed in the last 2000 years is the materials and fabrication methods of these orthoses. Today, many utilize computer-aided design and manufacturing to produce these devices, usually from an optical scan of the patient and measurements, and others still utilize plaster impressions. Most orthoses are fabricated from polymers or composites and are then custom fitted. The future may change these methods once more as three-dimensional printing expands its usage in society.

What has not changed over these millennia is the mechanism of action of how these orthoses are designed and work. First and foremost, the idea was to “straighten” the spine with whatever device is used. Secondarily, it was to maintain this straightening until maturity. A better understanding through current evidence has allowed us to improve on some of our methods, but the core mechanisms of action remain the same. One fundamental ‘mechanism of action’ of an orthoses for spinal deformity is the concept of endpoint control. End-point control is the mechanical constraints the orthosis places on the spine. The function of the pelvic portion of a spinal orthosis is to fix the orthosis to the base of the spine and represents the inferior constraint. The superior portion of the Milwaukee CTLSO is the neck ring and represents the superior constraint and functions to limit the lateral sway of the spine. The outcome of these constraints is that the critical load of the spine is increased. The critical load is the maximum load-carrying capacity of the spine before it undergoes deformational change and becomes unstable. The critical load is best-understood using Euler's buckling theory (Box 1). Using the constraints of orthosis can increase the stability of the spine and is particularly useful for deformities such as idiopathic scoliosis.


Box 1

Some authors have advocated using King's classification when considering how to approach different curve patterns orthotically.[19] King meant for his classification to be applied to surgically treated Adolescent Idiopathic Scoliosis for selecting instrumentation constructs. In orthotic treatment the editors feel instead that a simpler approach is indicated. The curve patterns suitable for orthotic management are a single curve (Thoracic, thoraco-lumbar and lumbar) or a double curve (double thoracic, double thoracic plus lumbar and double thoracic plus thoraco-lumbar).

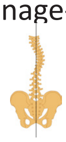


Fig 4

For orthoses, the desired effect is maximal curve reduction of the primary and any compensatory curves without increasing other deformities or creating an overall decompensation of the spine. For different curve types, the orthoses must have different configurations to maximize the desired outcome, that is minimal post-brace curve progression and minimal residual curves.

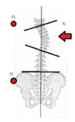


Fig 5

Single Right Thoracic

A right thoracic curve without a lumbar component (Fig 4) is already well balanced, this is because the L4 tilt is minimal. This is frequently the one that requires the least sophistication to obtain the best results. Constraints will be at the axilla, lumbar and pelvis and the thoracic pad is tightened and will synergistically increase the amount of the resistive loads (Fig 5).

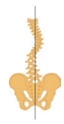


Fig 6

Double Right Thoracic and Lumbar Curves

This is a right primary thoracic with or without a left lumbar compensatory curve (Fig 6). This curve may have a tendency to left decompensation due to tilt sometimes present at L4. Since balance is a primary concern as is curve magnitude, this curve type needs an extra sequence in its correction phase. For the first month, the attempt must be made to shift the T1-L4 segment of the spine from left to right to restore balance by leveling L4, after which point right thoracic forces may be applied to correct the primary curve. Once balance is restored, curve corrections will have less resistance and more symmetry (Fig 7).

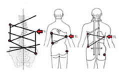


Fig 7

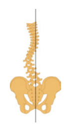


Fig 8

Single Lumbar Curve

For a primary lumbar curve with or without a compensatory thoracic curve (Fig 8), the configuration is quite simple. One three-point pressure system with a shifting force at the apex of the primary lumbar curve, resisted by the opposite side pelvis and a force at the apex of what would become a thoracic compensatory curve (usually T8-T9). Since the pre-braced spine is relatively well balanced, a force that shifts the convex side primary lumbar curve into a constraining force will usually be sufficient to maximally reduce the deformities while maintaining balance (Fig 9).

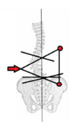


Fig 9


Fig 10

Single Thoracolumbar Curve

The thoracolumbar primary curve (Fig 10), can be either to the left or right and is easily managed with a little difficulty (Fig 11). The lumbar pad and thoracic sling must approximate one another to shift this long curve into its constraining counterforces.

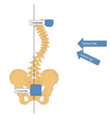


Fig 11

Double Thoracic Curve

A curve pattern with a primary right thoracic curve, a left lumbar curve, and a high left cervico-thoracic curve (Fig 12). Much like the right thoracic-left lumbar curve pattern, it usually presents with a significant counterclockwise tilt at L4. The mechanism of action to treat it is similar except the convex side shoulder of the cervico-thoracic curve must be depressed and the axilla must be shifted beyond the midline (Fig 13). The orthosis frequently looks like that depicted in figure 14.

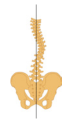


Fig 12

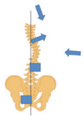


Fig 13


Fig 14

SUMMARY

Understanding the effects of biomechanic and pathomechanic loading of the spine is an important precursor to realistic and effective orthotic treatment of the spine. With this, and the knowledge of the underlying diagnosis, the medical team is more apt to select orthotic treatment that is appropriate, cost-effective and addresses the intended outcome. To improve the likelihood that these outcomes are achieved the proper design selection of an orthosis and effective application of the 'mechanism of actions' must be taken under careful consideration. When thoughtful attention is given to all of these factors the chance for success is that much greater for the medical team, family and most importantly the patient.

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Section 3:
Classification and Management of Spinal Deformity

6

Scoliosis Terminology and Classification

Tyler J Jenkins, Erik CB King, John J Grayhack

INTRODUCTION

Spinal deformity includes a wide variety of pathologies with a subsequently variable natural history and treatment course. The deformity can be classified in several fashions, including description of the deformity itself, underlying etiology, and associated conditions. Correct classification of the curve relies on obtaining a thorough history, physical exam, and radiographic evaluation. The classification of spinal deformity is essential to the appropriate understanding and communication with both patients and professionals in order to develop an optimal management program.

TERMINOLOGY

Correct classification of a scoliotic curve implies an understanding of the basic terminology used in scoliosis management. Understanding these key terms is crucial for communication with patients and between professionals. A glossary of basic terms used in scoliosis management can be found in Table 1.

Table 1

Scoliotic deformities are normally defined in the AP (coronal) or lateral (sagittal) plane. The normal spine is straight in the coronal plane and has balanced curvatures in the sagittal plane in the form of kyphosis (20 to 45 degrees in a normal pediatric population) and lordosis (35 to 60 degrees).[1] Deviations from the normal spinal curvature are referred to as scoliotic or kyphotic/lordotic deformities. The deformity of the spine is rarely in a true single plane, but is in actuality, multi-planar and, particularly in idiopathic scoliosis, rotational in nature. The rotation can be identified clinically and radiographically.

The clinical evidence of rotation is seen in the typical chest wall asymmetry, as demonstrated on the Adam's forward bend test by the angle of trunk inclination (ATI).[2,3] Although an exact correlation between ATI and curve magnitude does not exist, in idiopathic scoliosis curves of greater than 20 degrees are associated with an ATI of greater than 5 to 7 degrees.[3]

Radiographically, the rotational component of scoliotic curves causes a PA radiograph to act as an oblique view. The deformity rotates maximally at the apical vertebrae, which can be identified by the asymmetry of pedicles and other landmarks on the neutral PA radiographs. In order to truly assess the magnitude of deformity on a radiographic view, a film may instead be taken perpendicular to the rib prominence.[36] Individual vertebrae are assessed for anomalies including hemivertebae, block vertebrae, and wedging. Newer imaging modalities such as the EOS imaging system are emerging with benefits of 3-D reformatting and lower dose radiation exposure compared to traditional radiographs.[4,5]

The extent or degree of deformity is defined by the angle created in a given plane, such as the Cobb angle. The Cobb angle corresponds to those vertebrae that define the maximal extent of the deviation. The cephalad (cranial) and caudal vertebrae that are the most tilted are defined as "end vertebrae" and are measured from their endplates to determine the angle or magnitude of deformity.[6] Inter-observer and intra-observer errors in Cobb angle measurement have been demonstrated to be 3 to 5 degrees.[7] In the sagittal plane, these angles are defined by the end plates of the vertebrae with the greatest deviation from the neutral alignment. The description of a deformity includes the level of the apical deformity and the number of levels involved. In congenital deformities of the spine, the acute apical deformities may be measured and followed over time separately from the overall curvature and balance.

Measurement of rotational deformity, utilizing the AP radiograph, has been undertaken by two methods. The methodology of Nash and Moe evaluates the position of the pedicles relative to the center of the vertebrae,[37] while that of Perdriolle uses a template to assess the percentage deviation from one edge.[38] Both methods have significant errors of interpretation, but are helpful in elucidating this important component.

Overall balance of the coronal and sagittal planes has been given more importance in recent studies. In the sagittal plane, anterior or posterior deviations of the spine are measured in reference to a vertical plumb line from the C7 vertebrae to the posterior-superior corner of the sacrum. In the coronal or frontal plane, the overall balance is measured by a plumb line from the posterior spinal process of the seventh cervical vertebrae to the midline of the sacrum. This balance is determined by the compensation of the curvatures, often by minor (flexible or nonstructural) curves to the major (structural curves). The flexibility of the curves is assessed by side bending supine radiographs or a with a traction radiograph. Skeletal maturity can also be assessed by clinical and radiographic evaluation and is an important component of curve classification. An immature patient is at much higher risk for curve progression than a skeletally mature patient. Although no absolute method exists for grading skeletal maturity, the most commonly accepted methods include the Risser sign, triradiate cartilage status, and the apophyseal osssifications of other extremities, such as an AP hand radiograph for skeletal/bone age.

CLASSIFICATION

Accurate classification is crucial for patient care as management and outcomes are dependent on it. The most common etiology and the primary focus of this chapter is idiopathic scoliosis. Idiopathic scoliosis is defined as a structural curvature with a Cobb angle greater than 10 degrees, has identifiable rotation, no vertebral anomalies and no congenital or known etiology. Idiopathic curves are commonly subdivided by the age of onset. Other less common etiologies of scoliosis include congenital, neuromuscular (paralytic), or curves associated with a syndrome.

IDIOPATHIC SCOLIOSIS

Idiopathic scoliosis is the most prevalent etiology of pediatric patients having a scoliosis deformity, with a prevalence rate of 0.47-5.2% in the general population.[8-10] Despite extensive research, the exact etiology remains elusive. The Scoliosis Research Society recommends that idiopathic scoliosis should be further classified based on the age of the patient when diagnosed.[6] When diagnosed before age 3 years, it is termed infantile idiopathic scoliosis, juvenile idiopathic scoliosis from age 3-10 years, and adolescent idiopathic scoliosis when diagnosed between 10 years and skeletal maturity

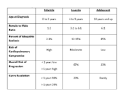


Table 2

(Table 2).[6] Eighty-nine percent of idiopathic scoliosis cases can be categorized as adolescent, with the remaining 10.5% and 0.5% categorized as juvenile and infantile idiopathic scoliosis, respectively.[11] A paradigm shift has occurred with idiopathic scoliosis classification with many authors arguing for a distinction between early-onset scoliosis (diagnosed before 10 years of age) and late-onset scoliosis (diagnosed after age 10 years) classification.[12,13] The rationale for this shift is that early-onset scoliosis has a higher potential of progression to severe thoracic deformity.[12,13]

Adolescent Idiopathic Scoliosis (AIS)

AIS is the most common form of spinal deformity for which orthotics are utilized. As previously noted, this refers to the onset of scoliosis of unknown etiology after the age of 10. This has been widely studied and, both the underlying pathology and natural history are relatively well defined. AIS is identified as a three-dimensional rotational deformity of the spine associated with normal vertebral development. The underlying cause of this remains poorly understood. It does not appear to be associated with activity or trauma. A myriad of different factors have been associated with AIS, including body habitus, maturity, onset of puberty, rate of growth, etc. Family history has been associated with the presence of idiopathic scoliosis, but not necessarily with its risk of progression. The genetic causes associated with idiopathic scoliosis have been carefully studied and while several patterns have been identified, no definitive genetic cause is widely accepted.

The scoliotic deformity in AIS is most progressive during the rapid growth phase (peak height velocity) just prior to puberty. As previously stated approximately 2-5% of adolescents have a scoliosis of 10 degrees or greater but relatively few experience progression of the curve to greater than 30 degrees where treatment might be a consideration.[9,10] The risk of progression of the curvature has been most widely associated with the magnitude of the curvature and growth remaining. Curves less than 30 degrees occur equally in both sexes but the ratio increases to 8:1 in girls to boys for curves of greater degree. Therefore, it is much more common for a female with AIS to require treatment than a male.[14] Right thoracic curves dominate and are present in an 8:1 ratio.[14] Other factors such as level of curvature (thoracic vs. lumbar, etc.) and imbalance (sagittal or coronal) have been associated with the risk of progression, but not well defined in this regard.

Remaining skeletal growth is related to the risk of curve progression. Peak height velocity has been associated with the greatest progression of curve magnitude, but is difficult to determine in real-time.[15] Factors to consider in order to estimate remaining growth include age (preferably, bone age) and menarchal status in females. Bone age is most often apreciated in these patients through the presence of an open triradiate cartilage at the center of the acetabulum and the graduated calcification of the Iliac crest caritlagenous apophysis (Risser sign). The Risser sign is graded from 0 (absent) to 5 (fully closed). For a patient with an initial 25-35 degree curvature, Risser stage 0 or 1 is associated with a 60 to 70 percent risk of curve progression, whereas a Risser stage 3 has a risk of less than 10 percent.[16] Although important, the Risser sign and menarchal status are imperfect predictors of curve progression because initial ossification the Iliac apoophysis and onset of menarche occur after the period of peak height velocity.[16] Closure of the acetabular triradiate cartilage and olecranon apophysis have been shown to more closely approximate the actual occurrence of peak height velocity.[17] More recently , the closure of the growth plates on a hand and wrist “bone age” radiograph has been most reproducibly predictive of the risk of continued progresson of the curvature near the end of spinal growth.[18] This is essential as brace treatment is effective only during adolescent spinal growth, not after.

In patients diagnosed with idioapthic scoliosis between ages 13-15 years and with curve magnitudes of 30-39 degrees, approximately thirty percent tend to stabilize in adulthood. However the remaining seventy percent of patients experience curve progression.[19] Thoracic curves between 50 to 75 degrees at skeletal maturity tend to increase at a rate of 1 degree per year there after, while thoracic curves less than 30 degrees tend not to progress. Lumbar curves greater than 30 degrees at skeletal maturity tend to progress over time.[19] Historical studies had shown that untreated scoliosis had a mortality rate twice that of the general population, bearing in mind that these studies included patients diagnosed with congenital, neuromuscular, and idiopathic scoliosis.[20] In contrast, recent studies of populations with adolescent idiopathic scoliosis exclusively have not demonstrated an increased mortality.[21]

Health consequences are associated with larger curves. Pulmonary function is impaired once Idiopathiic thoracic scoliosis progresses beyond 70 degrees. Furthermore, increased rate of mortality from cardiopulmonary complications is associated with thoracic curves greater than 90 degrees.[22] Studies have shown that patients with idiopathic scoliosis (with Cobb angles ranging from 15-156 degrees) are at an increased risk of chronic back pain as adults.[13,19] A 50 year longitudinal study showed that 65 percent of idiopathic scoliosis patients had chronic back pain compared to 35 percent of controls.[13] Cosmetic concerns and lower marriage rates also have been reported.[20,23]

<u>Juvenile Idiopathic Scoliosis (JIS)</u>

Idiopathic scoliosis that presents between the ages of 4 to 10 years is defined as juvenile and represents 8-16% of idiopathic scoliosis cases.[24] JIS differs from the adolescent version in several ways. JIS is more likely to present in males and with a right thoracic curve. When compared to AIS curves, JIS curves are more likely to progress, and they have a higher probability of causing cardiopulmonary compromise and severe trunk deformity.[24-26] Juvenile curvatures are most often observed up to 30 degrees. Curves greater than 30 degrees are almost always progressive and are first treated with bracing.[24,26] A high proportion of patients diagnosed with JIS will progress to surgical intervention.

Both Infantile and Juvenile idiopathic scoliosis are often examined further with MRI and/or CT scan in order to better determine any anatomical anomalies associated with the curve. Evaluation for genetic, cardiac, pulmonary or renal issues may be appropriate. Treatment of progressive curves not responding to conservative means may include surgical interventions. In children with significant growth remaining, these surgeries are often designed to allow for or promote further growth of the spine while maintaining alignment. The instrumentation in such growing constructs includes those that allow the vertebra to “slide” through the instrumentation, require direct surgical lengthening at given intervals or can be lengthened by external stimulus. These compensate for the growth remaining in the children who require early surgery and may be affected adversely by fusion and limitation of growth.

Scoliosis Terminology and Classification

Infantile Idiopathic Scoliosis (IIS)

Infantile idiopathic scoliosis is defined as scoliotic curves that present prior to 3 years of age with no congenital anomalies. Approximately 90 percent of IIS curves resolve without treatment and are self-limited.[27] Most curves are therefore initially observed. However, progression of infantile curves presents a challenge both because bracing is difficult in the young child and because it is preferred to delay surgery as long as possible to prevent the problems of crankshaft deformities and short trunk syndrome.[27,28] The most reliable way to distinguish between infantile curves that are likely to resolve spontaneously and those that will progress is by measuring the rib-vertebra angle difference (RVAD). RVAD is the angular difference between the concave and convex side ribs in relation to the apical thoracic vertebra. Mehta, in 1972, found that infantile curves with a RVAD less than 20 degrees resolved in 83 percent of cases, whereas 84 percent progressed with a RVAD greater than 20 degrees (Fig 1).[29] Curves that tend to be progressive may be treated initially with serial casting and/or bracing. The goal of these interventions can vary between resolving the curvature and slowing the progression to allow for later, more aggressive treatment.

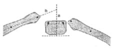
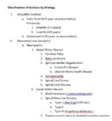


Fig 1

OTHER CLASSIFICATION SYSTEMS

The classification of idiopathic scoliosis assists in formulating a treatment plan for orthotic management and/or surgery. In addition, classification systems are useful in basic and clinical research. Scoliosis and kyphosis can be classified using many criteria. Classification by etiology is a common method for classifying scoliotic and kyphotic curves (List 1).[35] The classification systems commonly used today evolved from Ponseti and Friedman's five idiopathic scoliotic patterns.[30]


List 1

The patterns include:

1. Single major lumbar curve,
2. Single major thoracolumbar curve,
3. Double major curve (combined thoracic and lumbar curve),
4. Single major thoracic curve, and
5. Double major thoracic curve.[30]

Single thoracic and double curve patterns are more likely to progress than single lumbar or thoracolumbar curve patterns.[31] The King-Moe and Lenke classification systems for surgically treated AIS are the most widely used classification systems in the literature today. The King-Moe classification is a 5 part classification describing thoracic curve patterns, but is not comprehensive (Fig 2).[32] The Lenke classification is a more comprehensive and reproducible classification based on PA, lateral, and supine bending films and is used to guide surgical management (Fig 3).[33,34]


Fig 2

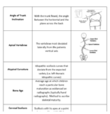


Fig 3

Congenital Scoliosis

Congenital spinal deformity is most commonly identified by the presence of vertebral anomalies, or vertebrae that are not fully formed or symmetrically segmented. As such, these deformities are normally identified by "failure of segmentation" or "failure of formation." Failure of segmentation consists of vertebrae that are united or connected anywhere in the vertebral ring. Failure of formation most commonly is identified as vertebrae of abnormal shape, such as a wedge or hemi-vertebrae. These are further divided by the growth potential and impact of such deformities. Hemi-vertebrae that have open disc spaces are referred to as "segmented", or" semi-segmented". Hemi-vertebrae lying within the spine not causing any curvature are termed "incarcerated". The potential for progressive deformity is related to the underlying pathology of the vertebral anomaly.

Congenital deformities can be further defined by their plane of deformation (scoliosis vs. kyphosis vs. kypho-scoliosis) and their location or level of deformity (thoracic, lumbar, thoraco-lumbar, etc.). While congenital scoliotic deformities can be relatively significant, congenital kyphotic deformities are most concerning because of their risk of neurologic impairment. The progression of the deformity, if associated with congenital anomalies, will not be impacted by the use of bracing or casting. Compensatory curves without congenital vertebral anomalies themselves may be impacted and therefore treated with casting or bracing. Different anomalies are most commonly associated with a different risk of progression with growth. Still, the definitive observation for progression is most often the only way to delineate this.

Congenital kyphotic deformities are separated in to 2 types. Type I is from failure of formation (hemi/wedge vertebrae) and type II a failure of segmentation. While both may demonstrate progression, the type I deformity carries with it a greater risk for progression. Congenital deformities, if progressive, may be treated with surgical intervention. These surgeries range from fusion in situ (in place), to hemi-arthrodesis (arresting growth unilaterally with the aim of correction through growth on the contra-lateral side), resection with correction of deformity, growing rod/constructs without fusion, and definitive fusion with instrumentation.

<u>Neuromuscular scoliosis</u>

Neuromuscular scoliosis (often referred to as paralytic scoliosis) occurs when the spinal deformity is associated with neuromuscular disorders such as cerebral palsy and muscular dystrophy. In addition to growth, these spinal deformities may be affected by muscular imbalance, or tone. The risk of progression is most commonly related to the severity of the muscular involvement or imbalance, or level of tone, along with the child's growth. The natural history of neuromuscular spinal deformity is closely intertwined to that of the underlying neuromuscular disorder. The impact on quality of life is defined not just by the spinal deformity, but instead by multiple other factors. In neuromuscular deformities, it is important to distinguish between fixed and flexible deformities. Almost all flexible or postural deformities may be impacted or realigned with bracing or adjustments to wheelchairs, whereas the fixed curves will not respond to these interventions. The longer term risk of progression of either of these curves has not been proven to be influenced by therapy, bracing or wheel chair modifications. Neuromuscular scoliosis is commonly a long single curve and other deformities including pelvic obliquity, infra-pelvic deformities (i.e. hip contractures), increased lordosis or kyphosis, and other muscular imbalance deformities.

CONCLUSION

Spinal deformity includes a wide range of pathologies with variable natural history and treatment options. An implicit understanding of the evaluation and terminology of these deformities is essential to curve classification and management. Patients with scoliotic curves are evaluated with a detailed history, physical exam, and imaging to determine the curve etiology. The most common curve etiology is idiopathic scoliosis and can be further classified by age of onset. Other etiologies include congenital and neuromuscular scoliosis, but these are less common. Proper terminology and classification of scoliosis is imperative for communication with families, patients, and health professionals.

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7

Physical Examination of Patients with Scoliosis

Walter Truong, Trenton Cooper

INTRODUCTION

Physical manifestations of spinal deformities can present in many different ways. Depending on the habitus of the patient and underlying comorbidities, the findings can be very different. Clinicians must be able to recognize which physical findings are within normal variance between individuals and which can be attributable to a spine deformity. In addition the treating clinicians must either diagnose or rule out any related causes for the deformity. This chapter will provide a systematic approach to the physical examination of ambulatory and non-ambulatory patients with scoliosis. Pertinent positive findings and appropriate diagnostic work up will be discussed.

EXAMINATION

The physical examination generally begins with inspection. The gait exam is very important to assess global balance and subtle neurologic abnormalities. Asking a patient to toe walk and heel walk, further stresses their ability to balance. Wide based and ataxic gait patterns raise concern for cerebellar dysfunction and a brain MRI may be warranted.

In adults, balance in stance is one of the most important factors with respect to quality-of-life and function. Sagittal balance in particular has been shown to correlate with health-related patient reported measures.[1] One study in children showed decreased patient reported outcome scores after spinal fusion when the patients had a positive sagittal balance.[2] C7 plumb line can be assessed on clinical exam by first palpating the most prominent (C7) spinous process of the cervical vertebrae. Extrapolating a point posterior in the center of the neck helps to estimate the C7 vertebral body. By dropping a plumb line vertically, while assessing the patient from the back, the clinician is able to see if the head is well positioned over the pelvis in the coronal plane. The neck should be over the sacrum and the S1 body specifically (Fig 1). Sagittal alignment in the form of cervical lordosis, thoracic kyphosis, and lumbar lordosis should also be noted at this point. Idiopathic scoliosis is frequently lordoscoliosis causing a decrease in the normal thoracic kyphosis.[3] Corresponding decreases in the normal cervical and lumbar lordosis is often noted as well. An increased in a kyphotic deformity in a patient with idiopathic scoliosis is highly unusual and would warrant further workup with a brain and spine MRI. In the coronal plane and viewed anteriorly, the head should be centered over the pubic symphysis.

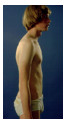
Fig 1

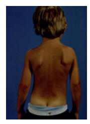
Fig 2

While the patient is facing away from the clinician, shoulder and scapular balance and symmetry is noted, as well as the trapezius neckline (Fig 2). Any pelvic obliquity is assessed at the iliac crest with the index fingers over each iliac wing (Fig 3). The posterior superior iliac spines are regionally close to the iliac crest and thus make it convenient to confirm pelvic obliquity and determine if a leg length discrepancy is present. Rotation is one of the most consistent physical manifestations

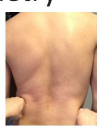
Fig 3

of scoliosis, however, a leg length discrepancy can create the illusion of lumbar rotation when doing the forward bend test (Adam Forward Bend Test) and therefore requires careful attention during the physical examination. If the patient has a known leg length discrepancy, the forward bend test should be performed with the child sitting or by placing a block under the shorter leg to balance the pelvis.

Rotation of the vertebrae within the curve span and noted posteriorly on the forward bend test (Fig 4) is best visualized with the concomitant rotation of the ribs and lumbar musculature. True scoliosis is associated with rotation, although significant trunk rotation can be seen in individuals with straight spines due to rib asymmetry or leg length discrepancies[4] and must therefore be ruled out. The most visible prominence, when viewed posteriorly, corresponds with the apical vertebra on the convex side of curve span. Up to 90% of adolescent idiopathic scoliosis (AIS) involves a right thoracic curve that would be noted on forward bend test as a rib and muscular prominence on the right (convex side). Rib prominence seen on the left should raise concern for neurologic abnormalities and further imaging (MRI) should be considered.[5] Abnormalities include, but are not limited to Arnold-Chiari malformations, syrinx, spinal cord tumors, and neuromuscular disorders. Visual detection of rotation can be quantified during the physical examination by using a scoliometer (inclinometer). The measuring device can be placed on the patient's back during the forward bend test and rotation determined once the scoliometer is placed over the greatest prominence. Rotation is generally greater than 5 degrees (+/- 1.9 degrees in thoracic spine and +/-2.3 degrees in the lumbar spine) on the scoliometer (Fig 5) for curves greater than 20 degrees on radiographic evaluation. Rotation over 10 degrees correlates highly with significant curves.[6]

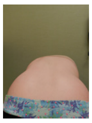
Fig 4


Fig 5

There is debate on whether routine screening should be done as some have brought the accuracy and reliability of the scoliometer and forward bend test into question.[7] Concern with screening for public health implications and increased radiation exposure to growing children have been raised. The US Preventive Services Task Force and the American Academy of Family Physicians do not recommend routine scoliosis screening for asymptomatic adolescents.[8] This recommendation is being revisited due to the recent BRAIST study results showing the significant impact of bracing on scoliosis progression.[9] The Scoliosis Research Society, American Academy of Orthopaedic Surgeons, American Academy of Pediatrics, and the Pediatric Orthopaedic Society of North America collectively recommend screening due to the effectiveness of bracing in preventing progression and avoiding surgery.[5] Negative self-image by patients, as assessed by Scoliosis Research Society Outcomes Instrument (SRS-24), did not occur until rotation was over 20 degrees or Cobb angle over 40 degrees in the thoracic spine.[12] Several authors suggest that clinicians should consider a radiograph if rotation is noted to be over 7 degrees,[10,11] but routine screening of asymptomatic patients should be up to the discretion of the provider.

With the dramatic rise in obesity in children, there has been concern about a relationship between body mass index (BMI) and delay in diagnosis of scoliosis as well as the effectiveness of bracing. Gilbert et al., found that children overweight and obese had larger curves at the time of diagnosis but did not have a higher rate of curves that required surgery.[13] However, Goodbody et al. found that all curves that were in the surgical range at initial presentation were in children that were either overweight or obese.[14] Another study also found children that were overweight had greater curve progression with brace treatment, compared to individuals with normal weight, and more children that were overweight progressed to beyond 45 degrees despite brace treatment; 45% versus 28% in normal weight children.[15]

As part of the continued physical examination of the patient, skin assessment and inspection should be given careful attention. The presence of café au lait spots, axillary freckling, varicose veins, and any easy bruising should be noted. The base of the spine should be examined for hairy patches that may be associated with dorsal closure defects and for midline skin dimples that could be associated with a tethered cord. Although, this association in healthy individuals with a simple dimple and tethered cord is questionable,[16] children with urogenital abnormalities have a very high rate of spinal dysraphism.[17] Connective tissue disorders and genetic syndromes associated with scoliosis such as neurofibromatosis, Marfan syndrome, and Ehlers Danlos syndrome should always be considered. Arm span greater than 1.1 times the patient's height raises concern for Marfan syndrome. The chest wall should be examined for any chest wall abnormalities such as pectus excavatum or carinatum. Hong et al., found a prevalence of scoliosis in 22.58% of patients with pectus excavatum. This prevalence increases to 38.46% in females.[18] Often scoliosis is the first manifestation noted by a patient or family followed by the physician's evaluation and eventual decision about the underlying diagnosis. Referral to a genetics clinic is recommended if these diagnoses are suspected. The evaluation of all patients having a spinal deformity must include a thorough neurological exam that includes the assessment of gait and balance as well. The exam should include an evaluation of cranial nerves, motor strength, deep tendon reflexes and sensation. The primitive reflexes, i.e. Babinski and abdominal reflexes should be included as they have been associated with spinal cord abnormalities.

PATIENTS WITH UNDERLYING NEUROLOGICAL CONDITIONS

Scoliosis is seen in up 77% of children having cerebral palsy. 30% of children that have quadriplegia will have a curve of greater than 40 degrees by the end of growth.[19] Gross Motor Function Classification System (GMFCS) level may point to the risk of progression and goals for intervention in patients with neuromuscular conditions. Children that are non-ambulatory (GMFCS IV and V) have the highest risk of curve progression.[20,21,22]

Fig 6

Examination of the patient that is non-ambulatory is very different than for those with idiopathic curves. Sitting balance is the most important aspect of the evaluation.[23] This is heavily influenced by their trunk control and ability to hold their head up in space. Children with neuromuscular scoliosis and poor trunk control generally have a kyphosing scoliosis that is often described as a long C-shaped curve pattern (Fig 6) that is very different from the idiopathic pattern.[24] Children with congenital myopathies, however, may have severely lordotic spines.

Pelvic obliquity and asymmetric ischial pressures can lead to skin issues[25] and pain.[19] This points to the importance of examining for impending ulcers. The skin on the concave side of the trunk may be creased and harbor fungal or bacterial infections. Unbalanced patients may try to compensate by leveling their shoulders, which may accentuate the curve and cause the ribs to come into contact with the iliac crest. This rib on pelvis impingement may be an additional source of pain (Fig 7).

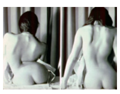

Fig 7

Neuromuscular curves associated with cerebral palsy are often lumbar curves. The trunk rotation causes severe prominence on the convexity of the curve. Seating systems are often customized to relieve this prominence. Repetition of neurologic exams is important at each visit to insure no worsening of their neurological condition.

SUMMARY

A proper physical examination of patients suspected of a spinal deformity will offer the provider immediate insight into the deformity and possible diagnosis. The importance of a thorough neurological assessment of each new patient to rule out an underlying condition associated with a spinal deformity cannot be over emphasized. Repeat neurological assessments at each follow up visit are equally important when there is an associated neurological condition.

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8

Radiologic Evaluation of Spinal Deformity

Thomas J Gilbert

INTRODUCTION

Plain radiography is the initial modality used to evaluate and the primary modality used to follow spinal deformities. Dynamic radiography, computed tomography (CT), magnetic resonance imaging (MRI), bone scintigraphy and dual energy X-ray absorptiometry (DXA) are useful adjuncts. In the following sections, the utility of each modality including its strengths and limitations will be discussed. Sections discussing imaging strategies for scoliosis, kyphosis, Scheuermann disease, spondylolysis and spondylolisthesis, and trauma follow this material.

PLAIN RADIOGRAPHY

Plain radiography is indicated to assess and to follow spinal deformities. It is readily accessible and relatively low cost, and allows the patient to be evaluated in the standing, sitting, recumbent or bending positions. Plain radiographs allow the treating physician to assess for:

- Coronal and sagittal plane spinal deformities with the patient upright
- Overall balance with the patient upright including truncal shifts in the sagittal and coronal planes
- Pelvic incidence
- Pelvic tilt and limb length discrepancies
- Rigidity of coronal curves on right and left bending views
- Rigidity of sagittal plane deformities on flexion and extension radiographs
- Instability on lateral flexion and extension views
- Congenital deformities
- Fracture or avulsion
- Neoplasm and infection

The sensitivity and accuracy of plain radiographs is limited because it is a two-dimensional technique. Spinal anatomy is complex and vertebral structures are superimposed on each other limiting the ability to detect and assess small or subtle bony lesions, fractures or complex vertebral deformities. Anatomic areas of interest are often oriented obliquely relative to the x-ray beam limiting the ability to detect disc space narrowing or vertebra fractures.

Plain radiographs use ionizing radiation. Young patients are at increased risk of radiation induced malignancy and every effort should be made to limit exposure of patients to radiation particularly if they are to receive multiple follow-up examinations.[1] Modern equipment using rare earth screens should be used, and the technique should be adjusted to minimize the amount of radiation delivered to the patient. Scoliosis radiographs are obtained in the PA rather than AP direction to limit radiation exposure to breast tissue. Gonadal shields should be used when possible.[2]

MAGNETIC RESONANCE IMAGING (MRI)

MRI is a primary modality for the evaluation of the spine. It allows direct visualization of neurologic structures and allows one to directly visualize the effect of pathologic entities on neurologic structures. MRI has high soft tissue contrast and is useful in the evaluation of disc and facet pathology. It is sensitive in the detection of disc herniations and provides an accurate assessment of the severity of spinal stenosis. MRI is able to detect and characterize intradural and epidural lesions, paraspinous soft tissue masses and lymphadenopathy.

MRI has a high sensitivity for bony processes such as fracture, neoplasm and infection. It is useful to detect and assess the chronicity of vertebral fractures, and to evaluate for underlying neoplasm. MRI is sensitive for septic arthritis, osteomyelitis, spondylo-discitis, and is useful to detect and characterize associated paraspinous and epidural abscesses. MRI is also sensitive for bony neoplasm. It is useful to characterize certain neoplasms, to grade primary neoplasm and to detect associated extra osseous disease.

The limitations of MRI are many. MRI is expensive and access may be limited. Standard clinical MRI systems are not able to directly visualize bony detail and are unable to assess bone mineralization. Image quality is susceptible to motion and metal artifact. Sedation may be required for patients with claustrophobia. Finally, many patients with metallic foreign bodies, metallic implants, implantable pumps or electrical stimulation devices may not be able to undergo MRI.

Technique

Basic MRI of the spine requires adequate signal to noise, high in-plane resolution and thin sections - 3mm for the cervical spine and 4mm for the thoracic and lumbar spine with a ≤ 1mm gap. Sagittal images should include the entire cervical, thoracic or lumbar spine and stacked axial images should be obtained through specific areas of interest.[3]

For the cervical and thoracic spine, basic MRI protocols should include the following:

- Sagittal T1-weighted sequence
- Sagittal T2 fast spine echo (FSE) and/or gradient recalled echo (GRE) sequences
- Axial T2 FSE and/or GRE sequences

For the lumbar spine, basic MRI protocols should include the following:

- Sagittal T1-weighted sequence
- Sagittal T2 FSE sequence
- Axial T1-weighted sequence
- Axial T2 FSE sequence

Sagittal Short Tau Inversion Recovery (STIR) or T2 fat saturation sequences are useful in the cervical, thoracic and lumbar spine to detect marrow signal abnormalities as associated with inflammation, reactive changes, edema, hemorrhage, neoplasm and infection. They are indicated in adolescent patients with activity related low back pain to evaluate for spondylolysis, and are useful to detect fracture, primary neoplasm, metastatic disease, spondylo-arthropathy and early infection.

MRI imaging with intravenous contrast is useful in limited circumstances: to differentiate abscess from phlegmon in cases of infection, and to detect and characterize abnormalities within the dural sac.

Indications

MRI is indicated for the detection and characterization of:

- Abnormalities within the neural axis
- Symptomatic disc and facet disease
- Spondylolysis and spondylolisthesis
- Stenosis
- Fragility and insufficiency fractures
- Evaluation of trauma patients with neurologic symptoms and signs or with suspected liga mentous injury
- Infection and neoplasm.

COMPUTED TOMOGRAPHY (CT)

CT is a useful adjunct in the evaluation of spinal deformities. CT is able to directly visualize bony detail and characterize complex bony deformities. It is useful to detect and to characterize vertebral fractures. It is more accurate than plain radiographs and MRI for the detection of chronic spondylolysis and is useful to characterize early or sub-acute spondylolysis. CT is indicated to evaluate for healing of fractures and spondylolysis, and is more accurate than plain radiography in the assessment of spinal fusions. CT is useful to characterize benign, indolent or low-grade bony lesions, and to assess the degree of bony destruction present with more aggressive neoplasms and infection. Quantitative CT can be used to assess bony density.

CT has several disadvantages and limitations. First, CT utilizes ionizing radiation. Second, CT has poor soft tissue contrast. Neurologic structures are difficult to visualize without intrathecal contrast. The sensitivity for disc herniations is decreased and delineation of the dural sac margins can be difficult in a patient with stenosis. Soft tissue detail is often degraded in areas of beam hardening artifact such as the cervicothoracic junction, with decrease contrast to noise in bariatric patients and secondary to metal artifact with instrumentation in the spine or braces in the oral cavity.

While MRI has been shown to be more sensitive and accurate than CT for the evaluation of several spine abnormalities, CT actually complements MRI. It is more sensitive for calcification and ossification and is less sensitive to motion. It can be useful to characterize abnormalities detected on MRI and is indicated in the evaluation of patients with incongruent clinical and MRI findings and in patients with multiple abnormalities ipsilateral to their symptoms. This sensitivity of CT to calcifications underlies its utility in the characterization of borderline bone lesions (more sensitive to endosteal scalloping), lesions that characteristically contain calcified matrix such as enchondroma or chondrosarcoma, and lesions that characteristically contain osseous matrix such as osteoid osteoma, osteoblastoma and osteosarcoma.

Technique

Given that CT utilizes ionizing radiation, it is important to limit the examination to specific areas of interest. This is particularly important in children, as ionizing radiation will have a disproportionate effect on the lifetime risk of cancer in these patients.

Computed AP and lateral radiographs are obtained and can be useful in a global assessment of alignment and to select targeted areas for scanning. Axial 2.5 mm sections should be obtained and used for viewing soft tissue detail. One-millimeter reconstructions are obtained and used for viewing bone detail. Images are reformatted in the sagittal and coronal planes using the 1 mm reconstructions. With larger curves, it can be useful to obtain curved coronal, sagittal oblique or axial oblique reformations.

CT is indicated for the detection and characterization of:

- Complex congenital abnormalities associated with scoliosis or kyphosis
- Symptomatic disc and facet disease
- Chronic complete spondylolysis and spondylolisthesis
- Stenosis
- Fracture detection, characterization and healing
- Characterization of abnormalities noted on bone scans
- Characterization of questionable findings on MRI
- Abnormalities in patients with incongruent clinical and MRI findings
- Characterization and follow-up of indolent or borderline bone neoplasms
- Assessment of bone destruction in patients with aggressive neoplasms or infection
- Fusion evaluation
- Bone density evaluation

CT is a useful imaging modality in patients who have contraindications to MRI or who are otherwise unable to undergo MRI. If abnormalities of the cord or intrathecal nerve roots are clinically suspected and the patient cannot undergo MRI, CT with intrathecal contrast may be necessary.

BONE SCINTIGRAPHY

Bone scintigraphy has several applications in the evaluation of patients with deformity. Bone scintigraphy with SPECT is useful to detect or excluded early or subacute spondylolysis in adolescents or children with activity-related low back pain. Focal increased uptake in the posterior elements of a patient 18 years of age or younger has a high likelihood of being spondylolysis or a pedicle stress fracture. On occasion, focal increased uptake can also be seen in the posterior elements with facet joint derangement or spinous process injury. Its use is limited to the detection or exclusion of spondylolysis however as it is not able to detect or exclude other causes of back pain in adolescents such as disc degeneration, disc herniation or

Scheuermann disease. Given these limitations and concerns about the use of ionizing radiation in children and adolescents, MRI has largely replaced bone scintigraphy in the initial evaluation of activity-related low back pain.

Bone scan can be useful to detect or confirm the presence of bone lesion in patients with painful scoliosis. Osteoid osteoma can be difficult to detect on plain radiographs and MRI, and bone scan can detect or exclude this diagnosis in adolescent scoliosis patients with the classic history of nighttime pain relieved with nonsteroidal anti-inflammatory drugs. Osteoid osteoma shows a classic bulls-eye pattern of uptake. Marked focal increased uptake is seen in the central aspect of the lesion or nidus, and mild or moderate increase uptake with the more peripheral lesion. Increased uptake can also be seen with other lesions such as osteoblastoma.

Whole body bone scan is useful in patients with a solitary bone lesion to exclude the presence of multifocal disease such as metastatic neoplasm or multifocal osteomyelitis. The presence of absence of uptake and the pattern of uptake can also contribute to the characterization of the primary lesion.
Bone scan can be useful to exclude an occult osseous neoplasm or infection in patients with deformity and poorly localized pain and normal radiographs. If the pain can be localized, MRI or CT might be more useful as cross-sectional imaging can both detect and characterize a lesion.

The utility of bone scintigraphy is limited as areas of increased uptake are poorly characterized. Limited CT is frequently required to further localize and characterize areas of increased uptake. In addition, bone scintigraphy cannot detect or characterize congenital abnormalities or the spine, soft tissue pathology or abnormalities of the neural axis.

DUAL ENERGY X-RAY ABSORPTIOMETRY (DXA)

Dual-energy X-ray absorptiometry is indicated to assess bone density in patients at risk for osteoporosis. Two x-ray beams of different energy are passed through the lumbar spine, hip and/or distal radius. After the soft tissue absorption is subtracted out, the bone density is calculated from the amount of x-ray absorbed through a designated area.

Scoring of the DXA scan is performed by comparing the measured bone density to normative values. Comparison to a set of age-matched controls results in a Z score. Comparison to normative values for a population of 30-year-old females yields a T-score. In adults, severe osteoporosis is defined as a T-score of ≤ -2.5, and osteopenia as between -1.0 and -2.5. Scoring of bone density for children and young adults is done using the Z score.

In adults, DXA scanning is indicated to diagnosis osteoporosis and to measure the response of the bone mineral density to treatment. In pediatric patients, DXA scanning can be used to assess mineralization in patients with metabolic bone disease, nutritional rickets, lupus and Turner Syndrome.

IMAGING STRATEGIES FOR THE EVALUATION OF SPINAL DEFORMITIES

Plain radiographs

Standing full spine PA and lateral radiographs are indicated in the initial assessment of scoliosis and to monitor patients for progression. Plain radiographs are assessed for the size, direction and location of coronal and sagittal plane deformities, for sagittal and coronal balance, and for the presence or absence of congenital deformities, bone dysplasias or bone lesions.

Scoliosis radiographs should be obtained with the patient standing 72 inches (183cm) from the tube. The patient is positioned with the feet a shoulder width apart. For the PA view the arms are placed at the side. For the lateral view, the elbows are flexed and the hands placed over the clavicle or holding onto an IV pole in front of the patient.[4] The arms should not be straight as this might allow the patient to lean backwards affecting sagittal balance. The arms should not be placed over the head as this might increase the degree of lumbar lordosis. The same technique should be used on follow-up views.


Fig 1


Fig 2

The PA view should include the cervical spine cranially and the pelvis caudally. The gonads are not shielded on initial radiographs, however are shielded on follow-up exams. The PA view is used to assess the magnitude of the curves in the coronal plane, coronal balance, pelvic tilting and skeletal maturity (Risser sign) (Fig 1). The lateral view should include the cervical spine superiorly and the femoral heads inferiorly. Lateral views are used to assess the magnitude of thoracic kyphosis and lumbar lordosis, pelvic incidence and sagittal balance (Fig 2). Depending on the available equipment and the size of the patient, the spine may not fit on a single radiograph and one or more views may need to be stitched together.

Major and minor curves are identified and characterized with reference to the apical vertebrae, magnitude of the curves, neutral vertebra and stable vertebra. The apical vertebra is the vertebra with the greatest deviation or rotation away from the midline.[4, 5] The end vertebrae are defined as those vertebrae showing the maximal tilt into the curve.[5, 6, 7] The neutral vertebrae are those vertebrae that show no rotation on the PA radiograph. Stable vertebrae are the most cephalad vertebrae below the end vertebrae of the distal-most curve that are bisected by the central sacral line – a line perpendicular to and bisecting the superior S1 endplate.[5] Pelvic tilt is measured using a horizontal line parallel to the more cephalad iliac crest and is reported as the distance between the horizontal line the more caudal iliac crest. If the patient wears a shoe insert or heel lift for a known leg length discrepancy, PA and lateral scoliosis radiographs can be obtained with the patient wearing their insert or lift.

The magnitude of coronal and sagittal plane deformities is most commonly assessed using the Cobb method.[4] The magnitude of a curve is assessed by measuring the angle between the cranial and caudal end vertebral endplates. When using the Cobb angle in the assessment and follow-up of sagittal plane deformities, it should be kept in mind that measurements can vary with patient positioning. Rotation of the patient can result in significant variations in curve measurements, and it can be difficult to position the patient to reliably obtain a true frontal view.[5, 8] The same position should be replicated on follow-up radiographs. Measurement error and inter-observer variation can result in substantial variation in Cobb angle measurements. Measurement error is minimized when the end vertebrae are specified and the same end vertebrae used on follow-up examinations.[6, 9, 10] A total error of between 2°-7° has been reported to result of variations in radiographic technique and measurement error.[6] Inter-observer error can also be substantial and has been reported to be as high as 10°.[9-11] Inter-observer error can be controlled by simultaneously measuring the Cobb angle on both the current and comparison views using the same landmarks and technique.13 Carmen et al. has shown that a measured difference of 10° has a 95% chance of representing true progression of a scoliotic curve.[10] This value is 11° for kyphotic curves. On a practical level, curve progression is measured in 5° increments.[11, 14, 15]

The differentiation of structural and nonstructural curves is made on bending or traction films. The rigidity of coronal spine deformities can be assessed using right and left side-bending views. These radiographs are obtained using an AP view with the patient supine and bending maximally to the right and left. Some authors promote traction methods or bending over a fulcrum to assess the rigidity of curves.[16,17,18] The rigidity of sagittal plane deformities can be assessed on lateral films taken with the patient lying supine over a bolster.

Coronal plane alignment is assessed by measuring cervical, thoracic and lumbar curves, elevation of the shoulder, coronal balance and pelvic tilt.[4] Coronal balance is determined by measuring the distance between a vertical line parallel to the edge of the radiograph through the center of the C7 vertebra (the C7 plumb line) and the center sacral vertical line (CSVL).[6] Pelvic tilt is assessed by measuring the offset of the two iliac crests and/or femoral heads in the horizontal axis. This is done by drawing a horizontal line tangential to the more cephalad of the two iliac crests, then measuring the amount of inferior displacement of the contralateral iliac crest. If the pelvic tilt is excessive (greater than 1.5cm) or if the patient wears a shoe lift for a known leg length discrepancy, then consideration might be given to performing scoliosis radiographs with the shoe lift on.

Sagittal plane alignment is assessed by measuring thoracic kyphosis, lumbar lordosis, pelvic incidence and sagittal balance.[4] Thoracic kyphosis and lumbar lordosis are measured using the Cobb technique by measuring the angle between those vertebrae showing the maximal tilt into the curve. Pelvic incidence is assessed on lateral views and is defined as the angle between a line perpendicular to the S1 endplate and a line connecting the S1 vertebral endplate at its midpoint to the axis of the femoral heads.[4,19] The axis of the femoral heads is the midpoint of a line connecting the center points of the two femoral heads. Sagittal balance is determined by measuring the distance between the C7 plumb line and the posterior superior margin of the S1 vertebrae.

The probability of curve progression is determined primarily by the magnitude of the primary curve and the spinal growth velocity.[14] Spinal growth velocity is correlated with the degree of skeletal maturity that is most commonly assessed radiographically using the Risser index. The Risser index grades the degree of ossification of the iliac crest as follows: Grade 0 – no ossification of the iliac crest apophysis, Grade 1- ossification of the lateral 25% of the iliac crest apophysis, Grade 2 – ossification of the lateral 50% of the iliac crest apophysis, Grade 3 – ossification of the lateral 75% of the iliac crest apophysis, Grade 4 – complete ossification of the iliac crest apophysis, and Grade 5 – osseous integration of the ossified iliac crest apophysis.[20]

<u>MRI Imaging</u>

MRI is used to evaluate for abnormalities of the neural axis in patients with scoliosis. Indications for MRI in scoliosis patients include infantile or juvenile onset, rapid progression, male gender, atypical (left-sided) curves, thoracic kyphosis ≥30 degrees, headaches, pain and neurologic symptoms or signs (including abnormal superficial abdominal reflexes).[15, 21-28]


Fig 3


Fig 4

A screening MRI scoliosis protocol utilizes T1 and T2 FSE sagittal sequences through the cervical, thoracic and lumbar spine. T2 FSE coronal images should be obtained through the major curve and T2 FSE axial sections through the conus medullaris and proximal filum. Axial T2 FSE images should also be obtained through any congenital deformities to assist in the detection of neural axis abnormalities, stenosis and neural impingement.

The most common abnormalities in patients with scoliosis are Chiari malformation, tonsillar ectopia and syrinx.[21-30] (Figs 3 & 4) Diastamatomyelia, tethered cord and cord neoplasm have also been reported. If an intrinsic cord or neurogenic lesion is detected on the screening exam, then a dedicated MRI of the spine with IV contrast is indicated.

Congenital scoliosis

With congenital scoliosis, supine radiographs are obtained in children too young or unable to stand or sit, and are often obtained in the initial evaluation of older children. Supine radiographs use a shorter focal length, which results in greater bone detail and better detection and characterization of errors in segmentation and formation. Upright radiographs are indicated to assess and follow coronal and sagittal plane deformities.[31]

The whole spine should be included on the initial radiographs as multiple deformities are often present. Both PA and lateral views should be obtained in order to appreciate deformities in three dimensions. Lateral views are essential to detect kyphotic deformities that can pose a greater risk of paraplegia with progression or during surgery.[31]

CT is useful to characterize complex abnormalities in patients with congenital scoliosis.[32-33] Axial 1 mm thin sections should be obtained through the major curve or through areas of deformity, and reformations should be obtained in the sagittal and coronal planes. Three-dimensional reformations can be useful to identify and characterize associated deformities of the posterior elements.[34] CT can also be useful to characterize and to detect bony septae in patients with Diastamatomyelia.

MRI is indicated to assess for abnormalities of the neural axis, which occur with greater frequency in patients with congenital scoliosis. MRI should be considered a component of surgical planning in these patients.[15,29,30]

Secondary scoliosis

Osseous neoplasm and infection can also present as painful scoliosis. Osteoid osteoma and osteoblastoma are the most common bone tumors presenting as pain-induced scoliosis.[15,35,36] Aneurysmal bone cyst and eosinophilic granuloma have also been described.[35] MRI is sensitive and specific for osseous neoplasm, osteomyelitis and spondylo-discitis.


Fig 5

The most common MRI finding in patients with osteoid osteoma and osteoblastoma is marrow edema (Fig 5). The primary lesion can be subtle and difficult to identify on MRI and x-ray. A bone scan will show a characteristic target pattern of uptake with marked increased uptake corresponding to the primary lesion and a peripheral zone of mild to moderate uptake corresponding to areas of marrow edema, reactive bone or periostitis. CT is indicated to confirm and characterize the primary lesion. Osteoid osteoma will typically show a central calcified nidus, an intermediate radiolucent zone and adjacent medullary sclerosis. The primary lesion with an osteoblastoma is larger than that with osteoid osteoma and the zonal architecture less consistent.

Eosinophilic granuloma, osteomyelitis and spondylo-discitis can also be seen with secondary scoliosis. With osteomyelitis, an osteolytic lesion is seen with adjacent marrow edema. A bone scan will show a cold nidus and peripheral zone of increased uptake. With spondylo-discitis, marrow edema is centered on the disc and involves each of the adjacent vertebrae. Eosinophilic granuloma typically presents as an osteolytic lesion in the vertebral body or vertebra plana. Aneurysmal bone cyst presents as an osteolytic expansile lesion in the posterior elements with fluid-fluid levels.

IMAGING STRATEGIES FOR THE EVALUATION OF SCHEUERMANN DISEASE


Fig 6

AP and lateral radiographs of the spine are indicated for the diagnosis and characterization of Scheuermann disease and Scheuermann kyphosis. The diagnostic criteria for classic Scheuermann kyphosis are a fixed kyphosis with three or more consecutive >5° anterior wedge-shaped vertebrae.[37] (Fig 6)

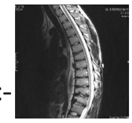
Fig 7

Patients with atypical Scheuermann disease show endplate irregularities, Schmorl node deformities, limbus-type deformities and disc space narrowing localizing more to the lower thoracic and upper lumbar spine.[38,39] (Fig 7) Scheuermann-like changes are associated with an increased incidence of thoracic disc degeneration and back pain.[38, 40] Patients with Scheuermann-like changes may also be predisposed to early or juvenile onset disc degeneration in the lumbar spine.[41] (Fig 8) Liu et al. showed the patients with Scheuermann-like changes were associated with a "heavy workload", reported more severe back pain and more marked progression of back pain.[42]


Fig 8

MRI is reserved for the evaluation of with Scheuermann patients with acute and/or chronic back pain. Both thoracic and lumbar disc herniations can occur in patients with Scheuermann disease and are associated with back pain.[43,44] MRI is useful to detect and grade the severity of disc degeneration and to detect the presence of disc herniations and neural impingement (Fig 9).


Fig 9

IMAGING STRATEGIES FOR THE EVALUATION OF SPONDYLOLYSIS AND SPONDYLOLISTHESIS

Spondylolysis is a common diagnosis in children and adolescent patients with activity-related back pain. Early detection is important to maximize the potential for healing with bracing.

AP and lateral radiographs are often obtained in children and adolescents with back pain. Plain radiographs can detect disc space narrowing, chronic pars defects and spondylolisthesis. They are insensitive, however, for early and subacute spondylolysis without spondylolisthesis.[45] Posterior oblique views have not been shown to increase the sensitivity for spondylolysis and are not recommended. Lateral flexion and extension views useful to detect segmental hypermobility in patients who are planning to undergo surgery.


Fig 10

MRI is indicated for the evaluation of spondylolysis in children or adolescents with activity related low back pain. MRI with STIR or T2 fat saturation imaging is sensitive for marrow edema which is the primary finding in patients with stress reactions, stress fractures and early spondylolysis (Fig 10).[45,46]

With spondylolysis, marrow edema localizes primarily to the ipsilateral pedicle, par interarticularis and inferior articular process. With incomplete or complete spondylolysis, marrow edema is associated with a defect in the inferior pars cortex. In patients 18 years of age or younger, the presence of isolated marrow edema in the pedicle and pars interarticularis is relatively specific for an early pars stress fracture.

Marrow edema may extend into the adjacent vertebral body if a stress fracture develops in the pedicle, and may extend into the lamina and spinous process if a pars fracture propagates medially. Marrow edema and reactive soft tissue changes also occur with facet joint derangement and with avulsions of the spinous process apophysis, each of which can be seen with chronic repetitive flexion/extension based injuries.

CT is sensitive and specific for the detection of chronic complete pars defects and is useful to evaluate for healing in patients with early or subacute spondylolysis.[46] CT is less sensitive than MRI for the detection of an early pars stress reaction or stress fracture. On CT, these lesions show linear radiolucency in the inferior pars cortex and rarefaction of adjacent bone. These finding are subtle, however, and CT is unable to detect marrow edema. In addition, CT exposes these young patients to ionizing radiation. When CT is used to characterize lesion detected on MRI or SPECT, imaging should be limited to the level of interest.

The utility of SPECT bone scanning is limited in patients with early or subacute spondylolysis. While SPECT imaging is sensitive for early or subacute spondylolysis, areas of increased uptake are nonspecific and limited CT may be needed to characterize areas of increased uptake.[46] In addition, bone scans are unable to detect other common abnormalities in adolescent patients with activity related back pain. MRI on the other hand, is sensitive for spondylolysis and can also detect other spine abnormalities such as disc degeneration, disc herniations, chronic spondylolysis, spondylolisthesis and Scheuermann Disease. The utility of SPECT is limited to the detection or exclusion of acute or subacute spondylolysis.

IMAGING STRATEGIES FOR THE EVALUATION OF TRAUMA

Plain radiographs are typically the initial study obtained in patients with suspected vertebral fracture following significant trauma. Plain radiographs are often obtained in patients back or buttock pain following chronic repetitive injury even though they are relatively insensitive for fatigue or stress fractures. They are indicated to evaluate for pathologic fractures following minor trauma in patients with known osteoporosis, elderly patients or patients at risk for osteoporosis (e.g. with malnutrition, chronic steroid medications and following oophorectomy).

In the lumbar and thoracic spine, AP and lateral radiographs are indicated and are often taken with the patient recumbent, as this will afford greater bone detail. In the cervical spine, AP, lateral and open mouth odontoid views are indicated and can be supplemented with lateral swimmer's views, posterior oblique views and lateral flexion-extension views as indicated.

Computed tomography (CT) is more sensitive than plain radiography in the detection of a vertebral fracture and is the procedure of choice to detect fractures in patients with major trauma such as a high speed motor vehicle accident.[47,48] Axial 2.5mm sections should be obtained through the entire cervical, thoracic or lumbar spine with 1mm reconstructions and both sagittal and coronal reformations. The axial

2.5 mm images can be viewed with soft tissue windows to evaluate for post-traumatic herniations, hematoma and ligamentous injury. Axial 1.0 mm reconstructions should be viewed with bone windows for fracture detection and characterization. Sagittal and coronal reformats are useful for the evaluation for traumatic spondylolisthesis or lateral listhesis and assist in the detection of transverse fractures. MRI can be useful in trauma patients with neurologic deficits or to assess for posterior ligamentous involvement.[48]

Fig 11

MRI is indicated for the detection of fatigue fractures, which occur most commonly in the sacrum and at L5. Fatigue fractures show linear areas of low signal intensity with adjacent marrow edema seen best on STIR or T2 fat saturation images (Fig 11).

MRI is indicated for the detection of fragility or insufficiency fractures in elderly patients, patients with known osteoporosis or patients at risk for osteoporosis. MRI is sensitive for marrow edema, which is the primary finding in patients with acute or subacute compression fractures (Fig 12). MRI is also useful to assess the chronicity of a wedge-shaped vertebral deformity noted on plain radiography, and is useful to exclude underlying malignancy.[48,49,50] Limited CT may be needed to assess the integrity of the posterior vertebral cortex and extent of vertebral collapse in anticipation of vertebroplasty. Limited CT is also useful to evaluate for underlying malignancy in patients with indeterminate findings on MRI. On CT, a benign compression fracture shows increased trabecular density adjacent to the fractured endplate while a pathologic fracture will show decreased trabecular density or osteolysis.

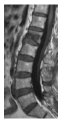

Fig 12

CONCLUSION

The many available radiographic modalities are important to understand when evaluating a patient with a spinal symptom whether it is pain or deformity. Specific studies are indicated for each suspected diagnosis. Care needs to be taken to avoid excessive radiation exposure and expense. A clinician referring a patient for a radiographic study will often benefit from consulting the radiologist to determine which studies may be indicated.

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9

Patient Evaluation: What the Orthotist Needs to Know

Carol J Hentges

A physical evaluation is important when determining an orthotic design for the treatment of idiopathic scoliosis. In our zeal to evaluate the radiograph we often overlook the importance of performing a thorough physical exam. We would never provide a lower limb orthosis without doing an evaluation of range of motion, manual muscle testing, gait, etc. The same is true when determining the orthotic treatment of the spine. Specific things to look for will be discussed along with how they may affect your brace design.

After taking a history and determining the patient's expectations, conduct a thorough examination. The patient needs to be disrobed wearing only an examining gown that will permit viewing their shoulders, trunk and pelvis. The order of proceeding with the examination is not as important as its completeness.

SHOULDER ASYMMETRY

An elevated shoulder may be secondary to vertebral rotation. The elevation signifies a structural curve. This is most helpful in determining if a curve is structural versus compensatory. The indication that a high upper left thoracic curve is structural would be an elevated left shoulder. This would require a CTLSO versus a TLSO. An indication that a right thoracic curve, in a double curve pattern, single thoracic with a lumbar or thoracolumbar curve,[1] is structural would be an elevated right shoulder. The shoulder balance should later be evaluated when in the orthosis. The thoracic pad should not cause the opposite shoulder to be elevated.

PELVIC ASYMMETRY

The pelvis may be asymmetrical due to a leg length discrepancy or due to a structural pelvic obliquity. Leg lengths should always be measured. A leg length discrepancy is not uncommon even for those without scoliosis and will affect pelvic alignment. It may not be necessary to correct this with a shoe lift but must be considered in the design of the orthosis. If this is not done, your orthosis will not sit symmetrically on your patient.

ROTATIONAL PROMINENCE

During the patient evaluation all rotational prominences should be noted. This should be done viewing from both posteriorly and anteriorly. A patient with a right thoracic curve may frequently have a protruding left lower rib line in front due to the rotation of the spine. All structural curves will present with a rotational prominence.

Patient Evaluation: What the Orthotist Needs to Know

FORWARD BEND TEST

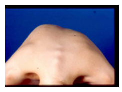

Fig 1

This is particularly important when evaluating a patient (Fig 1). Upon forward bend all compensatory curves may be determined, as those prominences will be less or disappear completely. This evaluation is crucial in determining the curve pattern. Orthotic design, pad placement and aggressiveness of correction will be dependent on the curve pattern. If the lumbar prominence resolves and the thoracic prominence remains, this indicates a structural thoracic with a compensatory lumbar curve.[1] In this case, a thoraco-lumbo-sacral orthosis (TLSO) is indicated with an aggressive correction of the thoracic curve and minimal or no corrective force applied to the lumbar curve. If the lumbar curve is compensatory, it will naturally correct itself as the thoracic curve is corrected resulting in two balanced curves. Over correcting a compensatory curve is a common mistake when treating patients with this curve pattern. When performing a forward bend test, if the thoracic prominence resolves while the lumbar prominence remains this will indicate that your structural curve is lumbar with the thoracic being compensatory. The orthosis design can be low profile with an aggressive correction of the lumbar pad and minimal or no corrective force applied to the thoracic spine. Understanding which curves are structural and which are compensatory will be the determining factor in fitting a cervico-thoraco-lumbo-sacral orthosis (CTLSO) versus a TLSO or a low profile TLSO. The amount of corrective forces applied to each curve is also mandated by whether the curve is structural or compensatory.

DECOMPENSATION

Decompensation can be measured by using a simple plumb bob. This is placed at the spinal process of C7 and is observed where it falls compared to the intergluteal cleft. In most cases, the patient will be decompensated to the side of the most structural curve. Any true leg length discrepancy must be taken into account as this may cause the decompensation. This also will be important in determining whether you need a trochanteric extension on the orthosis. The trochanteric extension will always be on the side to which a patient is decompensated. The trochanteric extension will aid in keeping the orthosis sitting straight on your patient.

TRUNK SHIFT

It is important to understand the difference between trunk shift and decompensation. There may be a significant trunk shift even when the patient's C7 balances over S1. This trunk shift needs to be addressed with the orthotic design. The goal of the orthosis is to center the trunk over the pelvis. When treating single thoracolumbar curves, a low thoracic or lumbar sling may need to be added in congruence with a lumbar pad to aid in correcting this trunk shift.

FLEXIBILITY

Simply by providing a force at the apex of any and all curves that you have determined are structural their flexibility can be assessed. This will help to determine how aggressive to be with your modifications and pad pressures. How they react to this force should also be noted. Do they shift over as expected or do they compensate by elevating the opposite shoulder or rotating their hips? These should all be noted and taken into account when designing the orthosis. Side bending evaluation can also be performed.

SAGITTAL PROFILE

The patient's thoracic and lumbar spine should also be evaluated. Lumbar hyper-lordosis and thoracic hypo-kyphosis (loss of the normal kyphosis) are very common. Patients with a thoracic curve will generally have a decrease or even a reversal of the customary kyphosis in the thoracic spine. This decreased kyphosis will make the rotational prominence seem more significant. This curve pattern is usually not flexible and will affect the orthosis design as pad placement will need to be more laterally placed, with a relief posteriorly, and the posterior trim line should be suprascapular as to not have any posterior to anterior force on the thoracic spine. A posteriorly directed force at the anterior lower rib line can be obtained by using an anterior gusset. This can be helpful in maintaining correct alignment. Orthotic treatment for patients with true thoracic lordosis is contraindicated. Significant thoracic hyper-kyphosis is unusual and is an indication for an MRI to rule out other etiologies.

Many patients with single lumbar or thoracolumbar curves have an increased lordosis. It is important to evaluate its flexibility and the ability for this lordosis to be decreased in the orthosis. This reduction of lordosis will allow for your lumbar pad to work more efficiently. A low anterior gusset may also be indicated to bring the spine back into the lumbar pad.

BODY TYPE

Obese patients and underweight patients will be treated differently when fabricating an orthosis. It will take much more pad pressure to provide the same correction on someone who has more adipose tissue. There will need to be more build up on bony prominences on those patients who have decreased subcutaneous tissue. Migration of the orthosis is commonly more of a problem on those who are overweight. Skin tolerance should be noted and taken into consideration while modifying and determining the pad pressures. Patients who have fair skin or skin that is easily irritated may need more of a gradual increase in pad pressure.

RADIOGRAPHIC EVALUATION

After completing a physical exam evaluation of a patient, the radiographs need to be evaluated. There is obvious and subtle information that can be found from this process. Once again identifying which curves are structural and which are compensatory is crucial in determining a treatment protocol and orthosis design.

<u>Cobb Angle</u>

An orthotist must be proficient in determining the Cobb angle of all of the curves in a presenting patient in order to that there is agreement with the referring physician for the selection of the type of orthotic management. The Cobb angle of each curve is documented and the apical vertebra or vertebrae are determined. The apical vertebra will be the most horizontal and the most rotated. The end vertebra will be the most tilted. Shorter curves tend to be less flexible and are more difficult to obtain an in-brace correction. Longer curves tend to be more flexible. When treating more than one curve, it is important that the corrective forces on either side of the trunk be placed so as to not oppose each other.

Vertebral Rotation

The rotational deformity can be evaluated by examining the position of the pedicles as seen on radiographs. Those curves that have more pedicle rotation will be more structural.

Shoulder and Pelvic Asymmetry

When care is taken in positioning a patient while taking radiographs, shoulder and pelvic tilt can be determined and true leg length can be measured.

Risser Sign

The Risser sign will help to determine the remaining growth potential. This should be documented at each follow up visit. Skeletal maturity will be a factor in the length of the treatment plan and for determining the risk of progression.

Side Bending X-rays

Supine side bending x-rays are taken to evaluate curve flexibility. These radiographs will be used to determine which curves are structural and which are compensatory. [See chapter 11] Compensatory curves will correct completely and in some cases overcorrect with side bending. Structural curves will not. The degree of correction on side bending of a structural curve will help to foretell its response in an orthosis.

Decompensation

Fig 2

Radiographs are also used to document presence or absence decompensation.   This trunk shift can be measured by determining the distance between the outer rib line and the lateral border of the pelvis (Fig 2).

Sagittal Curves

At the time of initial evaluation each patient should have a lateral radiograph. This baseline study will determine the presence of any decrease in thoracic kyphosis. An orthosis may complicate this structural problem. Patients with a decreased kyphosis are at risk for it progressing and should be monitored for it at each visit.

CONCLUSION

A broad understanding of the above issues and patient evaluation procedures is an imperative for determining the best orthosis design, fabrication methods and fitting. They will also help to determine the prognosis for the success of orthotic management of the deformity.

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10

Importance of Physician and Orthotist Interaction

Carol Hentges, John Lonstein

Implementing a treatment plan for a patient with idiopathic scoliosis relies heavily on the care team working together. The quality of communication between two of its members, the physician and the orthotist, is particularly important. Very often the orthotist is not part of a clinic visit. The evaluations that occur will be very important for determining the treatment plan. This chapter will highlight times and reasons for this interaction.

The critical times for communication are at the time the brace is recommended, when the prescription for the orthosis is written, at the time of brace fitting and at the time of follow-up visits when there might be brace adjustments. A good working relationship between the physician and orthotist is essential, and the orthotist needs to be knowledgeable about the physician's philosophy and bracing criteria. A successful bracing experience for the child is based on the support of the physician, the office staff, the orthotist and the parents. Consistent communication of information to the patient and their family from the physician, staff and orthotist is essential in achieving the desired outcome. The orthotist may be in the same hospital/clinic as the physician, or may be in a separate office location, and may be at all visits or available on an on call basis. Whatever the situation a communication method must be established (face to face, phone call, e-mail, text) to ensure optimal physician /orthotist interaction and patient care.

When a othosis is recommended and prescribed by the physician and the prescription order is written, two considerations are important in the process; those related to the patient, and those related to the brace.

PATIENT FACTORS

Family History – The evidence of a strong family history of idiopathic scoliosis will often determine the onset of treatment. Orthotic treatment may be recommended earlier for patients with a strong family history for spinal deformity. This family experience may influence understanding and compliance with treatment.

Personality/Family Dynamics – People naturally react in different ways to the news of needing treatment for idiopathic scoliosis. Some want detailed information and guidance while others don't want to be bothered and just want to proceed as efficiently as possible. How one proceeds is determined by various factors. Very often patients and their families have done their homework and may have already anticipated that orthotic treatment will be recommended. Others are caught off guard and for whom the recommendation of treatment is a complete shock. They may need time to process the information and discuss their options. There are times when the parents have a harder time than the patient accepting a treatment plan.

Maturity/Growth Status – An appreciation of the patient's growth and maturity markers is essential in the physician and orthotist discussion with the patient/family regarding length of time in the orthosis, follow-up visits, need for brace replacement and overall expectations of the results of wearing the brace. Good communication is essential so that the patient and family get the same “message” from both parties.

Compliance – The physician will discuss a wearing schedule and the importance of adhering to that schedule throughout the treatment process. This discussion will often include patient’s specific concerns and/or fears. These will be helpful for the orthotist to know prior to beginning treatment. Family dynamics and relationships, patient’s interests and activities, other social interactions, all factor into a patient’s compliance with treatment. Discussing these concerns or issues with the referring physician prior to the orthotist’s first encounter with the patient will be helpful in maintaining trust and cohesiveness and increasing the likelihood of compliance.

Clinical Evaluation – It is critically important to remember that a person is being treated and not a radiograph and that both the physician and the orthotist perform a full physical evaluation along with an evaluation of the radiographs. The physician’s physical findings may warrant further screening such as magnetic resonance imagining (MRI). Asymmetrical reflexes, hyper-reflexia, abnormal range of motion (ROM), large curve at a young age, rapid progression in the curve, are all signs of possible spinal cord concerns and would warrant a screening MRI to rule out or confirm an underlying neurological issue such as syringomyelia. This may not change the orthotic treatment but would change the diagnosis and prognosis.

The clinical evaluation will indicate to the physician, which criteria need to be included in the orthotic design. Rotational prominence, flexibility, sagittal alignment, pelvic alignment, decompensation, shoulder asymmetry, are all evaluated and taken into consideration when writing the prescription. The physician may have specific concerns about one or more of these clinical findings and impact what he/she feels should be included in the prescription criteria. Discussing all concerns with the orthotist allows both of them to not only understand what needs to be the focus of management but to also relay consistent and accurate information to the patient, information which might impact outcomes and expectations. There are many patients who may present with a curve and characteristics that maybe similar to idiopathic scoliosis but may in fact be secondary to syndromic disorders such as Marfan syndrome, Ehlers Danlos disease, dwarfism, Neurofibromatosis, Noonan syndrome and many others. It is essential that the orthotist know this specific diagnosis prior to treatment.

Radiographic Evaluation – Full spinal PA and lateral radiographs with flexibility films combined with the clinical features will determine the curve pattern and the curves that require treatment, as well as identifying other factors that effect the brace prescription and design (decompensation, pelvic obliquity, thoracic hypo-kyphosis). All double curve patterns (such as right thoracic and left lumbar) are not the same. If the thoracic curve is larger with a clinical prominence and radiographic rotation and the lumbar curve has no rotational prominence clinically and no radiographic rotation, only the thoracic curve needs to be treated. To aid in this type of situation, a copy of the films needs to be available to the orthotist to aid in the curve assessment, brace fabrication and pad placement.

ORTHOTIC FACTORS

Orthotic Design – Of most importance in selecting a brace design is determining the curve pattern. The physician uses both the radiographic and clinical evaluation in determining which curves are structural and which are compensatory as discussed previously. The orthotist needs to know what curve pattern has been diagnosed in order to design the most effective orthosis. The curve pattern determines not only the type of brace, (CTLSO, TLSO, LSO) but also the pad placement, the amount of pad pressure along with and opposite build-ups and reliefs. Communication between physician and orthotist is crucial at this juncture. There may be one element of the brace design that the physician may feel is the most important, i.e.: the sagittal alignment may be of more concern than the coronal, as when hypo-kyphosis is present.

Brace prescription - Ideally, the orthotist and physician should see the patient together when determining the brace design. Realistically, this cannot always happen and therefore a detailed prescription and corresponding physician notes are imperative. The prescription specifies the orthotic type, pads to be added as well as any special considerations (trochanteric extension for decompensation, reduced thoracic pressure and lower rib gusset for hypo-kyphosis). Once the patient is evaluated by the orthotist, there should be a discussion with the physician of any concerns of curve pattern and how it relates to brace design prior to the fabrication.

ORTHOTIC FITTING

The timing of fitting and physician follow up varies with each clinical situation and physician. In some situations, the orthosis is fitted and adjusted by the orthotist and seen by the physician at the same visit or on the same day, in other situations the orthotist fits the orthosis and the physician sees the patient at a separate visit 1-3 months later. At that time the brace will be checked for fit and a radiograph may be taken. The orthotist and the physician both assess the brace for its length, trim lines (posterior opening, anterior window, and sitting clearance), pad placement, strap tension, comfort and any redness under the orthosis. Any problem areas are communicated between the practitioners.

Most important is that the patient and family understand the treatment process and protocol. It is crucial that the physician and orthotist are instructing the patient similarly as to wear schedule, follow up, and expectation of outcomes. Each physician may have a different protocol for follow-up visits and whether the radiographs at those visits are in or out of the brace. The orthotist needs to be aware of what these protocols are so that the physician and orthotist are consistent with what they tell the patient.

ADJUSTMENTS AND FOLLOW UP

The orthotist establishes a follow up with the patient no later than 4-6 weeks following the initial fitting. This will allow the patient time to gradually wean into wearing the orthosis the prescribed amount of time and to be able to resolve any issues that may arise during this initial wearing period. Minor adjustments at this initial return visit are very commonly necessary.

Despite our best efforts there may be adjustments necessary once the initial in brace radiograph is taken. Both the physician and the orthotist should agree upon problem solving to arrive at what to change and how much to change. Very often it is a matter of moving a pad but may also include, increasing the room to shift, increasing trochanteric pressure, adding or removing a gusset. When the amount of kyphosis is of concern, an early in brace lateral radiograph should be taken. If there is concern regarding significant brace design changes or significant compliance issues, these should be communicated to the physician.

Importance of Physician and Orthotist Interaction

The patient should be instructed to follow up with the orthotist if there are ever any concerns with fit or function of the orthosis.

PHYSICIAN VISITS

Each physician has his or her own criteria for follow-up. Whether they wish to have in brace or out of brace radiographs is essential for the orthotist and patient to know in order for proper arrangements to be made for a timely evaluation. Every effort should be made for the patient to follow up with the orthotist at the same time/day as their physician visit. This allows for any adjustments or modifications that need to be made along with insuring that the brace continues to fit correctly. There should be an open line of communication between the physician and the orthotist during these visits in order to maintain quality and continuity of care.

At the time of follow-up the physician will include a physical exam, brace check, and radiograph generally at 4-6 month intervals. Patients will be monitored for growth, Risser sign, menarche, curve magnitude change, spinal balance, and rotational changes and to assess the fit of the orthosis. Sharing this information with the orthotist allows them to accurately assess and document any changes they may need to make to the orthosis. This is helpful for assuring the patient that all treating professionals are working with the same information.

CONCLUSION

In the treatment of Idiopathic Scoliosis effective physician and orthotist interaction is uniquely tied together. At the heart of this relationship is the ability to communicate effectively with one another and translate that communication into a seamless continuity of care. We have attempted to illustrate the importance and timing of effective communication between the physician and the orthotist.

11

The Effectiveness of Physical Therapy Interventions and Techniques in Adolescent Idiopathic Scoliosis

Amanda Guevara, Claudia Senesac

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is an abnormal lateral curvature of the spine that usually appears in late childhood or adolescence. The curve can be stable or it can be considered progressive, becoming more severe over time.[1] This chapter will examine the various physical therapy interventions that could be considered when treating a child with AIS.

Idiopathic scoliosis can be broken down into three different categories classified by the age of onset: infantile (birth to two years), juvenile (three to nine years), and adolescent (10 years and older). AIS is the most common type of lateral curvature of the spine accounting for 65% of adolescent patients with structural scoliosis and is present in 2-4 percent of children 10 to 16 years of age.[2,3]

Orthotic management of scoliosis is regarded as effective when the curve progression has been arrested and surgery has been avoided. Observation, orthotic management and surgery are important approaches, all options including non-invasive should be presented to the patient when deciding the most appropriate and effective treatment to address the spinal deformity.[4,5,6]

There is no clear consensus on the effectiveness of physical therapy when it comes to treating scoliosis. In Europe, the most common interventions for scoliosis include physical therapy as an outpatient or through in-patient rehabilitation, corrective bracing, and/or surgery. These interventions consist of scoliosis-specific exercises (SSE) as a stand-alone therapy or as an add-on to bracing therapy. In North America the standard of care for scoliosis includes observation of patients who are still growing and in those patients with non-progressive curves between 10 and 25 degrees. For patients with progressive curves between 25 and 45 degrees during the growth phase, bracing may be recommended, and with curves greater than 45 degrees spinal fusion is may be the best altervative.[4,7,8] Most experts agree that exercise alone will not affect the progression of a structural scoliosis, however a selective program of exercises in combination with bracing treatment may be beneficial.[9,10]

A variety of impairments can be commonly associated with a diagnosis of scoliosis including impairments of strength, balance, range of motion (ROM), respiration efficiency, and limitations of functional mobility and wellness.[11,12] Physical therapists (PT's) are health care professionals who are trained and licensed to diagnose and manage the impairments that can be associated with scoliosis.[13] There is little evidence however in support of physical therapy interventions in regard to slowing or decreasing the progression of the Cobb angle associated with scoliosis. However, there are a variety of therapeutic approaches that claim to be effective in addressing the secondary effects of AIS.[4, 7, 8, 9, 14, 15, 17, 19, 20] Research studies have focused on targeting the secondary effects of scoliosis such as muscle weakness or imbalance, decreased range of motion, impaired balance, and decreased respiratory function. The physical therapy techniques claiming to decrease the Cobb angle progression and secondary impairments will be addressed individually in the chapter.

THE SCIENTIFIC EXERCISE APPROACH TO SCOLIOSIS METHOD (SEAS)

The SEAS method, which began in the 1960's, is based on scientific principles that are continually changing based on updated literature.[15] The SEAS method is an individualized exercise program, which can be used in all stages of scoliosis management to assist in stabilizing the curve and helping to reduce disability.[15] The SEAS method focuses on improving the patient's awareness of their deformity, self-directed correction by the patient, the use of exercises to stimulate balance reactions, as well as the performance of in-orthosis scoliosis specific exercises using the orthosis as a training tool.[14] Since the etiology of the scoliosis curvature may be unknown, the SEAS method is focused on minimizing the effects of the symptoms of the condition. This method takes into account the stage of the condition the patient is in.[14] SEAS is based on two main treatment objectives; the first is active self-correction and the second focuses on improvement of spinal stability through strengthening.[14] The purpose of these exercises is to train the patient to find a strategy that allows a self-corrected position as they move throughout their daily activities. The scoliosis specific exercises (SSE) are based on 3 principles. Principle 1: "SSE exercises use an element of distraction for training the maintenance of self-correction." Self-correction and exercise are used together to help maintain the corrected position of the spine. Once the patient can perform this self-correction, an exercise component is added to generalize the alignment to a variety of situations of postural stress.[14] Principle 2: "The purpose of the SSE exercise is to improve the primary "target function" or the stability of the spine". The primary aim of exercises in this approach is to stimulate muscles that have the greatest potential to provide spinal stabilization. Principle 3: "The aim of the exercises is to improve the deficits found during the initial assessment, which can include strength deficits, muscular retractions, or impairments in motor coordination".[14]

In the SEAS method the patient undergoes an assessment of Cobb angle, plumb line, sagittal posture, and aesthetic parameters. In addition, an assessment of strength, flexibility, proprioception, hand eye coordination, and balance are performed. Once the assessment is complete the findings are used to develop the specific exercises to improve the baseline outcomes of the initial evaluation. The patient is instructed in exercises that are specific to stabilizing the spine.[14] The patient takes an active role in their therapy by asking the following questions: "1. Is my spine supported? 2. Is my body now more symmetrical than before? 3. Am I able to maintain the correction during exercise? 4. Am I able to see that my body returns back to the original position it was in before performing the self-correction?"[14] The self-correction is done in all planes (coronal, sagittal, horizontal) as well as various positions i.e. standing, sitting, all fours. The therapist adjusts the SEAS method every 3 months according to each individual's progress. The home exercises are based on each individual patient and increase in difficulty in parallel with the patient's abilities.[14] The purpose of the exercises is to train an automatic response to stimulate the maintenance of a three-dimensionally corrected posture during activities of daily living.[15] The SEAS method has no copyright and teachers are being trained around the world to make it a more available technique to treat scoliosis. Expertise on scoliosis, exercises, as well as patient and family management is required to be successful in this method.[14,15]

Multiple prospective, retrospective and case studies have investigated the SEAS approach. There is some evidence that the efficacy of specific scoliosis exercises in curves less than 25 degrees is effective in decreasing the progression of the Cobb angle.[15]

In a case study by Ishihara and Shiraishi the active self-correction of SEAS was purported to be effective in reducing the Cobb angle of a patient after skeletal maturity. A 14-year-old girl with a 28 degree thoracic and 28 degree lumbar curvature was followed. She was braced immediately at diagnosis and completed bracing at age 18 years with a Cobb angle of 31 degrees. Six months post bracing her thoracic curve increased from 31 degrees to 37 degrees. Once the patient turned 21 years old the SEAS approach was implemented for 3 months with an ending Cobb angle of 30 degrees.[16] Caution should be exercised when interpreting the results of this single case study. The change in Cobb angel was only 7 degrees and no long-term follow up was provided to determine lasting benefits.

The SEAS approach focuses on exercises that strengthen and improve stabilization of the spine. The best reported outcomes for this approach focused on the deviation of the vertebrae while utilizing exercises that strengthen and stabilize the muscles around the spine therefore assisting in counteracting the curve progression.[14]

THE BARCELONA SCOLIOSIS PHYSICAL THERAPY APPROACH (BSPTS)

The BSPTS was founded by Elena Salva circa 1968, and has been used in the Elena Salva Institut in Barcelona, Spain. The BSPTS is based on the original principles of Schroth, with modifications based on years of clinical experience and research. The method is described as "a therapy plan of cognitive, sensory-motor and kinesthetic training teaching the patient to improve his/her scoliosis posture and soft tissue imbalance, utilizing the assumption that scoliosis posture and soft tissue imbalance promote curve progression".[14] This approach emphasizes the importance of utilizing a multidisciplinary team including a medical doctor, physiotherapist, orthotist, and psychologist.

BSPTS is based upon the following three principles; Principle 1: "In idiopathic scoliosis muscle imbalance is a secondary effect to the deformity and its progression. Muscle imbalance can only be corrected by reaching the best possible three-dimensional self correction before isometric muscle tension is used to stabilize this position". Principle 2: "Repetition of the best corrected posture, with the help of proprioceptive and exteroceptive stimulation as well as visual control (mirror), is a useful mechanism to achieve a corrective body schema to substitute for the scoliosis body schema. Principle 3: "After the best possible 3-D correction is achieved, specific breathing mechanics can be introduced to increase the corrective effect, whilst at the same time re-shaping the deformed trunk".[14]

The BSPTS method emphasizes looking at each patient, as an individual, in order to find the "abnormal geometry" of the spine by using a principle of correction called detorsion. Detorsion is defined as the ability to attain the best correction until halted by the structural component. After attaining the best correction of the non-structural component, some degree of 3D deformity related to the structural component will still be noted. This deviation may be minor or major depending on the severity of the treated scoliosis. At this point, the therapist can ask the patient to gently intensify the corrective forces. However, the patient must always use the combination of forces in the three planes rather than correcting in an isolated plane, as would be the case when using bending exercises in any single plane, or by de-rotating one section of the body against an adjacent one.[14] According to the authors, the principles of this correction method are as follows:

1. Self-elongation from a stable corrected pelvis.

2. Combination of self-elongation with corrective tension in any part of the ventral or dorsal trunk. This asymmetrical sagittal straightening means that one hemi-body will be corrected in opposition with the other.

3. This principle focuses on improvement of the curve from the frontal plane concentrating on gentle movements and tensions performed in the frontal plane.

4. Breathing techniques are added to help increase the de-torsional effects by creating an internal pair of forces for de-rotation called Schroth rotational breathing.[14] This principle is very difficult to perform and therefore requires assistance from a physical therapist.

5. The last principle states that stabilization is achieved by muscle activation that helps to maintain the best possible correction in expiration. The BSPTS approach is very intricate and in depth with a relatively steep learning curve in order to implement this technique. Most therapists who practice this approach have successfully completed a theoretical-practical course.[14] The technique involves a great deal of guidance from the therapist with tactile stimulation provided to allow the patient to understand when to combine breathing to help create muscle activation in the correct curve.[14]

Using a Schroth program based on a BSPTS exercises Schreiber et al. in a randomized controlled trial in 2015 aimed to determine their effect.[7] The authors combined this program with the standard of care on quality of life outcomes and back muscle endurance compared to standard of care alone in patients with adolescent idiopathic scoliosis. This study randomized 50 patients with adolescent idiopathic scoliosis aged 10-18 years old with curves between 10-45 degrees into two groups; 1.Standard of care, 2. Schroth exercises plus standard of care. The interventions were done over a 6-month period of time. To assist in maximizing compliance, equipment was provided at home or they were given access to health clubs. The standard of care group consisted of observation or bracing, if they had met the standard bracing criteria. The controls attended a study assessment but no therapy sessions.[7] Outcome measures were taken at baseline, 3 months, and 6 months looking specifically at Biering-Sorensen back muscle endurance.[7,23] Statistical analysis was performed for baseline demographics and radiographs, for the entire sample. This study found that supervised Schroth exercises provided benefit to the standard of care group by improving SRS-22r pain, self-image scores and BME, however the outcomes selected did not document the progression of a scoliosis curve (the Cobb angle). Further, this study was carried out over a relatively short period of time (6 months) and the participants had not reached bone maturity at its conclusion. Therefore, the study has limited application related to the reported outcomes.

Some studies have shown that Schroth exercises may demonstrate improvement in breathing function, pain, back asymmetry, posture, muscle imbalance, and decrease the Cobb angle in the short term.[24,25] There is little evidence that specific exercises following Schroth principles, or any other physical therapy based principle can prevent curve progression in rapidly progressing scoliosis during the growth periods of adolescence through maturation. Therefore, little evidence exists that exercises halt curve progression. Caution must be exercised in drawing conclusions from these studies since they have only been documented in the European literature.[25]

LYON APPROACH

The Lyon approach, developed in 1947, emphasizes physical therapy in combination with the use of a plaster cast and the Lyon Brace. This approach consists of five different stages. The first stage emphasizes the importance of the patient's age, postural imbalance, and the Cobb angle. When a child is younger than 10 years of age with a diagnosis of juvenile idiopathic scoliosis physical therapy can be used for coordination and balance impairments. When assessing postural imbalance it is important to consider that a scolioic curve may be due to a bony deficit, or may be due to compensation. When the Cobb angle is greater than 25 degrees it increases the asymmetry and pressure placed on the spine. Stage two focuses on awareness of the trunk deformity. This approach makes the child aware of the corrective possibilities for their back emphasizing that scoliosis is an adaptation of the spine. The children are given visual feedback by using a mirror or other device. Stage three looks at exercises that are symmetrical in the supine position since the radiological scoliotic angle is larger when standing. The progression of the exercises they modified to reflect changes in pace, intensity, and duration. Stage four emphasizes the exercises and postures that should be avoided. These include extreme flexion and extension as they increase pressure on the spine and avoiding shortness of breath since deep breathing favors the rotation of the vertebra. The patients are taught to avoid strengthening of the superficial body building muscles. This approach focuses on endurance in the deep paraspinal muscles.[14,9] Stage five suggests patients participate in sport activities. The best results were found in patients who participated in sports more than 5 hours a week with sports requiring balance and coordination.

Once the scoliosis begins to progress the Lyon method combines physical therapy as well as the Lyon brace, a device consisting of radio-transparent duralumin, steel, and thermo malleable plastic. There are three types of this orthosis that can be prescribed depending on the patient's specific curvature.[22] While the cast is on PT is intensified with at least two sessions per week supervised by the PT including breathing control, mobilization of the ilio-lumbar angle, therapeutic patient education, and sitting posture check. With children who have a curve less than 30 degrees the orthosis is only worn at night. Once the curve exceeds 30 degrees the orthosis is worn part of the day and the exercises are performed with or without the orthosis on, typically performed in groups.[14]

The Lyon method focuses on exercises that are proven to be reproducible at home. The continuation of sporting activities is encouraged as long as they are not contraindicated. However some movements may need to be adapted to avoid positions such as deep, quick inspiration, and forward trunk flexion.[22] A retrospective study in 2011 by Mauroy et al. followed 1338 subjects who were diagnosed with scoliosis and treated in France and Italy according to the Lyon Brace method. The mean age of the subjects studied was 13 years and 10 months. Patients were classified into groups according to the type of Lyon brace prescribed and the results were expressed in the Cobb angle measurements. In addition subjects were grouped into aesthetic results of the rib hump level. The study found that if treatment was started when the patient had a curve less than 40 degrees, only 2% of the patients required surgery whereas if the Cobb angle was greater than 40 degrees at the start of treatment, the percentage rose to 20% requiring surgery.[22] Although this study was of a retrospective design it implies that the Lyon brace in combination with physical therapy exercises have positive results in decreasing the progression of the Cobb angle in those with AIS.[22] Of import; the study had no control group where patients received the brace without an exercise program, therefore the benefits of exercise remain largely unknown.

Limited numbers of publications are available depicting examples of specific exercises prescribed for the Lyon method. A reference manual for the Lyon scoliosis brace is available describing various brace types and principles of the bracing, however, it would be difficult to complete this method without extensive therapy training.

FUNCTIONAL INDIVIDUAL THERAPY FOR SCOLIOSIS

Bialek and M'hango, to help improve postural problems associated with scoliosis, developed the Functional Individual Therapy for Scoliosis (FITS) approach in 2003. This method was adapted from various approaches in order to have a therapy practice that could be used with patients during the progression of their deformity. The FITS method is indicated for use with any child regardless of the Cobb angle, in support of orthotic management, in preparation for surgery, or during recovery after surgery. This therapy is done in an outpatient clinic or as an inpatient for 1 or 2 weeks. Typically, the therapy is done by a physical therapist in combination with an orthopaedic surgeon and a psychologist.[14] There are multiple objectives included in this method which focus on awareness of the existing deformity of the spine and trunk while teaching correction, release of myofascial structures allowing for more movement. It focuses on stabilization while facilitating a correct breathing pattern, balance exercises, improvement of neuro-muscular coordination and correcting the scoliosis by teaching correct pelvic weight bearing in a sedentary position.

The FITS method is performed in three stages with the first stage including a full examination of the patient observing postures, lower extremity alignment, length of muscles in the lower extremities, and an assessment in sitting and standing of the possible curve correction. The second stage prepares the patient for 3D correction with detection and elimination of the muscular and fascial restrictions by utilizing contract-relax, myofascial release, trigger point therapy, and joint mobilization. The third stage includes building a repertoire of stabilization in new corrective posture patterns and functional positions. Stabilization exercises and facilitation of the three-plane corrective breathing is done after diaphragm release and restoration of the best joint mobility in the thoracic spine and thorax.[14] The exercises are chosen based on the Cobb angle, size and direction of the trunk rotation, position of the spine, and location of functional compensation. Ideally it is best to correct the structural curve in all three planes, however this may be difficult to accomplish.

Claimed strengths of this method include teaching the patients to be aware of their deformity, removal of muscular and fascial limitations, which restrict the correct movement, and teaching daily functional activities. The FITS method is a complex method requiring utmost accuracy, strict cooperation of therapist and parent participation as well as requiring a long duration of therapy. This method usually continues until the completion of skeletal maturity.

Negrini, et al. in 2008, examined the effectiveness of this approach in a retrospective review. The study looked at 41 children who had early onset of AIS with Cobb angle measurement between 11 and 30 degrees. Children received an extensive clinical assessment according to the FITS method principles.[24] The minimum follow up was 2 years with the maximum being 16 years after initiation of the FITS treatment. Out of 41 children, 27 improved, 13 were stable, and 1 progressed with decreased trunk imbalance.[24] This method may be beneficial in the treatment of scoliosis but appears to require specific training to be carried out appropriately and has little clinical evidence of effectiveness. No studies have been done using SRS criteria for proven curve progression. In addition, the majority are small curves being treated without, any scientifically demonstrated effect on the child.

THE DOBOMED APPROACH

The Dobosiewicz's Method (DoboMed) is a non-operative management approach for idiopathic scoliosis, which was developed in 1979 by professor Dobosiewicz and has been used routinely in Poland since 1982. This method claims to address both the trunk deformity as well as the respiratory functional impairment. The first principle is consideration for preventing curve progression. The second principle is to improve respiratory function. The effectiveness of this method depends on the curve flexibility and the patient's compliance. Active participation is the hallmark of the DoboMed and thus is not recommended for small children.[14] Like the other methods discussed in this chapter, the Dobo Method claims to focus on self-correction based on the pathomechanics of idiopathic scoliosis. At the beginning phases, non-specific exercises can be used, mainly as a warm up for the spine-specific exercises that are introduced later. The initial exercises are done in low positions against gravity (quadruped and high kneeling) consisting of closed kinetic chains in order to enhance their effectiveness. By starting the exercises in a low position the back muscles are allowed to relax. Exercises are progressed to active 3-D auto-correction exercises performed in upright positions with the spine positioned vertically allowing gravity to fully affect the back muscles. During these exercises it is essential to arrange the exercises around the ability to fixate the pelvis and the shoulder girdle with the upper and lower limbs during all phases of the respiratory cycle.[14]

There are nine principle features that are associated with the DoboMed approach: "1) Symmetrical positioning for exercising, 2) Asymmetrical active movements to accomplish 3D scoliosis correction, 3) Thoracic spine mobilization to increase thoracic flexion, 4) Transverse plane de-rotation, 5) Specific treatment emphasis is focused on the area of curve apex, 6) Concave rib mobilization to expand and de-rotate the ribs, 7) External facilitation, 8) Respiration-directed movements of the thorax and spine to improve respiratory function, and 9) 3D displacement of vertebrae to obtain 3D scoliosis correction".

One study reporting on the results of the DoboMed approach demonstrated it to have an inhibitory effect on the progression of the curve in idiopathic scoliosis.[14] The radiological evidence taken from x-rays has been assessed from retrospective and prospective studies with the best effects observed in those with single curves.[14] Another benefit was improvement of respiratory function noted by spirometry values. For best results DoboMed requires a parents' direct supervision of their child to ensure compliance.[14]

CONCLUSIONS

Cassella and Hall reflected on treatment approaches in their 1991 articles stating that children with a 25-30 degree Cobb angle require some sort of treatment intervention. However controversy remains in regard to the effectiveness of non-operative management as a stand-alone intervention to slow the progression of the curve. Today, most experts will agree that exercise alone will not affect the progression, however a specific exercise program in conjunction with bracing treatment may be beneficial.[14] Before an exercise program should begin in an adolescent with idiopathic scoliosis a comprehensive assessment should be done to include the following measures: posture, leg length, range of motion, muscle strength, breathing pattern, and functional activity levels.

A therapist assessing the posture of someone with scoliosis should take into the account the patients natural relaxed posture observing all views (anterior, posterior, and lateral) documenting any asymmetries of bony landmarks. Leg lengths should be measured on both sides from the anterior superior iliac spine to the medial malleolus as well as from the umbilicus to the medial malleolus. A leg length discrepancy may affect the child's standing postural alignment. Range of motion is an important assessment to obtain as progression in the Cobb angle can place various muscle groups at higher stress levels placing them at risk for shortening, especially the hip flexors, hamstrings, tensor fasciae latae, low back muscles, trunk, and shoulder girdle musculature. Muscle strength measured through manual muscle testing should be done with emphasis on abdominal and back muscle groups. When looking at breathing patterns it is important to note asymmetries in chest wall expansion and shoulder rise as well as to obtain information if the patient has any history of asthma or other respiratory conditions. Finally, documenting a patient's functional activity level at baseline provides information about their participation. These assessments will assist a therapist in returning the patient to his or her prior level of function or improving their functional status.[14]

The purpose of an exercise program is to develop postural awareness with the ability to maintain corrected alignment with or without an orthosis. Maintaining or improving proper respiration, chest wall mobility, muscle strength, joint range of motion, and spinal flexibility will assist in resuming prior levels of functional mobility. Therapists should teach the patient how to move, walk, run, and perform activities of daily living while wearing an orthosis.[14]

A 2008 paper by Negrini, et al. investigated the effectiveness and usefulness of exercises for AIS through a systematic review of the literature aimed at verifying the effectiveness of exercises in the treatment of AIS.[24] A variety of databases were used finding 11 papers, none of which were randomized, seven were controlled, two compared their results to historical controls, and one had a prospective design. The quality of the methodology used in the reviewed studies was found to be very poor and inconsistent. However, the published studies claimed the efficacy of exercises in reducing both the rate of progression and magnitude of the Cobb angle at the end of treatment. In the same paper Negrini et al. looked as whether exercises for AIS have changed over the years. The review looked exclusively at patients treated with exercises and the outcomes of their Cobb angles. Nineteen studies were found with 1 randomized control trial (RCT), 8 controlled studies, and 12 prospective studies. The most significant study in this systematic review was the RCT, which compared two groups of 40 patients demonstrated improvement of the curvature in all treated patients after 6 months, which is much too short to assess the effectiveness of any treatment modality. During this most recent search, three papers on Schroth exercises and four on the Lyon and SEAS methods suggested efficacy of exercises in reducing the progression rate, usually seen in early puberty and implied a reduced need for orthotic management. Taking into consideration that these recent papers primarily investigated scoliosis during puberty (a time of rapid growth) for a relatively short period of time, one should interpret the results with measured skepticism.[24]

This chapter has described the various treatment approaches in managing scoliosis utilizing physical therapy interventions with recent research supporting the use of exercise to help manage the secondary affects of AIS. The treatment approaches vary in difficulty and should only be used by a trained therapist. [Editors note: The reader needs to apply the standards of Evidenced Base Medicine to a particular method of physical therapy as few if any will meet those standards.]

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Section 4:
Orthotic Management of Spinal Deformities

12

Basics of Spinal Deformity Orthoses

James H Wynne, M Timothy Hresko

INTRODUCTION

Scoliosis is a broad term used to describe various conditions that result in changes to the spine, thorax and trunk. This term is further refined to describe specific types of scoliosis that can occur. Idiopathic Scoliosis means there are no related causes for these changes and will be the focus of this chapter. The Scoliosis Research Society (SRS) defines scoliosis as a lateral curvature of the spine, a coronal curve, as measured by the Cobb method of at least 10 degrees with axial rotation.[1] The Society on Scoliosis Orthopedic Rehabilitation and Treatment (SOSORT) further defines Idiopathic Scoliosis as a "three dimensional torsional deformity of the spine and trunk: it causes a lateral curvature in the frontal plane, an axial rotation in the horizontal plane, and a disturbance of the sagittal plane normal curvatures, kyphosis and lordosis, frequently, reducing them in direction of a flat back."[1] This chapter is an attempt to bridge the knowledge gap and to add to the evidence base of orthotic management of idiopathic scoliosis.

The non-operative treatment of idiopathic scoliosis involves a spectrum of options that are dependent on the risk of curve progression. That risk is dependent on the initial curve magnitude and remaining growth. At issue is accurately predicting which curves will progress and which will remain stable. In an ideal situation the clinical team should only treat those curves that require intervention and thereby not under or over treat a patient.[2] There is general agreement among the SRS and SOSORT that orthotic treatment is recommended for patients presenting with curves between 25 and 45 degrees with growth remaining. [The reader is referred to Chapter 16 for an expanded discussion of evidenced based treatment guidelines]

HISTORICAL PERSPECTIVE

An earlier chapter covers the various orthotic methods utilized over the centuries [See chapter 3]. This chapter will highlight the most common systems and is not meant to be comprehensive or to be interpreted as showing one system being more effective than another. Many orthoses have limited evidence for their effectiveness and therefore this chapter will only provide descriptions of those devices.

Fig 1

Hippocrates may be credited with one of the earliest documented treatments. His method consisted of elongating the spine under tension (traction) while manually applying pressure over the focal point of the curve all while the patient was lying on the Hippocratic Board (Fig 1).[3]

In 1936 Barr and Buschenfeldt describe a turnbuckle style orthosis.[4] They noted that many devices used at that time made an effort to correct the deformity. Barr notes a few authors and designs: Schanz described a variety of orthoses and corsets; The Chambers brace along with various forms of the Abbot jacket. Barr states that for a device to be useful it must be comfortable, not restrict respiration, be easily donned and be easily adjusted by the patient or assistant and not require too many repairs or need to be replaced too often for growth. These same device attributes are as true today as they were when he wrote in 1936.

Barr presents anecdotal evidence when describing their results. He stated that patients like the simplicity of the device, find it comfortable and that there were no instances where the brace was not able to obtain the same correction as witnessed in the physical exam.[4]

MILWAUKEE BRACE

Originally designed as a post-operative orthosis, the Milwaukee Brace was introduced by Walter Blount and Albert Schmitt in 1946 at The American Academy of Orthopaedic Surgeon's meeting and was first reported in a paper published in 1958.[5,6] It was one of the first described orthoses to have objective evidence showing effectiveness and a repeatable fabrication process. Figure 2 shows an early version of the Milwaukee brace.[7] In 1970, John Moe and David Kettleson reported their findings on one hundred and sixty nine patients with Idiopathic scoliosis that were fit with the Milwaukee Brace.[5] The authors stated that to be successful there needs to be cooperation of the patient and parents, (be responsible for wearing the orthosis) a well-constructed orthosis and a knowledgeable orthopedic surgeon who oversees the treatment plan. In this paper we see the emergence of a clinical program, the need to better engage the patient and the importance of competence of all members of the clinical team.

Fig 2

The Milwaukee orthosis is typically fabricated from a plaster impression while the patient is standing with knees slightly flexed in order to have the pelvis in a more neutral position and a reduced lumbar lordosis. It consists of a pelvic girdle and a super structure. The super structure has a single anterior metal strut with two posterior struts all of which are connected by a neck ring (Fig 2). Thoracic and axillary slings are attached to the metal uprights to provide passive curve correction. The Pelvic girdle, originally fabricated from leather stretched over the positive model of the patient is now made from thermal plastic.[8] Over the years as lower profile orthoses have been developed, the wide use of the Milwaukee has lessened. It is still in use for Scheuermann kyphosis, some juvenile curves and for high thoracic curves.

In Europe other systems where developing such as the Lyon Brace in 1945, presented by Stagnara and the Cheneau Toulouse Munster (CMT) Brace in 1970 presented by Jacques Chêneau. The design and material utilized for these European systems has evolved over the years, but the basic biomechanical principles have remained the same. Specific information regarding their current design philosophy as well as more recently introduced systems can be found at www.scoliosisjournal.com – the thematic series.[8]

The pages that follow provide brief descriptions of the various systems (common names) of orthoses that are currently utilized in practice today throughout the world. Some of the thoraco-lumbo-sacral orthosis (TLSO) designs may be unfamiliar in name due to their regional acceptance. Some may consider them variations of the more commonly known Boston or Cheneau braces. They have been included in this chapter to highlight the variation in orthotic design.

There are multiple ways in which the orthoses described below are fabricated. The term custom fabricated is used to describe an orthosis that is fabricated for a specific patient. This distinguishes it from a custom fitted device in which the basic component(s) are fabricated without a specific patient in mind and can be modified to fit a range of patients determined by curve type, body dimensions or both. Custom fabricated devices are fabricated from measurement/cast impression and/or scan.

Measurements

A series of circumferential, medial/lateral; anterior/posterior measurements are taken as specific anatomical landmarks (greater trochanter, anterior superior iliac spine (ASIS), anatomical waist, lower rib, xyphoid, chest and axilla). A custom fitted device would then be selected that best matches those measurements. In the case of a custom made from measurement device, either an existing patient model is modified to match those specific measurements or a computer aided design (CAD) model is modified in the computer software to reflect those measurements. In both cases a model, specific for that patient is created.

Cast Impression

When taking a negative model of the patient applying Plaster of Paris, either splints or rolls, onto the patient's torso, creates an impression. Fiberglass material, in roll form, is also used for this purpose. Corrective forces are often applied to the patient after the plaster/fiberglass is applied. If the patient is standing, the plaster/fiberglass is circumferentially applied over a cutting strip and allowed to set prior to trimming off the patient. If the patient is supine, splints (straight sections of unrolled Plaster of Paris that are several layers thick) are used to create a bivalve impression (anterior/posterior shells) of the patient. The anterior section is typically created first and the patient is log rolled prone. Care is taken so as not to augment the shape of the anterior section. Also, the width is maintained so as to not distort the medial/lateral dimension. A releasing agent (soap) is applied to the lateral edges and the process is repeated on the posterior aspect of the patient. The two halves are then removed and realigned to create a negative model of the patient. In all of these methods, the negative impression of the patient is then filled with plaster and a positive model of the patient results. This positive model is then hand modified to reflect the forces/reliefs required to obtain correction.

Scan

Scanning technology allows for electronic acquisition of the patient's trunk topography. Scanners can be in the form of a mobile hand held device or a stationary set of fixed cameras or lasers. The mobile devices use either a laser or white (structured) light sensors to capture a 360 degree image of the patient. In either case the patient is typically in a standing position (Fig 3). The laser scanner collects the shape through a series of "sweeps". The hand held device is held a constant distance from the patient as the laser follows their contours in a superior to inferior movement over lapping between sweep (similar to using sprayer to paint an object). The white light or structured sensor scanner collects the patient's shape, as the device is moved superior to inferior, left to right about the patient. The captured images are "stitched" together, much like a digital camera in panoramic mode. Stationary devices work in a similar fashion except that rather than moving the scanner about the patient, a series of lasers or cameras are mounted so that a 360 degree image can be captured.

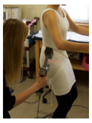

Fig 3

As all plaster/fiberglass negative impressions are filled with plaster to obtain a positive model, all


Fig 4

scans are imported into a software program to create a positive model using CAD software. These models are then modified in CAD and sent to a carving (milling) machine that will carve a positive model to be used to fabricate the orthosis (Fig 4).

Once the positive model is created, either via cast or scan, thermoplastic material is vacuum formed over the model to create the negative form that becomes the custom made orthosis.

THE BOSTON BRACE

The Boston Brace System developed by Marion “Bill” Miller and John E. Hall in the 1970’s at Boston Children’s Hospital had its first results described by Hall, et al. in 1975 (Fig 5).[9,10,11] The Boston has proven to be a repeatable, reliable and systematic approach to the non-operative treatment of scoliosis. Critical analysis of patient outcomes, common adjustments and reported compliance have allowed the system to mature and evolve over the years while the goal of preventing the curve from progressing and maintaining a stable spine in adulthood has been maintained.[12] Two independent studies (one combining both a randomized and preference cohort) show the Boston is effective in preventing curve progression in Adolescent Idiopathic Scoliosis (AIS) when worn for more than 12 hours each day.[13,14]


Fig 5

The original Boston Brace was a prefabricated standardized symmetrical modular (orthosis) system where selection of the specific module is determined by the patient’s measured dimensions.[9, 15, 16] The orthosis was then customized for the patient based on those measurements and curve pattern. Hall notes[9] that ninety five percent of the patients in their review could be fit with a prefabricated module; the remaining five percent were fit with a custom fabricated TLSO that followed the Boston Brace principles.

When the orthosis, following the Boston Brace principles, is custom fabricated from scan, cast, and or measurements (Fig 6) the term modular refers to the ability to change the pad placement and or alter its shape to maximize the orthosis’ effectiveness. The sagittal profile was originally standardized. Watts noted in his paper that there was concern that an anti-lordotic design would lead to a thoracic lordosis that was later found to have no merit.[9] Whether this was a natural occurrence or a result of physical therapy, Watts suggested that for best results the therapist needed to understand the specifics of the orthotic system. For the custom made Boston Brace, the current thinking is to retain a more normal sagittal profile of the patient, with minimal changes and greater focus on the overall sagittal balance.[1,12,17] The orthosis in Figure 6 is a typical Custom Boston brace – it has a large window (with an elastic gusset – this keeps the ribs from impinging on the inferior boarder and improves comfort. The anterior bib has a channel trimmed at the anterior lateral aspect to allow the bib to ease breathing and donning of the orthosis..


Fig 6

The Boston Brace Manual (SRS Bracing Manual Section Five) is available on the SRS website as are several other specific brace designs. The basic Boston Brace principles are outlined below. Its goals are to obtain curve reduction, improve overall balance, and not impede patient tolerance.[15]

Symmetry

The basic concept is to modify the patient’s asymmetrical shape (provided by the cast or scan) and balance that shape (make it symmetrical) (Fig 7). By doing this the form over which the orthosis is frabicated is symmetrical. It is made asymmtrical by the addition of strategically placed corrective pads and the trim lines.

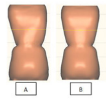

Fig 7

Blueprint

The blueprint (Fig 8) is a systematic repeatable way of analyzing the patient's radiograph in order to design an effective orthosis. It is understood that analyzing the x-ray is but one step in orthotic design. Studying the patient's shape, flexibility and desire to cooperate in the treatment are also important. The focus is on each individual vertebra and its relationship to the center sacral line. This allows for an accurate brace design, pad placement and ensures that each portion of the orthosis has a function. With the advent of computer-assisted design, the orthotist is able to superimpose the x-ray into the scan of the patient's torso (Fig 9). The blueprinting steps and principles are then incorporated into the modification process. By being systematic in the design, the clinician can better analyze the results with an in-brace x-ray. If the desired in - brace result is not obtained, the scanned torso and superimposed x-ray can then be referenced to determine if the principles were appropriately applied.

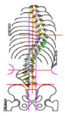

Fig 8

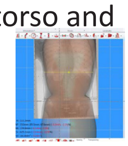

Fig 9

Relief opposite areas of force and Force couplers

These considerations insure that the trunk and or curves have somewhere to shift to in order to gain suitable balance or corrections (Fig 10). To obtain proper balance and curve correction the patient must be allowed to shift off of the transverse force application (pad) and into a void area. This is well demonstrated in relief areas A and B in Figure 8. Equally important is the concept of force couplers to address the rotary component of scoliosis. The application of corrective rotational forces is potentially more effective when "force couples" are used. Thus, for every rotational force applied another force opposite the desired center of rotation, in the same rotational direction, (both forces trying to achieve a clockwise rotation for example) is applied to enhance the desired correction. Thus, as shown in Figure 8, an anteriorly directed de-rotating force in the thoracic spine (Intrinsic Corrective Force A) is coupled with a posteriorly directed force in the anterior abdomen (Intrinsic Corrective Force B). Areas of relief (Intrinsic Relief A and B) are also present. These intrinsic force/relief areas are present globally within the system.

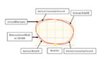

Fig 10

Just as scoliosis is a triplanar deformity, the Boston System works in all three planes to achieve balance. Figure 11 depicts a before and after posterior view where the intrinsic corrective force follows the shape of the patient. Additional corrective forces (pads) are then added to the brace along with cut outs (windows) to maximize area of relief. The force relief concept is consistent with Newton's third law that for every action there is an equal and opposite reaction. By creating strategically placed forces and opposite reliefs in the orthosis there is a greater chance at reducing, stabilizing or correcting the spinal deformity.

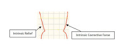

Fig 11

Lumbar and Pelvic Tilt

Attention to Lumbar and Pelvic Tilt has been a basic principle since the inception of the Boston Brace. As previously noted, there was initial criticism that a reduction of lumbar lordosis would lead to the development of a thoracic lordosis, but this has been found to have no merit. Ideal sagittal alignment of the lumbar spine and pelvis continues to be a source of discussion. Emans, in the most recent Boston Brace manual,[15] cited Moe, who did not think that the module needed to be at zero degrees lordosis. The pre-fabricated module was then changed to be 15 degrees and today with the custom made Boston the sagittal profile is respected. The original thinking was that a flexed lumbar spine and pelvis allows for a better grip on the pelvis and thereby a stable foundation for the orthosis. Currently more emphasis is placed on sagittal balance as well as on the asymmetry of the internal aspect of the brace. On the effected side (the left side for a lumbar curve) the lumbar pad acts to medially shift and de-rotate while a corresponding relief is built into the right side.

Active and Passive Correction

The patient is taught to actively pull away from the corrective pads while in the orthosis to enhance correction. Passive correction is a fundamental principle of any orthosis. The Boston Brace surface area is kept to a minimum to allow normal motion of the trunk and spine outside the area of treatment.

Pad Pressure at the Apex and Below

Mathematical modeling dictates that the pad pressure should be at the apex and below.[18] In the thoracic spine this means pressure in the mid-axillary line at the apical rib and below. When blueprinting the x-ray, pressure above the apex is transmitted to vertebrae that are angled in the opposite direction.

Team Approach

The team takes part in all aspects of the coordinated care of the patient.[15]

WILMINGTON BRACE

Fig 12

The Wilmington Brace (Fig 12) was developed by G. Dean MacEwen, M.D. in 1969 at the Alfred I. DuPont Institute with the intent to improve patient compliance by providing a less bulky and more lightweight TLSO when compared to a Milwaukee Brace, which is a Cervical Thoracolumbar Sacral Orthosis (CTLSO).[8, 19, 20] (The instruction manual is available on the SRS website at: SRS Bracing Manual Section Six.)

It is a total contact orthosis that is fabricated from a cast taken of the patient in the best-corrected position. This is accomplished with the patient in a supine position while longitudinal and transverse forces are applied with the patient is on a Risser table using, a head halter and a pelvic halter. An AP x-ray is then taken to confirm the curve reduction. Elongation of the spine with traction and a three-point pressure system in the coronal plane accomplishes correction.[21] The forces, on the convex side of both the lumbar and thoracic curves consist of medial and transverse (de-rotation) vectors at the apex of the curve(s). By pushing directly on the patient’s torso and shifting the segment that is lateral to midline towards the center line and rotating it to a neutral position the segments are held in a corrected position. If satisfied with the correction as seen on the x-ray, a custom-made TLSO is fabricated.

THE ROSENBERGER SCOLIOSIS ORTHOSIS

Richard Rosenberger developed his orthosis while at the University of Virginia.[22] (Fig 13) A bivalve impression is taken with the patient supine to capture an unloaded spine. While casting, a transvers force is applied on the apex of the curve with counter forces applied to both the contralateral pelvis and axilla. Unique to this style of bracing is the use of adjustable slings via moveable straps (thoracic/lumbar). A traditional lumbar pad shape is used and if a thoracic pad is needed it is placed to provide force at the rib corresponding to the apical vertebra and at least one rib below. The mechanism of action is elongation of the spine (traction) and medially and de-rotational force vectors acting on the convex side of the curves via additional padding added inside the orthosis at the level of the apex of the curve and below. The dynamic action of the thoracic pad is unique to this design. The thoracic pad is not static; a strap is positioned between the pad and internal section of the orthosis.[22] The concept is when the strap is tightened, the oblique vector (with a dorso-lateral to ventro-medial direction) will increase.[21]


Fig 13

CHARLESTON BENDING BRACE

The Charleston Bending Brace is a nighttime only scoliosis orthosis. Frederick Reed and Ralph Hooper developed it in 1979, for a patient who refused to wear a full time orthosis.[23] (Fig 14) The orthosis relies on overcorrecting the patient's curve and unloading the vertebral end plates on the concave side of the curve thus potentially reducing any asymmetric bone growth. Taking advantage of the Heuter-Volkmann Law that states that growth is retarded by increased mechanical compression and accelerated by reduced loading in comparison with normal values[24] to obtain this overcorrection, patients were originally casted supine while being maximally overcorrected (side bending). Today, a standing scan of the patient may be taken and the overcorrection achieved in a CAD system. The Charleston Bending Brace focuses mainly on the coronal plane deformity. The mechanism of action is a medially directed vector on the convex side of the curve, at the apex and below, that is coupled with a medially directed counter force on the concavity of the curve located above the apex to unbend the curve. Once the model is modified an anterior opening TLSO is fabricated. The King classification system is used to assist in the specific brace design.[25] Because of the over-correction, it is recommended the brace be worn only at nighttime (8 – 10 hours per day). The Charleston Manual can be found at: SRS Bracing Manual Section Seven.


Fig 14

PROVIDENCE BRACE SCOLIOSIS SYSTEM

The Providence Brace is another nighttime only scoliosis orthosis. It was developed in 1992 by Charles d'Amto and Barry McCoy at the Children's Hospital of Rhode Island.[26] (Fig 15) The Providence Brace Manual is available at: SRS Bracing Manual Section Eight.


Fig 15

Rather than overcorrect like the Charleston Bending Brace the Providence relies on medial and oblique vectors[21] applied at the apical areas to bring the curve toward midline. A lumbar pad provides the medial and de-rotational forces at the apex and below on the convex side of the lumbar curve. A trochanteric extension, always on the contralateral side of the lumbar pad serves as a counter force. If a thoraco-lumbar or thoracic curve exists, a thoracic pad provides an oblique vector.[21] This enhances the vector by rotation from of the upper section of the orthosis. An upper thoracic extension is used as a counter force on the concavity of the curve above the apex. Unlike other methods of casting or scanning of the patient, the Providence uses a polycarbonate measuring board containing a series of labeled horizontal and vertical holes (Fig 16). The patient is placed supine on the measuring board and both corrective and stabilizing pads are strategically placed and adjusted to obtain as neutral a position as possible. The orthosis is fabricated via CAD by combining both the patient's measurements and the positions (horizontal and vertical) of the corrective and stabilizing pad positions.


Fig 16

SPINECOR ORTHOSIS

The SpineCor orthosis is a dynamic tension based system developed by Charles Rivard and Christine Coilard at Saint-Justine Hospital in Montreal, Quebec (Fig 17).[27]

This orthosis is custom fitted and relies on active corrective movements, rather than passive correction, to prevent the curve from progressing. The corrective movement is thought to improve spinal alignment by influencing postural disorganization, unsynchronized spinal growth and muscular dysfunction that can lead, according to the brace developers, to spinal deformation.[8] The orthosis consists of a series of elastic straps and a bolero that attach to a flexible pelvic base. Originally thigh and crotch straps were used to stabilize the pelvic base, today shorts similar to spandex bike shorts are used. The fitting and adjusting techniques have proven not to be as easily repeatable as other systems. These difficuties are reported in the literature by two different comparative studies.

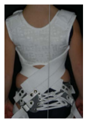
Fig 17

TRIAC BRACE

The TriaC is another tension based dynamic scoliosis orthosis. Its name comes from the three C's: comfort, control and cosmesis (Fig 18). This orthosis, developed by Albert G. Veldhuizen and Gert Nijenbanning, was reported in a prospective study by Gerben J. Bulthuis to be effective in preventing curve progression.[28] The orthosis is prefabricated and custom fit directly on the patient. It consists of two parts, lumbar and thoracic. They are connected via a flexible coupling. This flexible coupling acts as a cantilever that keeps the lumbar force and thoracic force pads in constant contact with the patient regardless of body position. The main mechanism of action for the lumbar part is a medially directed vector located on the convex side of the curve(s). The lumbar part is always located just superior to the iliac crest and is coupled with a counter force created by tightening a strap over the contralateral iliac fossa.[8,10] The thoracic part generates a resultant oblique vector directed dorso-lateral to ventro-medial direction.[21] It is located on the convex side at the apex. It is coupled with a higher thoracic pad located above the apex on the concave side of the thoracic curve. Very few reports in the literature exist on the TriaC orthosis. The orthosis has not been widely accepted. This may be due to fabrication and fitting challenges resulting from a lack of familiarity with the component materials.

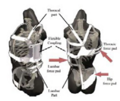
Fig 18

CHENEAU BRACE

The Cheneau-Toulouse-Monster (CMT) orthosis, more commonly known as the Cheneau brace, was developed by Jacques Cheneau in Toulouse France in the 1960's. It is a custom fabricated anterior opening thermoplastic TLSO that is made from a plaster impression and is fabricated asymmetrically. (Fig 19) The orthosis consists of multiple three point passive force mechanisms working in three dimensions to de-rotate the thorax and create an elongation and bending effect. Multiple oblique vectors in a dorso-lateral to ventro-medial direction located at the apex of the curve on the convex side are coupled with opposite oblique vectors to create force couplers.[21] To facilitate this type of convex to concave force transfer, there are large voids or open space areas opposite the pressure area. The active mechanisms include in theory asymmetrically guided respiratory movements of the rib cage, a repositioning of the spatial arrangement of the trunk muscles and an anti-gravitational effect.[8,29,30]

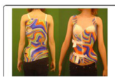
Fig 19

RIGO SYSTEM CHENEAU BRACE (RSCB)

The Rigo System Cheneau evolved from the original Cheneau orthosis. It too is an asymmetrical anterior opening custom made device (Fig 20). It provides a more systematic approach with the specific design of the orthosis guided by a classification system. This classification includes clinical and radiographic criteria (Fig 21).[31] SRS terminology is incorporated along with balance/imbalance at the transitional point and L4-5 counter-tilting.[31] The clinical criteria are used to describe four basic types: Type A – imbalanced thoracic; Type B – true double; Type C – balances thoracic and false double; and E type – single lumbar or thoracolumbar. The radiograph is then used to further refine the specific curve characteristics into nine sub-types.[31] The biomechanical principles include a three point pressure system in all planes. Lumbar and thoracic forces are incorporated into the design and are enhanced at times with additional pads. Vectors are located at the apex of the curve on the convex side providing a resultant oblique force in a dorso-lateral to ventro-medial direction.[21, 30] Counter forces are built into the model with void areas to allow movement. Emphasis is on the de-rotational aspect of curve correction. The sagittal profile is preserved and the posterior superior trim line is designed to help prevent the morphological thoracic flat back. This orthosis is custom made either by cast or scan; it is modified by hand or CAD.[8, 32] The classification system is crucial to the repeatability of this system.

Fig 20

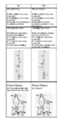
Fig 21

LYON BRACE

The Lyon Brace (http://www.scoliosisjournal.com/content/6/1/4) was first developed by Stagnara, Bouillat and Terrier in 1947.[33] The traditional Lyon protocol consists of the patient wearing a corrective plaster body cast for from one to four months, after which the brace is fabricated and fitted to the patient (Fig 22). Today the brace is fabricated from a plaster impression of the patient taken while the patient is supine on a Cotrel Frame (Fig 23). It is adjustable to accommodate growth up to seven centimeters. This anterior opening orthosis is symmetrical in design meaning there are intrinsic force couples in action to create multiple three-point pressure systems in all planes. The lumbar force is at the apex and below on the convex side of the curve creating a medially directed vector and is coupled with a void on the concave side to allow a truncal shift. The lower thoracic

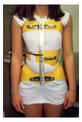
Fig 22


Fig 23

pad creates an oblique vector with a dorso-lateral to ventro-medial vector. This too is located at the apex of the curve on the convex side.[21] Today, the blueprint is based on the Lenke classification system (14 designs) and a specific physical therapy program is recommended for twice a week while the patient is in the cast and once a week while wearing the orthosis. Fabrication material made of Polymethacrylate is

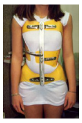
Fig 24

preferred due to its rigidity. The theory is that the stiffness of the plastic stimulates the patient to initiate an active axial auto correction decreasing the pressures from the areas of contact. Also since the plastic is transparent, pressures can be monitored and direct control of the force vectors and reliefs can be accomplished.[8, 33] The Lyon Brace has continued to improve with the progress of technology while adhering to fundamental biomechanical principles. The most recent advance of the Lyon is the Lyon ART brace. It was developed as a result of improved CADCAM technology. It uses the computer's ability to merge several postures that are described as segmental molding (Fig 24).

SFORZESCO BRACE

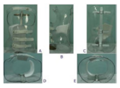
Fig 25

The Sforzesco brace, part of the Symmetric, Patient-oriented, Rigid, Three-dimensional, active (SpoRT) family of devices, was developed in 2004 by Stefano Negrini and Gianfranco Marchini in Milan, Italy.[34] (Fig 25) The full description of this orthosis is available as part of the Brace technology thematic series at: http://www.scoliosisjournal.com/content/6/1/8 .

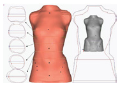
Fig 26

The orthosis, named in honor of the medieval Sforza family, was developed as a way to avoid casting the most challenging presentations. It is a custom made from a cast or scan externally symmetrical (internally asymmetric) anterior opening orthosis. Intrinsic force couplers exist due to the symmetrical design that acts to achieve balance. The lumbar and thoracic forces provide de-rotational and medially directed vectors that are located at the apex and below on the convex side of the curve. The orthosis is unlined with lumbar and thoracic pads added to create and enhance force vectors. Relief is built into the design; there are no open areas of relief present in many other systems.[8, 34] The orthosis consists of two pieces of polycarbonate material connected posteriorly with a single aluminum bar (Fig 26).[34]

DYNAMIC DEROTATION BRACE (DDB)

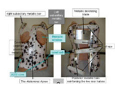
Fig 27

The dynamic derotation brace, designed in Greece in 1982, is custom-made from a standing cast or scan modification of the Boston Brace (Fig 27). The full description is available at: http://www.scoliosisjournal.com/content/5/1/20.[35] The biomechanics and mechanism of action is equal to the Boston Brace System. The unique feature is the addition of aluminum blades set to produce de-rotation and anti-rotation effects on the thorax. The de-rotation blades are attached to the posterior side of the orthosis and become active when the nonattached portion is placed below the opposite side. The de-rotation is accomplished though the continuous application of corrective forces at the pressure areas.[8] By altering the angle of the blade the direction of action can be modified. This orthosis is included here due to its unique features.

PROGRESSIVE ACTION SHORT BRACE (PASB)


Fig 28

The Progressive Action Short Brace (PASB) was developed in 1976 by Lorenzo Aulisa at the Institute of Orthopedics at the Catholic University of the Sacred Heart in Rome, Italy (Fig 28).[8,36] The full description of the brace is available at: http://www.scoliosisjournal.com/content/7/1/6. It is indicated for the non-operative treatment of lumbar and thoraco-lumbar scoliosis. It is a custom -made from a plaster cast and is an anterior externally symmetrical internally asymmetrical orthosis. The mechanism of action occurs during the casting procedure. The patient is placed in slight traction, while an oblique dorso-lateral to ventro-medial directed force at the apex of the curve on the convex side is applied to the patient.

CONCLUSION


Fig 29

There is no shortage of orthotic designs and concepts as are evident by the series of devices listed and described here. Many of the systems were developed in an attempt to improve adherence to specific orthosis wearing protocols. Various monitoring devices are now available that use temperature, pressure or a combination of both to provide objective data showing the actual hours of orthosis wear.[13, 14, 37, 38, 39] Computer programs are available that produce patient friendly reports (Fig 29) that can be reviewed with the patient and family. They are tools that when used in a positive way can celebrate success and work with the patients that are having a difficult time meeting set goals. By having objective information, creative solutions can be developed specific to the patient's needs.

One author describes scoliosis[40] in 4 dimensions rather than three. The fourth being time. The SRS and SOSORT are now recommending that all future studies on scoliosis involve a monitoring system that will record wearing time and this needs to be reoprted.[41] Additionally orthotic system reports must meet SRS standards of proven progression and indication guidelines before instituting treatment.

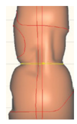
Fig 30

Computer Aided Design, Computer Aided Manufacturing (CADCAM) is becoming more commonplace in the orthotic prosthetic profession. Improvement in software and shape capturing devices (hand held laser and or white light scanners or stationary scanner) allow the orthotist to capture the patient's quickly rather than having to use a plaster cast impression. The CADCAM software allows for the x-ray to be imbedded or superimposed into the scan so modifications can be made directly to the CAD patient model (Fig 9). Overall balance, translation, derotation and forces can be built into the model. Specific trim lines can also be added (Fig 30).[42]

Simulation software is currently being developed that will allow the clinical team to see the results of the recommended brace design prior to fabrication.[8, 42] By combining the patients anterior-posterior and lateral x-ray with their scan the software creates a virtual patient. The orthotist then designs the orthosis according to the patient's presentation and orthotic principles. Trim lines and strap placement are added to establish force vectors. The simulation software then conducts a virtual fit. Predicted in brace results along with a report showing skin pressure and brace installation can be determined. If changes need to be made, to reduce pressure areas, improve balance or correction, they can be done prior to fitting the orthosis and having to wait six to eight weeks to determine areas of pressure and overall alignment. Once approved, the model is sent to the foam-carving machine and the fabrication proceedes.[42] Figure 31 depicts the process by which we can create a virtual patient and simulate the fitting of a virtual orthosis. Making the patient part of the process from the beginning may enhance their experience and encourage them to adhere to the program.

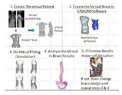

Fig 31

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13

Measurement, Fabrication and Fitting Principles

Man-sang Wong

The knowledge and understanding of scoliosis is an important prerequisite for orthotic treatment and is necessary for appropriate prescription, design selection, and principles of force application. It is also the precursor to treatment implementation where concepts are applied and put into practice. Proper implementation is critical to the success of the treatment plan and includes data acquisition and fabrication. The former is accomplished through measurements, conventional casting (impression of the patient's torso) or scanning of the torso using laser or white light technology. The latter is the actual making and material selection of and for the orthosis. When fabrication is completed the orthosis is fit to the patient and the trimlines, overall balance and proper position of force application/relief on the scoliosis curve are assessed. This chapter will discuss the principles of measurement, fabrication and fitting of Cervico-Thoraco-Lumbo-Sacral Orthosis (CTLSO) and Thoraco-Lumbo-Sacral Orthosis (TLSO) for adolescent idiopathic scoliosis.

ORTHOTIC TREATMENT FOR SPINAL DEFORMITIES

Scoliosis is a three-dimensional spinal deformity and the cause of most scoliotic curves is unknown (idiopathic). Rogala et al.[1] pointed out that idiopathic scoliosis can produce a truncal deformity, which might progress throughout the rapid growth period of adolescence. In a child with a progressive spinal deformity, if the curvature is detected early in adolescence while it is still of moderate magnitude, progression may be halted non-surgically with the use of a rigid spinal orthosis. Rigid spinal orthoses have been demonstrated to be effective for the majority of cases of moderate adolescent idiopathic scoliosis, providing that treatment is begun early enough and the orthosis is worn compliantly, i.e., wearing the orthosis 23 hours a day and under properly applied controlling forces.[2-10] The orthoses have an accepted place in the treatment of scoliosis. To obtain effective treatment, orthotists need to fabricate spinal orthoses that provide an effective in-orthosis correction (within the patients' acceptable tolerance) that can be achieved when pressure pads are applied at proper pressure magnitudes, locations and directions.

TYPES OF SPINAL ORTHOSES

Two types of orthoses are typically used in the treatment of idiopathic scoliosis; the CTLSO and TLSO. The CTLSO, has been prescribed for over 70 years and is considered the gold standard of treatment for idiopathic scoliosis. Due to its design, it has been shown to be the most effective orthosis for management of thoracic curves and is less restrictive around the chest and has more ventilation than other orthoses. There are, however, issues with patient acceptance and compliance do to the aesthetic appearance and inability to hide the neck ring component under clothing. With exception to the higher thoracic curves and corresponding componentry used to address the specific deformity, the force application and components used to address thoracic, thoracolumbar and lumbar curves are similar to what is used in the lower profile TLSO. Since this orthosis does not include a cervical component it is sometimes referred to as an “underarm or low-profile” orthosis. Despite the variety of TLSO designs that exist today, many of the bio-mechanical principles and design features are the same. For both designs it is necessary for the orthotist to obtain the appropriate measurements, cast or scan and to be able to convert or use this information to fabricate an orthosis that will effectively manage deformity and overall balance.

MEASUREMENT OF SPINAL ORTHOSES

The practice of taking measurements for CTLSO and TLSO designs is an important first step in the success of orthotic fabrication. The orthotists toolkit should include, but is not limited to:

- Tape measure
- Medial-lateral measurement gauge (M-L gauge)
- Angle finder
- Goniometer

The tape measure can be used for length and circumference measurements while the M-L gauge is effective for diameter measurements primarily taken in the coronal plane. The angle finder is useful for quantifying sacral tilt and the goniometer can be used to measure lordosis and kyphosis. The acquisition of measurements is beneficial and assists in the following manner:

- Confirm design and component location (e.g. pads, windows, extensions, trimlines, etc.)
- Guidance in the modification of the positive cast
- Removal of plaster material (changes to volume, force application)
- Addition of plaster material (build-up of bony prominences)
- Proper alignment of lordosis and kyphosis

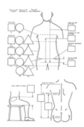
Fig 1

Many forms exist today (Fig. 1) for recording measurements and it is the responsibility of the orthotist to determine which is most useful. Forms with limited information are likely to raise additional questions while exhaustive forms with an abundance of information become overly burdensome and may be useless. At a minimum, circumferences and coronal diameters should be taken at the anatomical levels of the greater trochanter/pubic symphysis, ASIS, waist, xiphoid, axilla and neck (CTLSO). Linear measurements help to determine the overall length of the orthosis and should include:

- Pubic symphysis to waist
- Waist to Xiphoid to sternal notch
- Greater trochanter to waist to axilla
- Sacrococcygeal (SC) junction to waist to inferior angle of the scapula to spine of the scapula

- Xiphoid to the mandible (CTLSO)

CASTING METHOD

Apart from taking physical measurements of the trunk and corresponding body landmarks, the casting method plays an important role in capturing the three-dimensional anatomy and spinal deformity of the patient. In the body casting procedure, appropriate manipulation is required to give preliminary control of the deformity. A variety of casting methods exists around the world and may include different steps or a sequence of steps performed in a different order. Regardless of the casting method, the overall process is much the same and results in the acquisition of a three-dimensional cast of the patient. Described below is the casting method used for a CTLSO and the specific steps taken to acquire the cast:

1. Place two layers of stockinette onto the patient's body;
2. Locate a profile (rubber tube/ string) on the anterior aspect of the patient's body and in between the two layers of the stockinet for cast cutting and removal at the later stage;
3. Lead the patient to the casting horizontal bar, teaching him/her the proper position for casting with the anterior pelvic tilt which can reduce the lumbar lordosis, arms resting on the horizontal bar;
4. Use an indelible pencil to mark the bony prominences by palpation; e.g. ASISs, PSISs, pubis symphysis, xyphoid process; curve apex and other bond landmarks or pressure points;
5. Measure and record the dimensions between both ASISs;
6. Mark the reference point over the apex of the curve, xyphoid & inferior spine of the scapulae;
7. Wrap 5 layers of plaster bandage (15 cm width) from gluteal fold upwards to the level just below the flowing ribs (Fig 2);

Fig 2

8. Prepare plaster strips (8 cm x 6 layers rolled into a rope) for pulling forward from behind just above iliac crest and then straight down medially between both ASISs. First on the side of the convexity of the lumbar curve then on the opposite side (for making an indentation for pelvic griping purpose);
9. Hold the rope until the bandages become hard;
10. Continue to apply bandages to the higher region up to scapulae level or higher depending on the level of curvature;
11. Apply lateral three-point pressure at the lumbar curve apex or the corresponding rib of thoracic curve apex and at the regions above and below (creation of counteracting pressure) for deformity control, and wait until the plaster has cured and the cast become rigid;
12. Mark vertical reference points (3 points) outside of the cast shell posteriorly & laterally using a plumb-line as reference;
13. Insert wire saw into the profile and use the locking pliers grip the ends of the wire saw and break both ends of the profile and the plaster next to the tube before opening the cast or use a plaster cutter to cut the plaster;
14. Remove the negative cast carefully;

Teach the patient to remove the inner layer of stockinette and clean his/her body with warm water and towel.

CAST RECTIFICATION

The process of cast rectification begins with the removal of the negative cast from the patient and ends with modification of a positive cast of the patient's torso in order to fabricate an orthosis that is customized to that same patient. Similar to the casting method this is one of many ways to rectify the cast. The steps for cast rectification include:

1. After removing the negative cast, reinforce the landmarks on the inner surface of the cast with an indelible pencil to ensure they will appear on the surface of the positive cast;
2. The opening of the negative cast is sealed with plaster bandages, and the bottom is closed on to the horizontal table. Triangular wooden blocks will be used to block up the negative cast until the reference lines are vertical (markings from the plumb-line) (Fig 3);

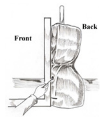

Fig 3

3. Put plaster strips (4 layers) to the base of the negative cast to seal the end, and to put nearly set plaster strips at the bases of the negative cast for reinforcing purpose (prevention of liquid plaster leakage in cast filling);
4. Fill with plaster;
5. Insert a mandrel with flatten lower end before the liquid plaster sets;
6. Strip off the negative cast, redraw all landmarks again on the surface of the positive cast;
7. Use a try square to draw a vertical line on both sides extending from ASISs to distal edge of the cast BB;

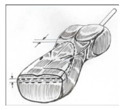
Fig 4

8. Lay the cast down; use the triangular wooden wedge block to position both ASISs in horizontal position;
9. Draw a bottom line match up the vertical line with level markers or spirit level gauge;

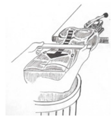
Fig 5

10. Draw a parallel line above the bottom line (12-15mm for lean patient), (15-25mm for obese patient) to indicate the outline to propose the intra-abdominal pressure area (from below xiphoid 12-15mm, ASISs to the bottom line of the cast) (Figs 4 & 5);
11. Use a surform file or wooden chisel to remove the excess plaster anteriorly from the costal margin downward (no matter how far the abdomen protrudes, the depth of cut should not be below the ASISs) (Figs 5 & 6);

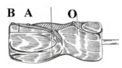
Fig 6

12. Erect a vertical midline perpendicular to the line between the ASISs after flattening the apron (it is parallel to the plumb-line but may not be on the same line if the patient has listing);
13. Cut the plaster away through the waistline to just the depth that will provide a symmetric & comfortable fit on the soft tissues over the iliac crests (it must not be exaggerated on one side as compared to the other side);


Fig 7

14. Prone the cast over to the posterior side and build up for reduction of lumbar lordosis (Fig 7);
15. Remove the plaster away below the apical vertebrae according to the corresponding ribs;
16. Build up the cast the same amount as removed on the opposite side;


Fig 8

17. Remove the plaster away below the axilla to recreate a three-point pressure system (Fig 8);
18. Draw the trimlines after smoothing out the texture of cast – the anterior-distal line starts from the pubic symphysis and then extend laterally along the inguinal folds (making butterfly shape) then projected

and extend laterally and posteriorly to buttock where it permits a 4cm clearance while sitting at 900. Antero-proximally the line starts from the mid-line about 12mm below the jugular notch then extends laterally to the axillary level, then going upward to the scapula level. A thoracic opening is required for chest expansion and an apron is made at the base of the opening for applying pressure to the abdomen. Posteriorly a 25mm opening at the midline of brace is required. An opening will sometimes be made postero-laterally opposite to the convexity of the curve for allowing spinal migration in the correcting process.

Upon completion of the cast modification for the CTLSO the next steps required to complete the overall fabrication of the CTLSO includes the attachment of the pelvic interface to a single anterior bar and two posterior paraspinal bars. The three bars connect superiorly to a neck ring and attached to the bars are various components to address the scoliosis. A comprehensive description of the steps for fabricating the CTLSO is beyond the scope of this chapter, but can be found by clicking on the following link: http://www.oandplibrary.org/

FABRICATION OF A TLSO

Once the cast rectification process is complete the orthotist should now have a finished positive mold/cast of the patient's torso that is in the desired alignment with the appropriate build-ups for bony prominences. Once this is complete, the fabrication of the orthosis can begin. Below is one method that can be used for the fabrication of a TLSO. The steps include:

1. Fix two plastazote paddings (12mm in thickness) from iliac crest to ASISs onto the cast;
2. Put a layer of stockinet (25cm width) onto the cast;
3. Cut and heat a sheet of high temperature thermoplastics that best fulfills the orthotic prescription. For this case, polyethylene (5mm in thickness) of appropriate size according to the trim line of the cast to 1800 C for 20 minutes (polyethylene putting on a layer of stockinette, which stretch and fixed on to a plywood board of about 4mm in thickness);
4. Place the heated polyethylene together with the stockinet and plywood onto the cast (the soften polyethylene is needed to be supported by the stockinet - preventing the elongation of soften polyethylene;
5. Nail one end of the polyethylene sheet to the plaster cast at the marked posterior opening;
6. Wrap the polyethylene sheet around the cast and then use a rope with a 5cm in diameter to wipe the areas just above the iliac crests;
7. Nail the other end of the sheet to the cast and cut the excessive materials;
8. Use elastic bandages to wrap onto the plaster sheet in total conformability with the cast till cooling to room temperature;
9. Take off the TLSO from the cast and cut according to the set trimline;
10. Fasten the 3-4 straps onto the TLSO for trial fitting (Fig 9).

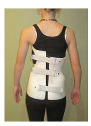
Fig 9

TLSO Fitting

The final step in this process is the actual fitting of the orthosis to the patient. During this stage it is important to establish clear expectations for both the patient and their family. The sequence of steps for the fitting process include:

1. Put the TLSO onto the patient's body and tighten the straps;
2. Adjust the trimline of the TLSO if necessary;
3. Use a plumb-line to assess whether the trunk listing has been corrected;
4. Remove the orthosis after 10-20 minutes to assess the skin and determine if force application from the orthosis is in the appropriate location;
5. Mark the straps so family knows how much to tighten the orthosis;
6. Drill holes for better ventilation after confirmation of proper fitting (after 2-3 weeks of adaptation period and with X-ray confirmation);

Precaution in Fitting

- The pressure applied to control the curve should be adequate and tolerable.
- Antero-inferior trimline of the orthosis should allow the patient to have 85° of hip flexion.
- Anterior thoracic opening should be adequate to allow the patient to take a deep breath and avoid excessive pressure on female patients' breasts.
- The orthosis should be washed with mild soap and cold water daily.
- An undergarment should be worn for better ventilation and wicking of perspiration.
- The orthosis should be worn the prescribed amount.
- The straps are tightened in a specific order. Waist strap first, then the lower strap, then the upper one with loosening and reapplying the middle strap with no pressure. The posterior opening should be equal with parallel edges.

SUMMARY

The knowledge and understanding of scoliosis is essential and fundamental to anyone that is treating or managing patients with scoliosis. This will only go so far if, in this case, the orthotist is unable to appropriately transfer and implement this into a workable treatment plan. Measurements, casting method, fabrication and fitting of an orthosis will likely determine how effective the orthosis will be at addressing the deformity. Finally, as dosage (daily wearing time in the orthosis) has become a primary factor in changing the natural history of scoliosis the comfort and fit may play an even bigger role in compliance and subsequent success in managing scoliosis. It is therefore important to consider the implications of data acquisition, fabrication and fitting as a means to comfort and compliance when using a CTLSO or TLSO.

CAD/CAM METHOD

The clinical practice of the orthotic treatment for AIS as described above has some drawbacks. Issues arise with conventional manufacturing of spinal orthoses such as measurements and casting of the patient. Furthermore, cast rectification can be time consuming, result in high plaster consumption and result in relatively low accuracy and no data storage for future references.[11-20] The use of CAD/CAM in spinal orthotics is a reasonable alternative to conventional practices and results in time savings and standardization of the fabrication process. This can lead to improvements in accuracy and allow P&O professionals to spend more time on patient interactions such as education, training and counseling. A CAD/CAM system generally consists of 3 units. The first unit is a digitizer/scanner that converts the 3-dimensional information of the body or limbs (positive or negative cast) into the data file in digital format. The second unit is the computer station that is used to receive a file, manipulate the image on the screen and allow P&O professionals to design using a mouse to click and/or input data. The third unit is the mill (carver) which receives a rectified file from the computer station and reproduces a 3-dimensional foam/plaster model in which the contour in according to the directives of the rectified file.

Acquisition of CAD/CAM can be an expensive endeavor and should be investigated to determine what system will best meet the needs of the orthotic/prosthetic facility. In some cases, the purchase of the scanner alone is the most affordable pathway. In this scenario the orthotist will scan the patient's torso, but will send the data to an outside facility that has a carver in order rectify a 3-D model for fabrication of the orthosis. For some, having the entire CAD/CAM (scanner and carver) operation on site offers a better and more efficient solution.

<u>Assessment of AIS and Fitting of Spinal Orthosis using 3D Clinical Ultrasound</u>

AIS is described as structural deformity with lateral curvature and vertebral rotation of the spine that happens in adolescence with unknown causes. The most commonly used parameter to measure scoliotic curvature is the Cobb angle. Spinous process angle (SPA), which is another parameter proposed to assess scoliotic curvature, is described as the accumulating angle formed by every two lines joining three neighboring spinous processes of a scoliotic spine.[21,22] Some corresponding studies[23,24] were conducted and a high correlation between the Cobb angle and SPA was obtained from both the pre-brace and in-brace stages.

In routine clinical practice, the blueprint of orthotic treatment prescribed for patients with AIS is mainly based on the patient's Cobb angle, vertebral rotation and curve pattern. The Cobb angle measured from the radiographs that are usually obtained at the pre-brace stage and regular clinical follow-up with a 4-month interval. However, no radiograph is usually taken in the fitting process of a spinal orthosis in consideration of radiation exposure. Although radiography is a standard way to diagnose and evaluate curve progression, over a lifetime of having radiographs, a scoliosis patient can be cumulatively exposed to high doses of ionizing radiation.[25] In particular, radiography exposes sensitive breast tissues to ionizing radiation. Females comprise about 80% of cases followed for scoliosis. The breast cancer rate has been reported higher in females who have been followed for scoliosis.[26]

In the conventional fitting method of a spinal orthosis, trunk listing is generally used as an indicator to check whether the orthosis is alleviating or worsening the deformity in the fitting process. However, there is no evidence for a direct relationship between the trunk listing and the spinal curvature. Moreover, to what extent the deformities can be controlled during the orthosis fitting is far from known with the existing arrangements and practice.

Many researchers demonstrated the possibility of using ultrasound to detect the spinous processes.[27-30] Some studies[31-34] investigated the possibility of using 3D clinical ultrasound (CUS) in the assessment and fitting of spinal orthosis. Li et al.[35] tried to improve the effectiveness of orthotic treatment for the patients with AIS using the 3D CUS method in which the optimal location of the pressure pad of the spinal orthosis was determined with the assistance of ultrasound image analysis. By means of a 3D CUS method, the spinous process angle (SPA) could be traced and used as a clinical parameter to estimate the Cobb angle in order to determine the location of pressure pad. The 3D CUS could be considered as an effective, non-invasive and fast assessment method to scoliosis, especially for enhancing the effectiveness of orthotic treatment. Its applications could also be further extended to other spinal deformities, however no studies have shown the use of CUS in following orthotic management for scoliosis.

P&O professionals will practice in a more effective and efficient way with the support of the advanced technology. They should focus more on the client interface, outcome evaluations and team approach treatment with evidence-based practices. The demand from clients is growing and P&O professionals should well prepare themselves to have a critical thinking and problem-solving skills to face those challenging clinical problems.

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Orthotic Management of Infantile Idiopathic Scoliosis

Tom F Novacheck

DEFINITION

Infantile idiopathic scoliosis (IIS) is defined as scoliosis that is first diagnosed between birth and 3 years of age with no apparent cause. It fits within the spectrum of early onset scoliosis (EOS). The term scoliosis is derived from the Greek word skolios ("twisted") and refers to a sideward (right or left) curve in the spine. Scoliosis is not a simple curve to one side but, in fact, is a more complex, three dimensional deformity.

Harrenstein coined the term IIS in the 1930's.[1] He related it to rickets, stating that the curve responded well to bracing. In 1951, in his preliminary report on IIS, James described the cases of 33 infants three years of age or less with a structural left thoracic curve with no apparent etiology.[2] Most were boys. He noted resolution of the scoliosis occasionally, but when it did progress it tended to progress to a very serious deformity.

Increased understanding of the interrelationship between rapid spinal growth, development of chest wall deformity, and pulmonary development prior to the age of five or six has led to the increased use and popularity of the EOS terminology. By definition, idiopathic scoliosis occurs in the absence of a known cause such as a neuromuscular diagnosis, spinal canal anomalies, congenital malformation, post-traumatic, and infections. The diagnosis of IIS is therefore a diagnosis of exclusion made based on physical examination findings of trunk or shoulder asymmetry and x-rays. Unlike adolescent idiopathic scoliosis, there is a greater preponderance of convex left curves. A 2013 study of two spinal deformity centers in Great Britain reported a rate of 11.1 % neural axis abnormalities (two syrinxes, one Arnold-Chiari Type I malformation, and five combined Arnold-Chiari malformation Type I and syrinx).[3] Similar rates of neural axis abnormality, as determined by magnetic resonance imaging (MRI), are found in reviews by Pahys et al. (13%) and Martin et al. (16%).[4,5] Clearly, an MRI scan of the central neural axis is necessary to confirm the diagnosis and rule out other pathologies (e.g. neural axis or congenital vertebral anomalies). The question of when to do the MRI was addressed by Martin, et al.[5] Because the need for neurosurgical intervention was relatively low in their series (28%), they recommended that for younger patients with small curves (<30°) who do not require orthopedic treatment, MRI under sedation can be delayed or avoided altogether if the child's spinal development is satisfactory with time and subsequent growth. Other investigators concur with this recommendation.[4,6] Clinical judgment (e.g. younger, smaller Cobb angles, and not requiring orthopedic treatment) can be exercised and MRI delayed when evaluating and treating patients with presumed IIS.

Two theories of the etiology have been proposed, but are unproven. Thus, this remains an idiopathic condition by definition. The first theory is intra-uterine molding, which postulates that spinal alignment is compromised in utero and that by the time of birth the spine is bent and could worsen with growth. The second, a postnatal theory suggests that placing the infant on his/her back will lead to flattening of the skull and scoliosis. Genetic causes have been suggested but remain unproven. This last theory is of interest because incidence studies suggest that more progressive curves occur in Europe than in the United States.

INCIDENCE

Infantile idiopathic scoliosis comprises about 1% of all idiopathic scoliosis in children. The proportion of males is much higher than for adolescent onset scoliosis, and is as much as 60% males.

CLASSIFICATION

Infantile Idiopathic Scoliosis has two forms: progressive and resolving. Most cases resolve spontaneously, but the reported rates vary widely, ranging from 12% to 92%. Spontaneous resolution is more likely in scoliosis that presents during the first few years of life than in scoliosis with a later presentation. Left untreated, the prognosis for patients with curves that progress is invariably poor. Differentiating between these two forms is therefore critical.

Radiographic predictors identified by Mehta can help the provider distinguish progressive from resolving curves.[7] These predictors consist of a Cobb angle of < 20°, a rib-vertebra angle difference (RVAD) < 20°, and a phase 2 rib/vertebra relationship. The rib vertebra angle is measured at the apical thoracic vertebra and is the angle between it and its rib on both sides (Fig 1). It is the angle between a line drawn from the mid-point of the neck of the rib to the mid-point of the rib head and a line drawn perpendicular to the upper or lower border of the vertebral body. Once the rib-vertebra angle is measured for both ribs, the RVAD can be calculated as the difference between the two. The larger the difference that exists between the angles, the poorer is the prognosis. Mehta found that approximately 80% of curves with an initial RVAD > 20° were progressive.[7] Infantile curves that reach 30 degrees tend to continue to worsen without treatment.


Fig 1

The phase classification is the relationship between the apical rib head and the corresponding vertebral body. When a rib head is in phase 1, the apical rib head on the convex side does not overlap the apical vertebral body on an anterior-posterior (AP) radiograph. In phase 2, the apical rib head on the convex side overlaps the upper corner of the apical vertebra (Fig 1). This finding indicates a severe rotational component. Mehta found that all curves with ribs in phase 2 progressed. Others have subsequently verified both of Mehta's findings. In borderline cases, Mehta recommended observing the curve for 3 months; if the RVAD improved, the curve was likely resolving even if the Cobb angle increased (Fig 2).


Fig 2

NATURAL HISTORY

James noted that the earlier the onset, the worse the final curvature and, hence, the prognosis.[2] The accuracy of his observation is well recognized in clinical practice and in the literature, as infantile and juvenile progressive curves are among the most challenging problems in spinal deformity care. The most serious implication of these spinal deformities is the effect on lung development and the subsequent impact on life span.

Since almost 90% of infantile curves in the U.S. resolve spontaneously, observation is usually the first method of treatment for a young child with this spinal deformity. Some children will have a curvature of their spine that is stable and unchanging, whereas other children will have a curve that demonstrates relentless progression. Monitoring the child every four to six months radiographically will determine whether the child's curve can continue to be observed (i.e. no progression or spontaneous improvement). A twenty-five year follow up study has demonstrated a normal quality of life in patients with non-progressive IIS.[6] If a patient has a progressive curve, a different form of treatment will need to be instituted. Serial casting can be used initially to partially correct the deformity and is a necessary precursor to augment orthotic management. A cast can be thought of, as full-time bracing. Both providers and parents prefer sometimes casting because it eliminates the issues of compliance and the difficulties of donning orthoses in young children who may not be cooperative. Some investigators recommend serial casting as the definitive method of management.[8,9] The initiation of early serial casting treatment (prior to 18 months of age) for infants who have smaller curve magnitudes (< 50°) is more successful and often leads to long-term sustained correction.[10] In some cases, scoliosis resolves as a result of casting in children under two years of age. Patients starting treatment at 18 months or later and with larger curves demonstrate less correction, however their deformities can be maintained with minimal or no progression. Typically, the serial cast changes are performed under anesthesia every two to three months with a minimum of five casts. Orthotic management is needed after casting is completed. Older children demonstrating "recurrence" can be re-casted for a few months followed by resumption of orthotic management. Casting can also be used to delay surgical intervention.[11] The technique of Mehta's derotational casting has been well described.[7,13]

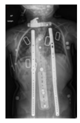

Fig 3

An operation is sometimes necessary to address spinal deformity in the young child (Fig 3). The decision to proceed with surgery is based primarily on progression despite bracing or casting or a very large curve at presentation that is not amenable to non-operative management. The goal is to stop the progression of the curve while promoting future growth of the chest and spine. Spinal fusion at young ages should be avoided if at all possible, as it stops spinal growth and is associated with decreased pulmonary function and lower quality of life.[14,15,16] Expandable surgical instrumentation systems have been developed in an attempt to restore spinal alignment while permitting spine and chest growth. Single or dual growing rods are inserted under the skin and attached to the spine above and below the curve. The child returns about every six months for an outpatient procedure to have the rods lengthened by approximately one centimeter to keep pace with and allow growth. Recently, magnetically driven automatic distraction systems, Phenix (France, trademark of Arnaud Soubeiran, PhD) and MAGEC (Magnetic Expansion Control System, Ellipse Technologies, Inc., Irvine, CA), have been developed and avoid the need for repeated trips to the operating room for manual lengthening. Surgeries without fusion, including growing rods and the vertical expandable prosthetic titanium rib (VEPTR), are currently the mainstay of treatment. Halo-femoral or halo-gravity traction may be used as an adjunct to spinal surgery prior to implantation of growth rods or spinal fusion to improve flexibility for severe curves.[17]

It cannot be emphasized enough that the focus of management for IIS is not only to maintain spinal alignment, as in older patients, but also limit deformity to better insure normal growth, development and respiratory function. This is dependent on three factors: alveolar development, chest growth, and spinal growth. Alveolar multiplication is essentially completed by five to six years of age.[18,19] Remaining lung volume development occurs in later childhood and is a result of alveolar growth (hypertrophy) rather then alveolar multiplication. Thoracic volume is only about one third of the normal adult volume at six years of age and at age ten, is 55% complete.[20] The thoracic spine grows 1.4 cm per year until the age of five years.[21] The length of the spinal column (T1-S1) increases most dramatically in the first 5 years of life (2.2 cm/year), is slower during the next 5 years (1 cm/year), and increases again at onset of puberty (1.8 cm/year). Achieving a T1-T12 length of at least 18 cm at maturity is associated with better pulmonary function. Thoracic insufficiency syndrome (TIS) occurs if thoracic development and lung growth is inadequate to support normal respiration. In this case long term outcome and focus of treatment shifts from the spine alone to the spine, chest wall, and lungs. If the spine and chest wall are not developing and growing well, then treatment is required with the goals of a well-aligned spine and a thoracic cavity sufficiently developed to support adequate pulmonary development and function.

ROLE OF ORTHOTIC TREATMENT

A recent review by the Growing Spine Committee of the Scoliosis Research Society stated that "bracing does not appear to be effective in the management of EOS, and the role of bracing is limited to post-casting or postsurgical maintenance of correction".[22] However, in the case of a non-resolving curve, orthotic management may be considered to maintain the results of casting or slow the inevitable progression of scoliosis.[23] In these circumstances, orthotic management can allow the child to attain sufficient growth before definitive surgery is performed. Orthoses are to be worn full-time and removed only for bathing and hygiene. Bracing can be performed after cast treatment to maintain the results of casting. Postoperative bracing indications vary but may be recommended if either bone quality is poor or compliance with postoperative restrictions is a concern.

Indications for bracing in IIS are essentially restricted to bracing after serial cast treatment, infants who do not tolerate casting, those with co-morbidities (e.g. gastro-esophageal reflux, severe eczema, or severe sleep apnea), or if casting is simply not available. Full-time orthotic treatment of progressive or persistent IIS may then be appropriate. If this treatment is undertaken in infancy, great care should be taken to not apply pressure over the thorax, except as a part of a derotation maneuver and to allow adequate room for expansion of the thorax.

If scoliosis is progressing and/or proving difficult to manage, and if advanced imaging has not been done to rule out syringomyelia, Chiari malformation, or a tethered spinal cord, imaging should be considered along with the orthotic or cast treatment. Surgical treatment of the Chiari malformation, syringomyelia, or tethered cord often results in improvement in the associated spinal deformity if performed early enough prior to the development of a secondary structural spinal deformity. A trial of observation following treatment of the neuraxis abnormality is therefore appropriate.[23] If the excessive kyphosis or scoliosis greater than 20° persists, treatment of the spinal deformity is indicated.

Contraindications to bracing include some curve location, large curves, associated thoracic lordosis, advanced chest deformity, and some medical and psychological conditions. Significant chest deformity often accompanies more severe curves and may be a contraindication to bracing. Continued orthotic treatment may worsen the chest deformity while seemingly stabilizing the spine deformity. The more severe the chest wall deformity, the more likely the patient will present, at the end of surgical treatment, with a functionally significant thoracic deformity and increased risk of respiratory insufficiency as an adult. Some associated medical conditions are also contraindications to bracing:

- Severe gastro-esophageal reflux may be exacerbated by abdominal pressure from an ortho sis
- Failure to thrive or anorexia nervosa may be aggravated by a constrictive orthosis
- Severe asthma (in particular periods of exacerbation)
- Difficulties with temperature regulation
- Severe eczema or other skin conditions

Other issues to consider include:

- Warm climates
- Adverse psychological reactions
- Family ambivalence
- Limited medical team experience with orthotic management

Deciding when to switch to surgical treatment from orthotic management is a challenging question. A large thoracic curve stabilized by an orthosis, with minimal chest deformity may continue to be managed orthotically in anticipation of eventual definitive fusion. In contrast, if a moderate thoracic curve is associated with a severe or progressive chest deformity, orthotic treatment should be abandoned in favor of growing rods, or if old enough, definitive fusion. Orthotic treatment should be stopped and surgical treatment instituted before chest deformity becomes irrevocable or severe. A web-based survey of the members of the Pediatric Orthopaedic Society of North America showed that non-operative management was the preferred treatment option in the very young (e.g. 2 year-old). Conversely, two-thirds of surgeons would recommend initial surgical management of a 5-year-old child with a large idiopathic curve.[24]

DISEASE SPECIFIC ASPECTS

Spinal deformity surgeons have less agreement as to the best way to treat infantile or early-onset scoliosis than scoliosis of later onset. As described above the options are many including bracing, casting, halo-gravity traction, fusionless spine techniques, definitive fusion, and chest wall devices. Current techniques of casting (advocated by Mehta and Dubousset) and the use of halo-gravity traction for the more severe cases have regained popularity and play an important role in the treatment of challenging cases.[12] In a review of fifty-five patients with progressive IIS, Sanders et al. found that all but 6 patients responded to serial cast correction using the Cotrel derotation technique.[8] Children with IIS respond better than those with a non-idiopathic diagnosis. Initiation of cast treatment at a younger age and a moderate curve size (<60 degrees) had a better prognosis. Serial cast treatment for infantile scoliosis often results in full correction in infants with idiopathic curves less than 60 degrees if started before 20 months of age. Cast correction for older patients with larger curves or a non-idiopathic diagnosis may frequently result in curve improvement along with improvement in chest and body shape. In many cases, bracing will not be effective and growing rod surgery will be appropriate. Serial casts may be an effective intermediate method of treatment.[25]

ALIGNMENT AND FORCE APPLICATION

A variety of orthotic designs are available. Orthoses may need to be replaced as frequently as 6-12 months prior to three years of age due to rapid growth. Since infants and toddlers have large abdomens, extra room for the abdomen is needed to avoid excessive pressure. In addition, the body habitus is more cylindrical compared to juveniles and adolescents. These two factors make proper pelvic molding difficult. Making the orthosis sufficiently flexible for donning and doffing is more challenging than for older children. The young child's inability to cooperate during molding for the orthosis can make molding challenging. Molding under anesthesia is a consideration. Young children have more pliable ribs, therefore care must be taken to modify or reduce the three-point pressure as the apical ribs can deform the chest wall by pushing the ribs toward the spine.[26] As a result, the orthosis functions predominantly to stabilize a deformity rather than reverse it. Bracing is less likely than casting to permanently correct a deformity in a patient with IIS. Nevertheless, bracing plays an important role in delaying the need for surgery.

Manuals and technical details for most North American bracing systems are available online at the Scoliosis Research Society http://www.srs.org/professionals/online-education-and-resources/srs-bracing-manual.[27]

Common principles espoused by all systems include the recognition that idiopathic scoliosis is a three-dimensional deformity and that correction should be sought in all three planes by forces applied in all three dimensions. Orthosis construction should be planned in all dimensions using the following considerations:

- Control coronal deformity using lateral pressure
- Control rotational deformity by rotational pressure on both the front and back of the thorax
- Wherever possible, couple derotation forces. For example, derotation of a typical right tho racic curve will include posterior to anterior pressure on the right posterior rib hump and anterior to posterior pressure on the left anterior rib prominence (e.g. avoiding excessive pressure as previously described to avoid creating/worsening chest wall deformity)
- Take care to avoid worsening sagittal malalignment. In some cases, it may be improved. Include an area of relief, void, or window in the orthosis opposite the applied force, to both enhance the asymmetry of the force and provide an area into which the spine and trunk may shift as it moves toward a corrected position
- Avoid unnecessary constriction, particularly of the chest

When in-orthosis correction is less than anticipated, a careful reassessment of the orthosis and plan for new orthosis construction should be considered. The typical goal of 50% correction in the orthosis that is anticipated in older children should not be applied in IIS due to all of the issues listed above. Bracing should begin with full-time wear, and then switch to part-time if the curve is controlled. If the curve as measured out of the orthosis is reduced to approximately 15 degrees or less or the RVAD reduces to less than zero, part-time use can be instituted with close observation. In the preadolescent growth phase, many patients will need to shift back to full-time use.

A team approach to management of spine deformity with bracing is sought at most pediatric deformity centers and is related to successful orthotic management. Typically, the "team" includes a physician, an orthotist, a physical therapist, and a nurse or other coordinator. The family and patient should also be viewed as part of the team. Broadly stated goals for IIS patients include achieving maximum spine growth and length, maximum spine flexibility, optimal respiratory function and lung growth, and a minimum of hospitalizations and procedures.

ACTIVITIES WITH ORTHOTIC USE

With either casting or orthotic care, children with IIS can function in an age appropriate fashion since children at these ages are dependent on their parents for all activities of daily living (ADL) anyway. Sitting, crawling, rolling, pulling to a stand, standing, and walking are all possible and essentially unimpeded by external supports.

EVIDENCE BASED REVIEW

The emerging high quality evidence of efficacy in adolescent idiopathic scoliosis is not matched by reports for IIS partly because it is much less common and less uniform in regard to natural history. Defining success depends on defining goals of intervention. Is the goal complete correction, prevention of worse deformity, or slowing of progressive deformity, acknowledging that surgery will eventually be needed? Success is clearly linked to experience, as fabrication of an orthosis for small children is inevitably more challenging than for older individuals.

In a retrospective study of the treatment of patients with IIS, 31 consecutive patients (average age, 25 months) with a primary diagnosis of IIS were reviewed. Treatment modalities included orthotic management, serial casting, or VEPTR. Of the 31 patients, 17 were treated with an orthosis, 9 of whom had curve progression and subsequently received other treatments. Of the 8 patients who responded to orthotic treatment, overall improvement was 51.2%.[28]

Mehta's casting series reported in 2005 is a landmark paper.[9] Her study included patients up to 48 months in age. Ninety-four of 136 patients were treated early (average age one year and 7 months) with resolution of the scoliosis by 3.5 years of age. The series of casts were discontinued when the trunk was balanced, the curve corrected, and apical rotation resolved. Patients were then transitioned to a TLSO. If the deformity remained corrected after 6 months, the orthosis was weaned and discontinued. Results were maintained for a ten-year follow-up. Children who presented later with larger curves typically progressed and required operative treatment. Her experience is relevant to orthotic treatment of early onset curves as it shows convincingly that with growth and appropriate application of external pressure, the deformed growing spine can be improved. This experience clearly shows that the deformed growing spine can be guided through growth not just with stabilization of deformity but also with actual long-term improvement in deformity, and that complete correction may be possible if the early infantile growth rate is harnessed to result in curve correction. The obvious advantage of casting includes full time use without the need for adherence to orthosis regimens.

Experience with orthotic treatment alone for IIS is sparsely reported.[29-33] McMaster and Macnicole documented Milwaukee brace treatment in 27 children with infantile idiopathic scoliosis, of whom only five did not require surgery during adolescence.[34] Most authors agree that if orthotic management in isolation is effective then it probably was not needed at all and the curve would have spontaneously improved without it. The role for orthotic management in IIS may be limited to maintaining alignment until definitive surgical management, maintenance of correction obtained with casting, and postsurgical protection of implants.

CHOICE OF ORTHOSIS/DESIGN SELECTION

A major concern with orthotic management for IIS is the potential for irrevocable harm to the growing thorax. The ribs are pliable and subject to deformity if pressure is applied inappropriately or continued too long despite worsening thoracic deformity. However, orthotic treatment is a useful adjunct to cast treatment of infantile idiopathic scoliosis despite the lack of high quality evidence in the literature. The availability of modern growth-oriented surgical treatments for spinal deformity such as expandable spinal rods or VEPTR should lower the threshold for discontinuance of orthotic treatment and initiation of surgery to a point before spine or chest deformity become too severe. Severe, permanent chest wall deformity can result from prolonged inappropriate orthosis use.[23] Casting and/or orthotic treatment can be useful to delay surgical intervention to decrease the number of operative interventions to lengthen the growing rod system and to allow satisfactory growth to a size where the child and his/her skeletal structure is satisfactory for the placement of the spinal implants.


Fig 4

Success rates for the available types of orthoses are apparently similar. The Kallabis (often misspelled in the literature) brace has several straps that are applied over the shoulder and bend the child in the opposite direction of the curve (Fig 4). The original English translation of the work of Manfred Kallabis was in 1965.[35] The modern applications of the principles of the Kallabis brace are:

- Three-point pressure
- Used for children too young or small to fit with a CTLSO, usually < 12-18 months old
- Custom molded pelvic section (like other TLSO's and CTLSO's)
- Straps attaching a thoracic pad over the apex of the curve
- Straps attaching to a shoulder ring on the opposite sided, and
- Stability provided by attaching the shoulder ring to the pelvic section with a vertical bar.

The Wilmington brace is a custom-molded TLSO that has molds to push and correct the curve. The Boston brace is similar, but uses pads inside the orthosis to push the curve. The Milwaukee brace, one of the first orthoses developed for scoliosis treatment, is less popular for adolescent idiopathic scoliosis due to its design (neck-ring). However, a cervical-thoracic-lumbosacral orthosis (CTLSO) is favored over a TLSO for IIS as it has less circumferential pressure on the rib cage and allow chest expansion as these children at


Fig 5

young ages are growing and developing rapidly (Fig 5). Head tilt and higher thoracic curves can be controlled more effectively with a CTLSO. A custom fabricated parietal pad and/or shoulder ring can also be beneficial additions to a CTLSO.[26] Pad placement is similar to that previously described for adolescent orthotic prescription. Padding the neck ring is also a consideration for small children to avoid pressure. Younger children accept the CTLSO better than do adolescents.

FOLLOW-UP VISITS

Initial follow-up is early, perhaps several times in the first few weeks with the orthotist. First follow-up with the MD should be 6 – 8 weeks after the fitting of the orthosis to assess the fit and efficacy with x-rays. More frequent follow-up than for juveniles and adolescents is required due to the more rapid rate of growth, typically every 3 months up to age three and every four to six months after that.

POST-OPERATIVE CONSIDERATIONS

Is there a role for orthotic care in the post-operative period? Postoperative bracing is typically used after placement of growth rods until spinal fixation points have stabilized, typically about three months. After that, most surgeons do not use orthoses for their patients. Additional considerations for postoperative orthotic use include poor bone quality or if compliance with postoperative restrictions is a concern.

SUMMARY

This chapter has emphasized the unique aspects of Infantile Idiopathic Scoliosis when compared to Adolescent Idiopathic Scoliosis in diagnostic evaluation, natural history and treatment considerations. Neither one has an explanation of causation and is therefore are called idiopathic but that is where any similarities ends. The importance of understanding these differences is of paramount importance.

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15

Natural History of Adolescent Idiopathic Scoliosis

Eiman Shafa, John E Lonstein

INTRODUCTION

Scoliosis, which has been clinically recognized for centuries, can be defined as a lateral curvature of the spine. The condition however is more accurately defined as a complex three-dimensional spinal deformity. Spinal curves of less than 10 degrees of coronal angulation as measured radiographically by the Cobb technique are defined as spinal asymmetry while those of greater magnitude are scoliosis.[1]

Scoliosis can be categorized based on etiology. Idiopathic scoliosis is the most common and most studied form of spinal deformity in the young patient. The diagnosis of idiopathic scoliosis is made in the absence of all other possible causes including congenital, functional, inflammatory, traumatic, infectious, secondary due to pathologic or intra-spinal lesion, and neuromuscular. James popularized the classification of idiopathic scoliosis by age at onset as infantile (birth to < 3 years old) (IIS), juvenile (3 years to <10 years old)(JIS), and adolescent (10 years old to skeletal maturity)(AIS).[1,2] These age intervals represent distinct peak periods of spinal deformity, each with a unique natural history. Though this classification system is widely used, it is undoubtedly difficult to determine the precise onset of scoliosis leading likely to overlap among the groups.[3]

This chapter aims to review the prevalence and natural history of adolescent idiopathic scoliosis. This information is invaluable in diagnosing the condition and discussing treatment options with patients and their families as all treatments must be aimed toward changing the natural history of the condition in a positive manner.

ADOLESCENT IDIOPATHIC SCOLIOSIS

Adolescent idiopathic scoliosis, also known as late-onset scoliosis, is a condition of unclear pathogenesis. It likely represents a systemic condition of complex heterogeneous genetic etiology with multiple potential dependent or independent factors.[3,4] The condition can be diagnosed clinically, and confirmed and further described radiographically.

The prevalence and natural history of AIS is now well characterized and understood. The result of school screening programs has shown the prevalence of this condition ranging broadly from 0.3% to 15.3%.[5-11] The wide range in the reported epidemiologic data likely represents variations in populations studied, detection methods, and how scoliosis is defined. Curves greater than 10 degrees of coronal plane curvature have a prevalence of 1.5-3.0%.[5-11] Larger curves, meaning those that require treatment or closer observation are much less common. Curves, which are greater than 20 degrees, are reported to have a prevalence of 0.3-0.5% and those greater than 30 degrees comprise 0.2-0.3% of the population.[5-11]

Treatment of AIS remains a complex challenge for the orthopaedic surgeon and depends on a thorough understanding of its natural history allowing the clinician to make appropriate intervention in the form of observation, orthotic management, or surgery. Precise timing of treatment plays an essential role in effectively changing the natural history and prognosis of the condition. The timing of treatment relies on an understanding of when a given curve in a given patient will likely progress. Thus, early diagnosis and assessment of risk factors for curve progression are key components in clinical decision-making.

Early long-term natural history studies of idiopathic scoliosis were poorly designed, as they included a heterogeneous mix of neuromuscular, congenital, infantile, and juvenile etiologies with adolescent idiopathic type. These studies depicted a dismal prognosis leading to a generalized misunderstanding that idiopathic scoliosis would lead to eventual disability from back pain, cardiopulmonary compromise, psychiatric disturbance, and increased overall mortality.[12-16]

Nilsonne and Lundgren[12] presented their findings in a minimum 45-year follow-up study of 113 patients diagnosed with idiopathic scoliosis between 1913 and 1918. They traced 90% of the patients who were identified as idiopathic type by the exclusion of paralytic and congenital cases. No radiographic data was reported; thus the etiology of spinal deformity was not well defined. They found that 45% of patients had died, with a mortality rate particularly high after age 45 and 2.2 times that of the general population at the time. This was a figure similar to that reported by Ascani et al.[13] Most deaths were attributed to cardiopulmonary disease. Ninety percent of surviving patients had back symptoms and 30% were disabled. Of the female patients, 76% had never married. As no radiographic data and age of first detection is available in these studies, they are probably a combination of IIS, JIS and AIS cases.

In the same year in a peer-reviewed journal, Nachemson[14] reported a 38-year follow-up of 130 untreated patients with scoliosis diagnosed between 1927 and 1936 at age 0 to 30 years. They too found a mortality rate twice that of the general population. When analyzing only patients with thoracic curves, the mortality rate was 4 times that of the general population. In this author's series, 37% had constant back pain, 14% had cardiopulmonary symptoms, 37% were disabled due to their deformity, and none were involved in occupations requiring heavy labor. In this study, only 59 patients (45%) had idiopathic scoliosis, the remainder included congenital, paralytic, as well as secondary to tuberculosis and neurofibromatosis. Phersson et al.[17] reassessed this data, analyzing by etiology of spinal deformity. The average age of death was 54 years and of the 55 patients who had died, 26 were due to respiratory failure and 17 were due to cardiovascular etiology. They confirmed an increased mortality rate in untreated scoliosis if all causes are considered. This included both infantile and juvenile scoliosis but not adolescent idiopathic scoliosis. Though these studies are primarily of historical interest only, they do help highlight the differences in the prognosis and natural history of various spinal deformity conditions.

In the case of AIS, it is helpful to divide the natural history of the condition into pre- and post-skeletal maturity. Study of skeletally immature AIS patients helps us better understand the prevalence and risk factors for curve progression and response to treatment such as orthotic management. Study of skeletally mature patients with AIS allows us to assess clinical and radiographic long-term outcomes. The natural history of the condition is best depicted in the untreated patient population.

NATURAL HISTORY DURING PRE-SKELETAL MATURITY

Factors related to curve progression are divided into those determined by growth potential and those determined by curve characteristics. Curve progression is best assessed radiographically and defined as greater than 5 degrees over 6 months or greater than 10 degrees from the time of initial presentation while under observation. The growth potential of a preadolescent can be predicted by the assessment of secondary sex characteristics, history of menarche in females, and radiographic findings such as the Risser sign, status of the triradiate cartilage, Tanner-Whitehouse III score, digital skeletal age, and the Sauvegrain method[11,18-20] [See chapter 4].

Progression of AIS is closely related to rapid growth and as such, the skeletally immature child with AIS is at particular risk for a progressive deformity due to the remaining pubertal growth spurt and duration of skeletal growth.[21] Reported progression rates in the literature vary widely from 5.2-40% (Table 1).[18] Though this relationship is now well documented, it was first elucidated by Duval-Beaupere in 1971.[4] She studied 560 female patients with scoliosis (500 post-polio and 60 idiopathic) to assess growth and deformity progression and compared this cohort with 53 sex and age-match females without scoliosis. In all subjects she observed steady increase in growth until a point she called P when there was accelerated growth. This growth increase plateaued after the child reached a second point she called R. Point P marks the onset of the pubertal growth spurt, while point R is the end of spinal growth. In regard to markers of maturity, point P occurs with the onset of secondary sex characteristics, (Tanner stage 2) and point R coincides with Risser 4. Risser 4 indicates end of growth in females, while Risser 5 indicates the cessation of height increase in males.[4,20-24]

Table 1

In females, point P occurs during physical markers of maturation and secondary sex characteristics consistent with Tanner stage 2 with development of breast buds and pubic hair around the chronological age of 10-12 years. The growth spurt lasts for 2.5-3 years with the point of maximum growth velocity occurring 1 year after the onset. Menarche, and axillary hair growth occur 1.5-2 years after the growth spurt onset.[21] In males, pubic hair develops before point P or the onset of the pubertal growth spurt that occurs during Tanner stage 2 or 3. This coincides with a chronologic age of 11-16 years. Peak height velocity occurs at an average age of 14 years only after which axillary and facial hair growth can be appreciated. The growth spurt in boys lasts for between 3.5 and 4 years and is hence significantly longer than in girls. It is important to recognize that these chronological ages are defined in the Caucasian population and cannot be extrapolated to patients of other races.

Curve magnitude is also a key role in deformity progression. Lonstein and Carlson[18] assessed curve magnitude and skeletal maturity, defined radiographically by the Risser sign, to determine rates of curve progression. They found that for curves of less that 19° in an adolescent of Risser 2 or greater, the risk for progression was 1.6%. However, in skeletally immature adolescents of Risser 0 or 1 with the same curve magnitude, progression risk was increased to 22%. In larger curves of 20-29° and Risser 2 or greater, risk of progression was also 22%, while in patients with Risser 0 or 1 with the same large curve the risk increased to 68% (Table 2). In this series, 32% of patients with progressive curves and 68% of those with non-progressive curves had reached menarche at initial evaluation.

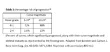

Table 2

The patient’s sex has been suggested to be a risk factor for deformity progression, in multiple studies. According to scoliosis school-screening studies[5-11] an approximately equal sex ratio exists; yet curves requiring treatment are largely in female patients. Unfortunately, all large series publications have too few males to definitively proclaim a different incidence of progression between males and females, however some trends have been established. Contributing to this disparity may be the fact that males have a longer growth spurt and grow until the complete fusion of the iliac apophysis (Risser 5).[22, 23]

In 1985, Bunnell[19] published a retrospective review of 326 female patients with untreated idiopathic scoliosis (age range 10.5-15.6 years old) and reported on various prognostic factors for curve progression. Prognostic factors for curve progression included age at diagnosis, sex, curve pattern, curve severity or magnitude, history of menarche, and the Risser sign. Factors not related to prognosis of curve progression included family history, height-weight ratio, lumbosacral transitional abnormality, thoracic kyphosis and lumbar lordosis, and overall coronal balance. He also highlighted the value of screening programs showing that patients seeking care due to a noted deformity by a lay person averaged 44° curves at diagnosis while those noted by trained observers were identified early at as little as 5°-10°.

Soucacos et al.[10,11] performed a 5-year prospective study of 85,622 children through a school scoliosis-screening program in a Greek population looking for any risk factors associated with curve progression. In total, 1,436 children (1.7%; 2.6% of girls, 0.9% of boys) met criteria for progression, 839 of these patients were assessed with follow-up examination. Their data (mean follow-up of 3.2 years; range 1-4 years) showed 18% of curves remained stable while curve progression occurred in 14.7%, the majority of which were only small progression of 4-9°. In total, 27.4% of curves improved at least 5 degrees, where 9.4% resolved fully. The remaining 40% had insignificant changes. Risk factors included age, curve magnitude >30°, skeletal maturity, curve pattern, and female gender. Though females progressed more commonly, this did not hold true for a progression over 10°. Left thoracic curves and all thoracolumbar curves had a high percentage of curve improvement. No left-sided curves showed progression during this study. Double curves progressed the most followed by right thoracic, then lumbar, then thoracolumbar curves. Both males and females demonstrated a small but notable incidence of progression during the pubertal growth spurt. In stable or improved curves, 52.3% of females presented post-menarche while this population only accounted for 35.6% of progressing curves.

Multiple novel radiographic methods have been proposed for predicting AIS curve progression. In 1983, De Smet et al.[25] in a small sample of 12 patients, proposed a "top view" for analysis of scoliosis curves and in the following year reported on analysis of 31 females with right thoracic curve AIS in an effort to assess the relationship between degree of scoliosis and the degree of kyphosis, maximal curvature, and apical vertebral displacement. They found a positive correlation for scoliosis with a maximal curve and apical displacement but not with kyphosis.[26] Kohashi et al., reporting on 51 patients collected prospectively, and found four factors correlated with curve progression using the top view analysis. These included relation of frontal and sagittal size, magnitude and direction of maximum curvature plane in thoracic and lumbar regions, and balance between thoracic and lumbar curves.[27]

More recently, Sanders et al. devised a simplified skeletal maturity scoring system and demonstrated its reliability.[20] [See Chapter 4] They found that the Tanner-Whitehouse III (radius, ulna, and selected metacarpals (RUS)) method of skeletal maturity assessment was closely related to curve progression behavior and was highly useful in identifying the curve acceleration phase in early adolescence. Given the low correlation of radius and ulna of the RUS growth centers with curve behavior, the scoring system focuses on a digital skeletal age with a modest learning curve. Assuming a threshold of >50° for surgical indications, they proposed a logistic projection of probability in Lenke 1 and 3 type AIS curves.

Other reported risk factors have also been suggested in the literature. Hung et al.[28] in their study of 324 Chinese adolescent females with AIS, found a high prevalence of osteopenia at both the femoral neck and spine (23.1% and 27.5%, respectively) in this population compared to an age matched non-AIS cohort (17% and 17.7%, respectively). They also found differences in progressive versus stable curves, noting younger age, lower Z-score bone mineral density of the spine and both femoral necks, and a later onset of menarche. They report a curve progression odds ratio of 2.3 in patients with osteopenia in the femoral neck ipsilateral to curve concavity. To better understand the role of paraspinal muscles in periods of curve progression and non-progression, Cheung et al.[29] performed an electromyography (EMG) study. He found not only a correlation between growth velocity and enhanced EMG activity, but also noted a high EMG ratio associated with axial rotation and diminished kyphosis just prior to periods of rapid increase in Cobb angle.

Great effort has been put towards better understanding of the genetic basis of scoliosis, which is believed to be of primary importance in both development and progression of scoliotic spinal deformity.[3] A saliva-based DNA test, called ScoliScore (DePuy Synthes, Inc.), is available and has a potential prognostic utility in managing AIS. The test uses an algorithm to predict curve progression incorporating genotypes for 53 single nucleotide polymorphisms and the patient's presenting curve magnitude by Cobb measurement. Logistic regression was used to develop this algorithm based on a large DNA database from patients with AIS of known final outcome. The test scores 1-200 is calculated for the risk of curve progression to a curve >40° at the end of skeletal growth. A score <40 shows low risk of progression with a negative predictive value of 97-100% in three separate cohorts studied.[30] A score of 40-180 represents an intermediate risk, while those >180 are associated with a high risk of progression to >40° at the end of growth.

According to Roye et al., the AIS prognostic test (AIS-PT) provides unique information compared to traditional predictors of curve progression.[31] In their experience, the test predicted approximately 16 times more low risk and 5 times fewer high risk patients in regard to curve progression to surgical magnitude curve (>40°) when compared to the clinical prediction using the Lonstein-Carlson formula, which takes into account chronological age, Risser sign, and curve magnitude. It should however be noted that the latter formula is intended to predict curve increase of 5-10° beyond presenting curves of under 30°.

In summary, curve progression in AIS is driven by multiple risk factors including patient-related and curve-related characteristics. They include:

1. Curve pattern – All curve patterns had 25 to 30% progression rate except for single lumbar or thora columbar curves, which progressed 10-15%.[10,11,13,18,36,41]
2. Curve magnitude – Larger curves show greater incidence of progression.[4,10,11,13,18,36]
3. Age – Older patients have lower rates of progression.[10,11,13,40,41]
4. Gender – Progression is more common in girls.[10,11,13,40,41]
5. Risser sign – The higher the Risser score, the lower the incidence of progression.[13,18,41]
6. Menarche – Progression is less common after menarche.[10,11,18]

Other factors studied in adolescent idiopathic scoliosis, but not proven valuable in determining progression have been rotational prominence, decompensation, family history, height-weight ratio, lumbosacral transition anomalies, and a number of radiographic assessments including thoracic kyphosis, lumbar lordosis, curve balance, rib vertebral angle difference of Mehta, and vertebral rotation.[10,11,19]

NATURAL HISTORY OF POST-SKELETAL MATURITY

Our understanding of the natural history of idiopathic scoliosis in the skeletally mature adult, which is gleaned from multiple long-term studies of AIS into adulthood, allows for interventions that can positively affect outcomes. As such, our treatments have to be tailored toward outcomes that are more favorable than the condition's long-term natural history. Scoliosis in the post-skeletally mature patient is not amenable to orthotic management.

In this effort, Collis and Ponseti reviewed patients previously studied by Ponseti and Friedman at the University of Iowa who were available for interview and physical examination, who had not been treated, and who had available radiographs and clinical records.[32] This included 106 of the original 358 patients. The initial cohort included idiopathic scoliosis patients over 8 years old meaning that not all were AIS cases.[33] Average follow-up time was 24 years. In total, 3 patients underwent surgical fusion in adulthood and 17 had died. Eighty-nine patients filled out a questionnaire. They found that most curves had progressed after skeletal maturity. Thoracic curves of 60°-80° progressed most significantly with an average of 28° increase, while those less than 60° progressed an average of 9°. Lumbar curves >30° progressed an average of 18°, while those less than this threshold did not progress. Backache was a complaint in 54% of patients. Pulmonary vital capacity was decreased in all thoracic curves >60° and 40% complained of dyspnea, especially those with >85° thoracic curves. In general, the study provided important insight into the natural history of AIS though it is significantly limited due to a high dropout rate.

This cohort was followed in time and Weinstein and co-workers published outcomes at 30, 40, and 50-year follow-ups. They reviewed 102 patients with available radiographs observed for an average of 40 years and found 68% of curves progressed after maturity; this trend was continued at 50-year longitudinal follow-up.[34] Thoracic curves less than 30° did not progress while those above 50° progressed after maturity at a rate of 0.75 to 1 degree per year. This progression lead to the recommendation for surgical intervention for curves reaching a 50° magnitude. All progressive thoracic curves had >30% apical vertebral rotation and Mehta angle greater than 20°.[35] No lumbar curves less than 30° progressed after maturity. Factors leading to lumbar curve progression were noted to be a curve >30° and apical vertebral rotation >33%. Thoraco-lumbar curves manifested the most significant apical rotation that was associated with translatory shift forces at the lower end of the curve. This rotation can lead to a significant local curve progression.[34] At skeletal maturity 20% had at least one translatory shift while at 50-year follow-up, 71% had at least one segment with translational shift.[36]

The findings of these studies regarding curve progression for all curve types were similar to those found by Ascani et al. in a multicenter Italian study of 187 patients observed an average of 33 years.[13] The rate of progression of each curve pattern was not reported and they reported that all curves increased after skeletal maturity an average of 0.4° per year, though thoracic curves >40° progressed twice the rate of those below this threshold (average 20.1° vs. 9°, respectively).

Weinstein et al. studied mortality rate, back pain, pulmonary function, depression, and body image. In their 30-year and subsequently 50-year follow-up studies, all but 4 patients were normally active. Though both acute and chronic backache were somewhat more prevalent relative to controls, there was no significant difference in intensity, duration, or disability.[37] A curve magnitude of greater than 50° was associated with an increased odds of developing shortness of breath, but a thoracic curve apex alone was not an independent predictor. There was no increase in mortality compared to the general public. A single case of cor pulmonale was the cause of death due to advanced spinal curve. This study reported 21% having mild psychological response to their deformity along with lower body satisfaction scores. In all, 32% believed their life was limited by their scoliosis.[37] Ascani et al. report pain in 61%, cardiopulmonary symptomology in 22%, and psychological disturbance in 19%. Most symptoms were in females with curves >40°. They also found that work capacity was similar among all curve types except lower curves were overall less well able to adapt to heavy labor.[13]

With the information from these studies, one can reasonably observe curves <30° after maturity and entertain surgery for curves >50° with significant and progressive deformity recalcitrant to non-operative measures. However, to date, less is known about the natural history of moderate curves. In this effort, Cordover and colleagues studied 34 adult patients with curves 20-50 degrees at an average follow-up of 22 years.[38] A greater portion of the study group reported back pain compared to controls (65% vs. 32%). When considering only those with back pain, there was no difference in pain level between the study and control groups nor between curves >30° and those <30°. There was no difference between the groups in the rate of significant disability score. There was however a larger portion of scoliosis patients with poorer body image (26% vs. 3%). None of the study group required surgery or hospitalization for back problems. More recently, Mehbod presented findings of 46 patients with 30-50° curves and a mean 19.5 year follow-up.[39] He found a rate of progression of upper thoracic, thoracic, and lumbar curves of 0.23, 0.47, and 0.28 degrees per year after skeletal maturity. Average change per year was less that 1° in 95% of the patients. Few of the patients had functional limitations by Short Form-36, Roland Morris, and Oswestry outcome scores. Only two patients had undergone surgery for treatment of spinal degenerative disease.

The findings of multiple natural history studies have allowed us to gain insight into the radiographic and clinical outcomes of non-surgically managed idiopathic scoliosis. They allow us to make predictions, counsel our patients, and offer treatment options in the form of observation, orthotic management, and surgery, which can be tailored to the individual based on patient factors and curve characteristics.

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Effectiveness of Orthoses in Idiopathic Scoliosis

Nanjundappa S Harshavardhana, John E Lonstein

INTRODUCTION

Idiopathic scoliosis (IS) is a three-dimensional deformity of the spine associated with lateral curvature in addition to vertebral rotation and is the most common form of scoliosis.[1,2] Its etiology is multifactorial and is best described as "unknown," though numerous theories have been proposed.[3-5] Though non-operative treatment methods have been extensively studied over the past six decades with the advent of the Milwaukee brace, Hippocrates recognized the principles of distraction back in 400 B.C. and applied lateral pressure and corrective forces to address the coronal plane deformity.[6] This chapter provides a comprehensive summary of existing evidence for use of orthoses in IS. We aim to cover:

- Brace type (various braces both in Europe and America),
- Duration of brace wear (full-time vs. part-time) and its monitoring,
- Flexible vs. Rigid braces,
- Sex (males vs. females),
- Age groups (juveniles vs. adolescents), and
- Curve pattern (curve location).

This chapter concludes with a summary of the findings of BrAIST (Bracing in Adolescent Idiopathic Scoliosis Trial, 2013), which was funded by the National Institute of Health (NIH), and a look at the possible complications of bracing that one should be aware of.[7,8]

For any treatment modality to be effective, one must compare the therapeutic benefit it offers with that of the natural history. Following publications by Weinstein et al., particularly their fifty-year follow-up study, the natural history of untreated scoliosis is becoming better-understood.[9] The key findings from their study were:

- Longevity was not compromised in IS
- Restrictive lung disease and cardio-pulmonary ailments were common for curves whose Cobb angles were ≥80° (mainly thoracic curves)
- Dyspnoea and breathlessness were seen at rest when thoracic curves attained magnitude of ≥110°
- Patients with IS had a higher incidence of back pain compared to the general population without scoliosis.

Curves whose Cobb angles measured ≥50° at maturity did progress albeit at a slower rate throughout adulthood, 1°-2° / year, and surgery was one of the options aimed at preventing this over the long term. In addition, the spinal deformity was associated with appearance changes with poor body self-image and lower self-esteem (esp. in larger curves with severe truncal asymmetry). The costs associated with scoliosis treatment were second only to the management of childhood appendicitis in the United States, costing no less than $514 million.[10] Hence, scoliosis care attracts significant attention, particularly for children.

Conflicting reports and evidence exist in the published literature regarding the effectiveness of bracing in IS. Goldberg et al. found that braces did not alter the natural history of adolescent idiopathic scoliosis (AIS) and questioned the recommendation for bracing, notwithstanding the costs incurred with such a program.[11] The surgical incidence of a braced cohort was similar to an observed group of patients in their series of 153 patients, comprising of 11 boys and 142 girls, and the surgical incidence was 28.1%. Goldberg recommended a randomized controlled trial (RCT) to be conducted to settle this dispute.

In a follow-up to the research initiated by Goldberg et al., investigators in the Netherlands attempted to set up a randomized controlled trial (RCT) to evaluate the efficacy of bracing in AIS.[12] However, their study never went forward owing to poor recruitment (only four patients in two years) and was thus abandoned.

The NIH funded the BrAIST (Bracing in Adolescent Idiopathic Scoliosis Trial) study to address whether the braces were effective and should be used in the management of AIS by a multi-centric RCT involving twenty-five institutions in the United States and Canada.[7] The inclusion criteria adhered to the stringent Scoliosis Research Society (SRS) criteria developed by Richards et al.[13] which were:

- Risser grade 0 – 2
- Pre-menarchal or within one-year post-menarche
- Age ≥10 years and ≤15 years
- Main curve Cobb angle magnitude of ≥20° and ≤50°
- Follow-up to skeletal maturity (which by definition meant):
    - Closure of all phalangeal physes
    - Height gain of <10 mm in the past 12 months
    - Risser grade ≥IV or two years post-menarchal in girls
    - Risser grade V in boys.

Owing to poor recruitment and the reluctance of parents/caregivers to participate in randomization, the investigators added a preference cohort to increase patient participation in the BrAIST study. A total of 242 patients (RCT=116 and preference cohort=126) were thus recruited over a two-year period and the study was stopped prematurely due to the convincing and overwhelming benefit of bracing (42% successful curve control with observation vs. 75% successful curve control with bracing). The odds ratio with 95% confidence intervals was 4.[11] (95%CI = 1.85 – 9.16 and p=0.001).[7] The study also used a temperature sensor to monitor the compliance with brace wear (i.e. hours spent wearing a brace). Other key findings of the BrAIST study were:

- The percentage success with bracing was positively correlated with duration of time spent wearing a brace
- The results of bracing in those who wore the brace for ≤6 hours / day was no better than that of the observation group

- The rate of failure was 25% in the braced cohort vs. 58% in the observed cohort of patients.

Over the past six to seven decades, many orthoses have been used to arrest curve progression. Orthoses act by applying corrective forces by force vector / mechanical pads and by reinforcement of proprioception. They guide the growth of the spine with time, aiming to either contain worsening / correction of the deformity. Spinal orthoses can be broadly divided into:

a. American/European
b. Flexible/Rigid.

NORTH AMERICAN ORTHOSES

1. The Milwaukee brace (MB)

The Milwaukee brace (MB) was the first orthosis developed for the treatment of idiopathic scoliosis by Walter Blount and his orthotist Al Schmidt in 1946[14], and it is the only orthosis effective in treating the high thoracic curves of idiopathic scoliosis (i.e., apex of scoliosis at T6 or above).[15]
In a cohort of 1,020 patients, Lonstein et al. reported a success rate of 78% in obviating the need for surgery (i.e., only 22% eventually needed surgery).[16] The brace was less successful in children who had i) curve magnitude with a Cobb angle of >30° and ii) Risser grade 0 & 1 at the initiation of bracing. The success rate of MB as reported by other investigators is summarized in Table 1.[16-20] The success of the MB in controlling the curve with < 5° progression at 3.5 to 8 years after discontinuing the orthosis was 64% to 77% with a surgical rate of 5-22%.


Table 1

2. The Thoraco-lumbo-sacral orthoses (i.e. TLSO)

The TLSO were devised to address the limitations of the MB and cater to those who refused to wear it, owing to compliance and appearance issues/concerns. The most common TLSO used in North America are named from the cities from which they originated. These include: - a. The Boston brace, b. The Wilmington brace, c. The Rosenberger brace, d. The Charleston night time bending brace, and e. The Providence brace.

2a. The Boston brace (BB)

Dr J. E. Hall and his orthotist Mr M. E. Miller[21-23] first introduced the Boston brace in 1971.[21-23] It is a pre-fabricated posterior opening rigid orthosis that was recommended for curves with an apex at or below T8.

Emans et al. reported the results of its use in 1986 and found that only 13% of patients needed surgery in a cohort of 212 patients.[22] The average correction achieved in the BB was 15° (best-in-brace radiographs) and 11° at final follow-up. The best results were seen in patients whose curves had an apex between the T8 and L2 vertebrae. The results of success with the BB with respect to the surgical incidence and its confidence intervals as observed and reported by other investigators in published literature, are summarized in Table 2. The best-in-brace correction of >50% was predictive of success with bracing using the BB. The results were poorer in patients who were either Risser


Table 2

grades 0 or 1 and with pre-menarchal status at the time of initiation of bracing. The BB did not alter the natural history of curves whose magnitude was >50°.

2b. The Wilmington brace (WB)

The WB is a rigid anterior-opening custom molded TLSO that was developed by G.D. MacEwen at the Alfred du Pont Institute in Wilmington, DE. to cater to the needs of a patient who refused to wear a MB.[28]

In a study by Gabos et al. that included 91 females treated by the Wilmington brace (WB) who wore it full-time (i.e. at least 23 hours/day), the progression rate was 13% (i.e., they had a treatment success of 87% with the WB).[29] However their paper did not quantify the percentage of patients who needed surgery or were later treated surgically. Allington et al.,[30] reported a surgical incidence of 20% in a cohort of 98 patients treated with full-time wear in the WB (Table 3).

Table 3

2c. The Rosenberger brace (RB)

The Rosenberger brace (RB) is an anterior opening rigid TLSO that was first developed by R. Rosenberger at the University of Chicago and was used clinically by W. Bunch.[31] The results of the RB were presented by Spoonamore et al.,[32] with a low success rate and a high surgical rate. (Table 3) The series are small and the success rate varies greatly, all being of the centers that developed the orthosis.

EUROPEAN ORTHOSES

The common European braces are: a) Cheneau – Toulouse – Munster brace (and its derivatives), b) Lyon brace, c) TriaC brace, d) Sforzesco brace, and e) Progressive action short brace (PASB).34 All except the TriaC braces were rigid orthoses and TriaC had low rigidity.

1. Cheneau brace

The Cheneau brace and its derivatives were developed in the 1960s. It is an anterior opening rigid orthosis that relies primarily on corrective translational forces to correct the scoliosis. In a series published by Zaboromeska–Spofeta et al., the orthosis was successful in 25% of the patients, and stabilization occurred in an additional 23%.[35] The Rigo brace is an off-shoot of the Cheneau brace which provides a three-dimensional correction and is popularly used in Germany. In a series published by Rigo et al., the mean follow-up was 16.8 months. The brace was successful in obviating the need for surgery in 81% of the patients.[36]

2. Lyon Brace

The Lyon brace was developed in 1947 by Stagnara et al. and has aluminium bars and plexidur (high-rigidity material) and was mainly developed for AIS. In a study by De Mauroy et al., the rib asymmetry correction was better than the curve correction (i.e. the Cobb angle) – 33% vs. 50% and produced better aesthetic correction than radiographic correction.[37] In the large series of 1,338 patients treated by this orthosis, 67% had improved, 28% stabilized, and only 5% progressed or deteriorated.[37] The percentage of patients who required surgery, however, was not reported.

3. TriaC Brace

The TriaC brace was developed by Dutch investigators Velduzien AG et al. and is a low rigidity anterior-opening orthosis, which emphasizes Cosmesis, Correction, and Comfort (i.e., triple 'C').[38] It has been recommended for the treatment of thoraco-lumbar/lumbar scoliosis only. In a series published by Bulthius et al., the TriaC was successful in 76% of patients in either preventing or stabilizing the curve.[39] The authors concluded that TriaC did alter the natural history of AIS and was superior to observation alone.

4. Sforzesco brace

The Sforzesco brace was developed in Italy by Negrini et al. in 2004.[40] It was based on the SPoRT (Symmetric, patient-oriented, rigid, three-dimensional, and active) principle that has a few characteristics of the Milwaukee brace, the Risser cast, and the Lyon and Cheneau braces. In a recent small series, Lusini et al. recommended the use of Sforzesco brace for curves whose Cobb angles were ≥45° wherein the patients refused surgery.[41]

5. PASB

Table 4

The PASB (progressive action short brace) was developed in 1976 by Lorenzo et al. in Italy and is primarily aimed at treating thoraco-lumbar/lumbar curves.[42] In a study by Aulisa et al., all patients had improvement and 94% had correction of scoliosis while 6% stabilized.[43]

The success rates with some of the European braces are summarized in Table 4.[35-37,39,41,43]. They are all from the center that introduced the different orthoses, and except for the Lyon study[37] are all small series.

EVIDENCE FOR DURATION OF BRACE WEAR (FULL-TIME VS. PART-TIME)

1. Charleston night-time bending brace (CNBB)

In an attempt to further improve the compliance, some physicians questioned the need for full-time brace wear and modified designs to increase the corrective forces, thereby reducing the duration their patients spent wearing the brace. The Charleston night-time bending brace (CNBB) was developed in 1979 by F. Reed in Charleston, SC in collaboration with R. Harper.[45]

The CNBB was recommended for 8-10 hours of wear only at night-time or during sleep. Despite this attractive reduction in the duration spent in wearing the brace the compliance with CNBB was similar to other orthoses. The results of this orthosis is 80% with a surgical rate of 7-15% in small series as seen in (Table 5).[46-49]

Table 5

2. The Providence brace (PB)

This brace relies on the same principles as the CNBB, but it exerts a less aggressive corrective force and is better tolerated than its counterpart and is more compliant. The brace was first designed and used by C. d'Amato and B. McCoy at the Children's Hospital in Rhode Island in 1992.[47] The results of this orthosis are in series of d'Amato et al.[47] with an 82% success rate and 18% requiring surgery.

EVIDENCE FOR FLEXIBLE VS. RIGID ORTHOSIS

The flexible orthoses (i.e. SpineCor and its counterparts) were developed to further address the limitations of rigid orthoses and improve patient compliance. The concerns that promoted Coillard et al. to devise one such orthosis were;[51] a rigid and bulky TLSO that provided little ventilation and concerns of appearance and self-esteem during the adolescent years.

In a published case series of 195 patients treated by this orthosis, only 29 of them had attained a follow-up of two years and most were still skeletally immature. Coillard et al. reported curve stabilization in 38%, curve improvement by ≥5° in 55% and only 7% progressed by ≥5°.[52] However, the main criticism of this publication was that it did not meet the SRS bracing criteria for inclusion into the bracing program.[13]

Table 6

In an randomized controlled trial (RCT) of 43 patients (22 wearing SpineCor and 21 rigid orthosis group) evaluated by Wong et al., rigid orthosis was significantly better than SpineCor, out-performing it by 95% vs. 68% (p=0.046).[53] A meta-analysis was performed comparing the SpineCor (and its flexible orthosis counterparts) vs. rigid orthoses. Four articles met the inclusion criteria, and the sample size from pooled data of all studies yielded 175 patients (168 girls and 7 boys). The success rates of rigid and flexible orthoses from these comparative studies are summarized in Table 6.[53-56] Only two studies had adhered to the SRS bracing inclusion criteria[55,56] and two were LoE I studies (i.e., prospective randomized controlled trials).[53,56] Both orthoses were effective in altering the natural history of AIS, but rigid orthoses had superior results. The compliance with both orthoses was similar as the possible advantages of the SpineCor were offset by significant problems with toileting owing to the groin straps of the SpineCor orthosis.

EVIDENCE FOR BRACING IN BOYS VS. GIRLS

Idiopathic scoliosis is most commonly seen in girls, and though the Male: Female ratio for JIS is 3-4:1, it increases to 8-9:1 for AIS. Few publications have studied the natural history of IS in boys and compared the results of bracing in boys and girls.

Suh et al. evaluated 50 boys with IS from a consecutive series of 256 patients at the Alfred du Pont Institute and followed them to skeletal maturity.[57] The IS in boys tended to progress up to Risser grade V (unlike grade IV in girls). The curves also tended to be stiffer and rarely progressed beyond maturity unlike in girls who progressed at 1° / year for those whose Cobb angles were ≥40°.

Yrjonen et al. undertook a comparative study of 51 boys vs. 51 girls (n=102 subjects) following them for at least one year.[58] They observed poorer compliance in boys compared to girls by at least 10% and failure with bracing to be 31.4% vs. 21.6% in girls.

Karol et al. evaluated 112 boys with AIS for an average of 1.2 years post-cessation of brace therapy and noticed a failure rate of 74%. Forty out of 98 patients eventually needed surgery and the compliance rate was at best only 38%.[59] RCT or Prospective comparative trials (i.e. LoE I & II studies) comparing the results of bracing in boys vs. girls, are desired to settle this dispute with certainty as the BrAIST study did not look into this sub-analysis. The summary results of the efficacy of bracing in boys are summarized in Table

7.[57-59]


Table 7

EVIDENCE FOR BRACING IN JUVENILES VS. ADOLESCENTS

The results of therapeutic efficacy with bracing for juvenile idiopathic scoliosis (JIS) is unclear in published literature as studies have either included adolescent idiopathic scoliosis (AIS) cohorts or the follow-up to skeletal maturity was lacking. The published results exclusively for JIS show a success rate of 12 – 70% and summarized in Table 8.[60-68]


Table 8

Harshavardhana et al. undertook the retrospective study involving 133 patients over five decades with follow-up to maturity and found that the success rate for bracing with JIS was 47%. There was no difference for the type of brace worn (i.e. the MB vs. TLSO).[60] The success rate was better for curve pattern other than single right main thoracic curve and for curves that measured ≤30° at the initiation of bracing, which was also statistically significant. A similar success rate was observed by investigators from The Royal Hospital for Sick Kids, Toronto, wherein the success for JIS with brace therapy was 47%.[59] A small proportion of patients braced during juvenile years and weaned might need to be re-braced during their adolescent growth spurt to prevent the progression of deformity, which only emphasizes that any JIS cohort of individuals should be strictly and diligently followed up to maturity irrespective of the chosen method of treatment (esp. so if managed non-operatively).

EVIDENCE BASED ON CURVE PATTERN

The apex of scoliosis is instrumental for success with brace therapy. Many studies have used numerous brace designs and have reported better results with higher success rates for thoraco-lumbar/lumbar curves, compared to single right thoracic curves. The results for double structural and false double major curves are mixed with intermediate success rates. Table 9 summarizes the success rate by curve pattern/location and brace worn (mainly the MB and BB).[24,32,33] Braces tend to be less effective in high thoracic/proximal thoracic scoliosis wherein the apex is at or above T6, and only the MB is effective for such curve types. The efficacy of bracing for triple curves is unknown, since they are rare and it is difficult to come to any meaningful conclusion given such small numbers.


Table 9

Nevertheless, the single most important factor that was more important than curve pattern was the patient's menarchal status.[69] Patients who were pre-menarchal or those within one year after the attainment of menarche had poorer results with bracing compared to those who were one year (or more) post-menarche.

COMPLICATIONS

Despite the distinct advantages and benefits of bracing for IS, it is not without complications. The most commonly reported complications include: a) bursa formation, b) skin pressure sore / skin abrasion, while the rarer complications include: a) winging of the scapula[70], and b) ileus.[71] In addition, historically the MB was associated with mandibular hypoplasia with retrognathia and dentition anomalies, and, as a result, the design was changed from a throat pad to a neck ring that eliminated the problem.[72]

CONCLUSION

Convincing evidence exists to recommend using the orthosis in the non-operative management of idiopathic scoliosis as observed in BrAIST study which found the overall success rate with bracing to be 75% (compared to 42% for observation).[7] An orthosis is recommended for AIS patients who are:[13]

- Aged between 10 – 15 years
- Curve magnitude of 20° – 40°
- Risser grades 0 – II and who are either pre-menarchal or <1 year post-menarchal.

The success rate with MB was 58%, whilst that of TLSO was 69% and was not statistically significant. It is difficult to design and execute a study comparing the results of MB vs. TLSO as the recommendations for prescribing each of these orthoses are different and guided by unique curve characteristics and different apices. The MB has also fallen into disrepute in the contemporary era given its poorer compliance.

The surgical rate for AIS in the braced vs. observed group was similar in a meta-analysis from a pooled data of fifteen studies at 23% vs. 22% reported by Dolan et al.[73] It is not known if orthotic management reduces the incidence of surgery for curves >30° despite its role in curve stabilization and / or improvement in AIS, and the existing evidence is weak (Grade of Recommendation(GoR) 'D'). A recent publication has reported that orthotic use did substantially reduce the risk of curve progression to a magnitude warranting surgery in a cohort of patients who were highly compliant with brace wear.[74]

Summary

- Orthoses work (the BrAIST study has convincingly demonstrated this) and alter the natural history of AIS.
- It is not known if orthoses reduce the incidence of surgery in AIS (which warrants the cohort of patients in the BrAIST study to be followed-up for at least the next 5-10 years to answer this question, which forms grounds for further/on-going research).
- Flexible orthoses, though effective in altering the natural history of IS, perform poorly with similar compliance rates compared to rigid orthoses.
- Males respond poorly to orthotic management compared to females probably due to poorer compliance and stiffer curves. The natural history of IS in males might also be different in comparison to females with no convincing progression in adulthood for curves >40°.
- Thoracolumbar/lumbar curves respond well with better results compared to single right thoracic / double structural or false double major curves.
- Other prognostic factors that are predictive of success with orthotic use are:
    - Menarchal status
    - Curve with Cobb angle of <30°
    - Degree of apical vertebral rotation (Weak evidence)
    - At least 50% correction of Cobb angle on best-in-brace radiographs. (Weak evidence)
- Though orthoses are not without complications, their benefits outweigh the minor risks.
- Success with bracing is directly correlated with the hours spent wearing it, and pressure sen

sors overestimate the duration of wear in contrast to temperature sensors, which underestimate it.[75]

Finally, as different orthosis designs made of numerous materials exist, the decision to prescribe a brace has to be individualized and should be guided by patient preferences, institutional logistics, and the experience of treating physicians/orthotists.

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17

Orthotic Management of the Paralytic Spine

J Martin Carlson and Mark J Payette

INTRODUCTION

Neuromuscular spinal deformity and its management have little in common with other idiopathic spinal deformities except for the collapsing effect of gravity on the erect spinal column and the role of skeletal growth. Individuals who are likely to develop neuromuscular deformities may lack protective sensation, refined automatic postural responses, muscle control, or all three. Orthoses designed for managing idiopathic scoliosis (IS) or Scheuermann disease are therefore very seldom appropriate for the treatment of neuromuscular spine deformity.

Spinal deformities associated with neuromuscular diseases vary widely and are dependent on severity and/or disease stage. A realistic orthotic goal is to reduce the rate of deformity progression during the growing years to either delay or avoid the need for fusion. Because orthotic treatment is seldom actually corrective, as it may be in IS, surgical rates are much higher for a neuromuscular than for the idiopathic diagnosis.

The vast majority of neuromuscular patients with spine deformity may use a wheelchair for mobility and other activities of daily life. They lack the control needed to maintain a level pelvis during the extensive daily periods of sitting. The paralytic circumstances, in combination with wheelchair function, constitute a profound difference between idiopathic and neuromuscular spinal deformity. However, realizing the important role of pelvic alignment exposes a powerful opportunity to provide useful orthopedic support. Therefore, much in this chapter is about sitting support. Seated patients present a set of challenges, considerations and opportunities that are, unfortunately, seldom part of the training or practice of orthotists. Because of the large number of patients within this group, it is important to know how to provide the best possible orthopedic spine support within a functional wheelchair.

In the authors' experience, there are five spine support devices that are very useful for people with neuromuscular spinal deformity: custom molded sitting support orthoses (SSO); non-molded sitting support systems; two-piece molded body jacket type thoraco-lumbo-sacral orthosis (TLSO); and fabric corset type TLSOs. The wheelchair lap tray is another very effective aid for reducing kyphotic collapse in addition to its more obvious functions. Each of these five devices has a place in the armamentarium of spinal support. The patient's diagnosis, severity and age dictate the appropriate choice.

Of these devices, the SSO, in its many variations, is the most practical and effective but very underutilized except at a few specialized centers. The plastic shell TLSO is frequently advocated in the literature in spite of its limited pelvic control and how the rigid confinement negatively impacts the patient's already marginalized balance and upper body function. It is best suited for short-term use, for resisting curve progression during a growth spurt or following spinal fusion. This TLSO is usually not prescribed for wear at night or other periods of extended recumbence. The exceptions would be in post-fusion cases when the surgeon is unsure of the internal fixation or bone quality.

The fabric corset TLSO is very interesting because, for many patients, the pulmonary function benefits are more important than the spinal support it provides. Both spinal support and the pulmonary benefit of this orthosis occur only when the patient is sitting or standing. This orthosis is also used much less often than is justified by its value.

The wheelchair lap tray may seem like an unlikely item to include in this orthotic text. It was discovered early at Gillette Children's Specialty Healthcare (GCSH) that simultaneously addressing both spine support and upper body function results in significant additional benefit for both.[1-3]

When a person cannot walk, he/she carries out most daytime functions of life from a seated position. The adequacy and safety of their sitting environment (i.e., wheelchair with a seating and adaptive equipment system) profoundly affect self care, comfort, work, and general health. A high percentage of people who permanently function from a seated position have either profound, extensive loss of protective skin sensation, or profound loss of trunk control motors, or both. Muscle tone abnormalities, either high or low, in the absence of well defined sitting support often lead to mal-positioning, which in turn, contributes to orthopedic deformities. These can develop very rapidly in growing children. It makes sense to utilize the daytime hours as fruitfully as possible to not only provide the needed functional stability, but also the orthopedic support and control necessary to resist the progression of spine, pelvic, and lower extremity deformities.

The transition from a flexible mal-alignment to structural orthopedic deformity may occur in adults as well as children, but it proceeds at a much slower rate. In the adult non-ambulatory population, there is a much higher incidence of pressure ulcers because of the different diagnostic mix and the impaired skin health. When a custom orthotic seating system can effectively intervene regarding pressure sores and/or orthopedic deformities, it is very cost-effective. The expense of long term care for people with those chronic issues is immense.

MAXIMIZING UPPER BODY FUNCTION

The importance of facilitating and improving function is perhaps paramount when we provide devices for long-term use. With that in mind, it is helpful to be aware of an over-arching physical control principle critical to optimizing patient function. Patients with a neurological impairment generally exhibit a top-down control hierarchy. For instance, if a patient with cerebral palsy (CP) has very minimal voluntary control of body segments, it will most likely be some control of the neck and the head. Head and neck control is then improved if or when control is improved when the upper spine is in good, stable alignment. Lesser impaired patients will have some control of shoulders and upper limbs. Improved function of any of those segments requires either active or passive stability of the next lower body segment from which it arises. Likewise, functional alignment and control of the upper spine depends on a stable lower spine, which in turn, depends on its base, the pelvis, for firm alignment.

The orthotic system should, therefore, improve and control the alignment of the pelvis and the spinal segments going upward far enough to meet the patient's level of voluntary control. Terminating support too low will fail to facilitate all of the patient's potential function. Carrying support too high will deprive the patient of the opportunity to fully develop voluntary movement capability.

SPINE MECHANICS

The un-impaired human head-neck-trunk-pelvic complex receives its stability partly from the spinal column acting as a loosely connected stack of vertebrae that can support compression loads. A multitude of short deep paraspinal muscles and ligaments contribute stability and alignment between neighboring vertebrae. Longer, larger and more superficial muscles provide power for controlled movements of the vertebral column. Among that second group are the abdominal muscles. An able bodied individual also has the very important proprioceptive and voluntary control necessary to maintain stability of the sacrum and pelvis that serve as the base of the spinal column.

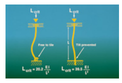

Fig 1

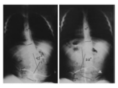

Fig 2

The foundation is vitally important to the stability of any structure, especially if the structure is a vertical column. A fundamental engineering concept is that the stability, i.e. resistance to buckling, of a longitudinally loaded column depends greatly on the “end conditions”. When the base end of a column is constrained to prevent tilting or rolling, the column can bear twice the load before beginning to bend/buckle.[4] The column buckling analysis is not an exact approximation of the spinal column (Fig1). However, clinical experience and radiographs have shown that the engineering column analysis has significant validity (Fig 2).

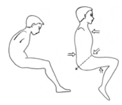

Fig 3

The importance of controlling alignment at the base of the vertebral column applies in all planes. The left diagram (Fig.3) depicts the kyphotic collapse posture commonly encountered. Posterior tilt of the pelvis can be resisted by how the thigh, pelvic and lumbar support surfaces work together. Anterior support to the upper thorax is often needed for children with cerebral palsy.

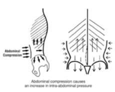

Fig 4

It is important to be very aware of the spine-stabilizing role of the abdominal wall muscles. Normal abdominal wall muscles actively constrain the abdominal viscera. Circumferential constriction causes the abdominal contents to act hydraulically upward on the diaphragm and other thoracic contents while also acting downward upon the pelvic floor.[5] When the abdominal muscles are contracted, the result is a reduction of the abdominal circumference. The abdominal wall and viscera become a hydraulic column, a sort of anterior strut, relieving the spinal column of a large amount of axial and forward bending load (Fig 4). The orthopedic implication, of course, is that when the neurological condition creates flaccid abdominal muscles, we should definitely consider orthotic approaches to abdominal circumferential control. Patients with cerebral palsy seldom need corset or wide belt devices because of their existing muscle tone. However, these orthotic additions are commonly beneficial for other neuromuscular conditions without muscle tone.

PATIENT EVALUATION

Specialists in wheelchair seating know that for people who are not ambulatory, there is a profound relationship between seating design and all aspects of life. Health, function and other needs are interwoven in highly individualized ways. We must recognize this to approach optimum outcomes. Custom seating design is a process involving the discovery of problems, hopes and opportunities that may not become clear until the fitting and trial stage of orthotic system delivery.

In addition to the physician and orthotist, it is important to solicit and invite input from family members, other caregivers and advocates which may include the classroom teacher. The excellence of the outcome depends heavily on starting out and proceeding with comprehensive information and input of ideas and concerns. Some adult clients, of course, have an independent life style and can advocate for themselves very clearly.

During the evaluation process, which may last from 60-90 minutes, discussion should cover quite a range of topics and issues. First obtain a very clear idea of what the client and principle caregivers expect the seating system to accomplish. Following that, discuss, observe, and examine to get a picture of the client's status with regard to functional ability, orthopedic status, skin sensation, muscle tone abnormalities, wheelchair operation, etc. Evaluators should also learn what seating and wheeled mobility equipment the client presently has, what they have had in the past, and what has and has not worked well. Also discuss issues such as transportation, residential situation, work, recreation, and other lifestyle factors. All of these will impact the design of the seating system in some way.

The creative aspect of designing the patient's seating and mobility system begins during the evaluation. Ideas, no matter how radical, that the participants might have should be expressed. These ideas, particularly those of the client, are very important to ensuring the success and value of the outcome.
By the end of the evaluation, all members of the team should have a solid concept of how specific issues will be addressed in the final design. It is important for one person on the evaluation team to summarize what is planned in writing and distribute the document to the rest. That document serves as a certificate of medical necessity (CMN) when there are third party payers involved and should contain a complete rationale for the most important design features of what will be provided. It is a vital document useful in many ways. It is signed by the evaluating care professionals and by the prescribing physician. Appendix A contains an example of a form for recording information obtained during the evaluation, CMN examples typical for CP and Spinal Cord Injury (SCI) diagnoses, and a form to record information needed by fabricating personnel.

CEREBRAL PALSY

Approximately 25% of all children with cerebral palsy (CP) will develop scoliosis.[6] The incidence rises to about 60% for those children classified as spastic quadriplegic. Most children with CP of Gross Motor Function Classification System (GMFCS) levels IV and V[7] are not ambulatory by the age of about 10 and usually do not develop good independent sitting ability. Patients in this subgroup are the ones most likely to develop spinal deformities of consequence. If they are not provided quality sitting support, most of them slump into a single, long kyphotic or kypho-scoliotic curve with a postero-laterally tilted pelvis (Fig 5).


Fig 5

Within the GMFCS IV and V classification levels there are large variations in the extent and complexity of the sitting support system needed. Some of these patients will need only pelvic and low thoracic components. Others will need passive alignment up to and including the head.

If pelvic mal- alignment and spinal column collapse are left to progress unchecked, cardio-pulmonary function may become compromised. During adult years pressure ulcers may also develop and care may become very difficult and expensive.

Goals

Many of the goals of the orthotic and adaptive equipment system for people with severe CP also apply to other neuromuscular diagnoses. When the seating and adaptive equipment system is complete it should enhance virtually all functions, for both the patient and his/her family. For instance, when a patient cannot eat independently, it will make it easier for a caregiver to feed him/her. It will improve the patient's field of vision, increase his/her comfort and maximize his/her level of independence. A functional seating system improves the patient's education and social development, creating a more enjoyable existence for the entire caregiving family.

A wheelchair mounted lap tray is almost always an essential component of the adaptive equipment for GMFCS IV and V patients. In addition to being a functional surface for reading, writing, communication devices, etc., the lap tray almost always serves an orthopedic purpose as well. When closely fitted and installed at the right height, the patient's elbows and forearms will support a significant portion of the weight of the patient's upper body. The lap tray (Fig 6), padded if necessary, will then relieve the spine of a considerable flexion bending moment. This will markedly reduce thoracic hyperkyphosis so the patient is able to more actively maintain a more erect, functional, attentive and cosmetic posture.

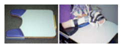

Fig 6

The orthopedic issues in CP are caused by the neurologic problems so it is important to reduce muscle tone and minimize spastic reflexes. By incorporating body positions, which reduce reflex patterns into the seating system, upper body function will be improved and the progression of deformities may be reduced. This is a very prominent consideration in the design of the Gillette SSO and will receive more discussion later.

Wheelchair seating safety issues are very important to consider. (Automobile seat safety requirements vary and will not be addressed here.) First, a safety belt must wrap around the child and seat and be anchored to the wheelchair with an easily released buckle. Most wheelchairs can be equipped with posterior anti-tip components. On many wheelchairs, rear wheel position may be adjusted to create a longer wheelbase. The potential for forward overturn of the patient, equipment and wheelchair as a whole is addressed by positioning the patient adequately back and down in the wheelchair. Often that requires special recessing adaptations for both seat and wheelchair. See appendices B and C.

Gillette Sitting Support Orthosis (SSO)

The Gillette SSO was developed to address the progressing deformities and functional needs of the many youngsters with severe CP arriving at that institution. Those children presented a wide variety of neurologic and orthopedic conditions. With regard to spinal deformity, it was recognized that these non-ambulatory patients needed pelvic alignment control that could not be provided by a TLSO. The GCSH position on the inadequacy of a TLSO for this patient group was corroborated by Olafson, Saraste and Al-Dabagh[8] who reported dismal results from Boston Brace treatment of a group of 66 non-ambulatory neuromuscular patients.


Fig 7

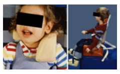
Fig 8

The Gillette SSO proved to be very user-friendly and an effective spinal orthosis for this population (Fig 7). Its effectiveness was due, in part, to providing enough comfortable hip flexion to greatly reduce initiation and strength of the hip-knee extension spasms that often exhibit overflow to the upper spine and limbs. As an orthopedic device, it affords a way to manage pelvic alignment, thoracic support and even cervical and cranial control as needed (Fig 8).


Fig 9

The SSO shell is a thin strong structure that fits closely where support is needed. Because the thermoplastic shell is thin, thoracic support can extend high into the axillae without blocking upper limb adduction needed for comfort and function (Fig 9). The open front of the SSO serves an important function. It allows easy palpation of the iliac crests to observe the degree of lateral pelvic tilt and guide adjustment during donning. The shell is rigid enough for mounting the essential pelvic belt as well as a wide variety of headrest, head control and thoracic support panels.

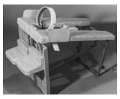
Fig 10

Fabrication of a Gillette SSO begins with obtaining an impression of the patient's dorsal and lateral surfaces in the seated alignment necessary to achieve the neurologic and orthopedic goals. This is best accomplished with a special casting frame (Fig 10). The process of obtaining the impression, fabricating and fitting are described in appendix B.

The completed Gillette SSO, like any orthopedic device, must be properly donned or, in this case, "gotten into". The non-ambulatory patient with cerebral palsy is likely to experience some hip extension reflex and increased tone when caregivers transfer him/her into the SSO, preventing the pelvis from sinking down and back into the pelvic area of the SSO. After loosely fastening the pelvic belt and locking the wheels, the caregiver should proceed to the back of the wheelchair. With wheels locked, he can then tip the wheelchair, SSO and patient about 45 degrees posteriorly, leaning the upper back of the wheelchair against his midsection. In this position, which recruits the help of gravity, it is easy to tuck the patient's pelvis down and back well into its proper location in the SSO and to straighten his pelvis at the same time. If the patient has scoliosis, his pelvis will tend to tilt laterally in the direction of the scoliosis convexity. If the scoliosis curve is convex right, the right side of the pelvis will be lower than the left. The caregiver must pull upward on clothing at the right hip area to level the pelvis as much as possible. Simultaneous downward pressure on the opposite side will assist this correction. This procedure is referred to as "pelvic leveling" and is easily accomplished with the wheelchair leaned back against the caregiver as described above. Immediately after the pelvis is leveled, the SSO lap belt should be fastened snugly. The wheelchair may then be returned to its upright orientation and the safety belt secured.

Before caregivers take the wheelchair seating system home, and at every other opportunity, proper positioning and pelvic leveling should be reviewed. In addition, caregiver education includes a discussion of how long a child might be expected to remain seated; the importance of checking for reddened areas; and the need for regular, frequent clinical assessment and modifications by the seating specialist.

Because of its durability, the SSO can serve an adult for more than a decade with minor periodic refurbishing. When provided for a growing child, the shell should include removable pelvic growth pads bilaterally at the greater trochanters. These may be thinned and finally removed as the child grows. Strategic heating and reforming of the postero-lateral quarters may accommodate thoracic width increase. Vertical sub-axillary extensions can be welded onto the shell if and when thoracic support needs to extend higher. If the technician is adept at making such modifications, the SSO will serve a school age child for between two and three years.

In some parts of the world, technical labor is very expensive and premanufactured seating components are commonly utilized. Those systems are available in many sizes and are very adjustable to meet a spectrum of head, neck, spine and pelvic support needs. The biomechanical principles presented earlier should be a valuable guide regarding how to select and fit premanufactured systems.

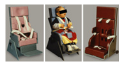

Fig 11

When circumstances prevent provision of either the Gillette SSO or premanufactured sitting support systems a more rectilinear sitting support (RSS) may be the next choice (Fig 11). In this case, the seat fabrication starts with a wood or plastic frame sized to the individual. This design may be either a free standing unit or it may be attached as components to a stroller or wheelchair. The frame is appropriately padded and upholstered. Thoracic and head supports are mounted as needed. The rectilinear frame designs also may be a very adequate choice and preferred in cases where scoliosis concerns are minimal and closely conforming orthopedic support is not required. The fabric corset-type TLSO can be used in combination with an SSO but that is rarely beneficial for CP patients who usually exhibit good abdominal muscle tone.

Some ambulatory children with CP do develop scoliosis. When this is the case, a plastic shell TLSO may be useful to control progression during the growth spurt.

DUCHENNE MUSCULAR DYSTROPHY

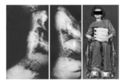

Fig 12

Approximately 90% of boys with Duchenne Muscular dystrophy (DMD) will develop a significant spine deformity.[9] The scoliosis begins to develop after they become non-ambulatory. If they manage to prolong ambulation into the teen years, the spine begins to acquire a full-length lordosis. These youngsters carry that fairly stable posture into their years of wheelchair use (Fig 12). Boys who stop ambulating earlier are likely to develop a severe kypho-scoliotic deformity including, of course, a mal-aligned pelvis. Spine fusion, where available, is the preferable option to avoid the consequences of allowing deformity to progress.

<u>Goals</u>

As with CP, managing a spinal deformity for a patient with muscular dystrophy (MD) is not an isolated goal. It must be tempered and tailored for a best fit with other very important interwoven goals. To the extent that they can be addressed individually, the five main goals will be discussed in the following order: optimize comfort; optimize upper limb-hand function; manage spinal deformity; preserve or improve pulmonary function; and be as safe and stable as practical.

Providing adequate comfort in the sacro-pelvic area is a challenge for all MD patients. Pain associated with prolonged pressure and friction-induced shear at supportive bony areas are major issues. If the patient's seat cushion can reduce pressure, shear, moisture and heat, he will be more comfortable. He will need repositioning and unweighting less frequently, thereby reducing caregiver burden. Complete information for alleviating pressure, shear, moisture and heat is found in the section on spinal cord injury (SCI).

With properly designed sitting support and adaptive equipment, these young men can retain hand function until their disease is very advanced. That optimum function depends on several things:

- An easily adjustable anterior support strap, anchored to the SSO that allows them various degrees of forward body incline. A bandolier style strap works well and is cosmetically more acceptable than a horizontal chest strap;
- A lap tray closely and securely mounted on the wheelchair at a height determined by self-feeding, writing and joystick trials; and
- A forearm bolster located on the lap tray under the forearm near the elbow of the patient's dominant side to act as a vertical and horizontal pivot point. Without such a little bolster the patient will often "crawl" his non-dominant hand across to act as the lift and swing fulcrum for his dominant forearm. Just like the lap tray, trial and error will determine optimum bol ster thickness and placement. The non-dominant hand can then be employed as a helper to stabilize items on the tray.

With the right amount of forward incline and lap tray set-up, a patient may be able to bring his hand to his mouth by simultaneously lowering his head, dominant shoulder and upper arm. His forearm will pivot at the bolster to raise his hand toward his mouth. Writing, drawing, gaming, keyboard operation and using a powered chair joystick are possible even with limited movement of the upper extremity and shoulder.

Fig 13

If a spinal fusion is not performed, boys with MD do best if they receive a fabric TLSO for use with their custom SSO soon after fulltime wheelchair use begins. In this case, a comfortable, symmetrical, corset TLSO can be fabricated from measurements (Fig 13). The combination of pelvic alignment and hydraulic spinal support will provide patient comfort and function until a fusion is performed. The TLSO should be of a tailored heavy-duty corset material reinforced with flexible stays. The abdominal support needs to be flexible to allow for some forward bending, and air permeability for moisture and temperature moderation. Two corset TLSOs should be provided because each must drip-dry for about 24 hours after laundering.

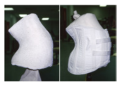

Fig 14

The seating expert who must provide wheelchair spine support for an MD patient with an unfused spine and already severely collapsing kypho-scoliotic spine has a challenge of heroic magnitude. Scoliotic collapse progresses rapidly if the pelvis is free to tilt laterally. The spine deformity quickly loses flexibility and becomes very severe including a pelvis that cannot be completely leveled. Comfort issues become very difficult to manage. In such cases, a cast and model of the patient's torso may have to be obtained for corset fabrication. Fabric panels may then be fit to the model and sewn into a more shape-conforming corset (Fig 14).

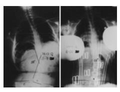

Fig 15

A well-fitted corset TLSO and SSO combination can provide powerful spine stability and improved comfort if caregivers consistently use the pelvic leveling procedure described earlier (Fig 15). More information about the Gillette SSO appears in the cerebral palsy section and in appendix B.

It is especially gratifying when one fits an orthosis to achieve a certain benefit and discovers a surprise additional benefit. In the biomechanics analysis near the beginning of this chapter, we discussed how a fabric abdominal corset type TLSO reduces axial and bending loads on the spine. Such a corset has been provided for many patients with flaccid abdominal wall muscles. Quite by chance, we discovered that, in addition to spine support, some of those patients also gained significant pulmonary function benefits including stronger voices, stronger coughs, and less anxiety.

The secondary pulmonary benefit was discovered when we straightened the sitting posture of a boy with MD who was very slumped forward in his wheelchair. When we brought his shoulders up and back, extending his thoraco-lumbar spine, he could not adequately breathe. In that straightened position the opening between his rib margin and pelvis was enlarged, allowing abdomen to protrude and pull down his diaphragm. His compromised inspiration caused him great anxiety. The simple answer to improve both posture and lung function was a fabric corset with circumferential adjustability. Circumferential constraint can then be titrated to best satisfy the patient.

Safety concerns relating to dynamic overturn instability have been mentioned earlier in this chapter. Boys with muscular dystrophy are very conscious of susceptibility to forward overturn. Most will refuse to use a system that places the center of gravity (CG) of their body too far forward and/or elevated relative to the wheelchair.

SPINAL MUSCLE ATROPHY

Spinal muscular atrophy (SMA) comprises a spectrum of severity levels. Type I SMA is evident in infancy. It is the most severe type. Types II and III begin to develop later in childhood. The three types represent more of a spectrum of severity rather than distinctly separate types. Scoliosis develops in virtually all of the most severe, type I cases, most of the type II and approximately half of the type III.[10] The spine progressively loses stabilizing musculature and tends to collapse under the influence of gravity.[11] Pulmonary function will then decline.

The SSO and fabric TLSO are the most appropriate orthoses for SMA. The biomechanical considerations for improving spinal support and pulmonary function are very similar to DMD.

SPINAL CORD INJURY

If the spinal cord injury (SCI) occurs before the age of 10 years, a secondary spine deformity will develop.[12] Spine fusion before the deformity becomes severe is usually recommended where available. However, the vast majority of spinal cord injuries happen later, near the close of, or after, physical maturity. This reduces the probability that scoliosis will develop. If it does, a laterally tilted pelvis is almost always part of that deformity.

Most of the muscles which contribute to thoraco-lumbar stability and control are segmentally innervated. In addition, a spinal cord lesion may be incomplete and/or asymmetric. Consequently, it is wisest to evaluate the sensory level, volitional control, pulmonary function and story of the patient rather than rely on a specific lesion level report. As with all neuromuscular diagnoses, each patient presents you with a specific combination of sensory level, abilities, concerns, aspirations and critical information about his activities of daily living and work-life.

Orthotic Management of the Paralytic Spine

Following acute stabilizing surgery, a rigid TLSO, with cranio-cervical components when necessary, may be used to help maintain stability of the fracture site until the fusion is solid. As a result of the improved stability of new implants not orthosis may be necessary. As the rehabilitation process continues and the fusion matures, maintenance of a functional posture becomes very important. People with low paraplegic level lesions have considerable voluntary trunk control. They can sit very erectly and can easily straighten up after bending forward.

Most people with paraplegia secondary to SCI live independently soon after they are discharged from rehabilitation. They typically use a lightweight, highly maneuverable manual wheelchair with a low lumbo-sacral back support, a cushion and no lateral supports. Freedom of movement within the wheelchair is key to realizing their functional potential.

Progressively higher lesion levels leave the SCI patient with less control of spinal musculature. People with low quadriplegia level lesions may be able to be independent in most activities of daily living. Most can, at least for some years, use a manual wheelchair. Their upper body function depends on trunk stability achieved through a “slumped” posture, that is, a very kyphotic thoraco-lumbar spine supported on a posteriorly tilted sacro-pelvic base. This posture provides a fairly solid base for upper spine, shoulder and arm function. That partially collapsed posture also provides close upper extremity access to the manual drive wheels. It seems counterintuitive, but for certain lesion levels, some degree of postural slump also facilitates pulmonary function. The downside of the slumped sitting posture is that it makes it more difficult for the thighs to share some of the upper body weight. The consequence is greater peak skin surface pressure and friction loading on the sacrum and ischial tuberosities.

People with high quadriplegic level lesions need a full-length posterior support and bilateral thoracic supports in combination with several degrees of recline. It is highly recommended that the seat bottom and back recline as a unit.

Decubitus Ulcer Prevention

People who use wheelchairs for daily mobility and function, specifically those with impaired sensation such as the case with SCI, are at constant risk of developing a serious sub-pelvic or sacral ulceration. Decubitus ulcers, also called pressure ulcers, destroy careers, marriages and quality of life. Septicemia secondary to these wounds is a common cause of early death among people with spinal cord injury.
It is extremely important that we focus on prevention because of the severe consequences and because each occurrence or reoccurrence of a stage III or IV ulcer multiplies the difficulty of preventing the next one. Even in parts of the world where the best “off-the-shelf” adjustable cushions are available, some decubitus ulcer issues are so severe that a custom fabricated cushion is prescribed. In all cases it is important that providers understand seat cushion design features that will help prevent decubitus ulcers from developing.

The first step in prevention is a full understanding of the direct causes operating at the ulcer site. There are four physical conditions at the skin surface of potential ulcer sites that contribute to tissue trauma and which seating design can affect; those four are: pressure, friction, temperature, and moisture.

Pressure

Of the four, pressure is the most obvious. When contact pressure is too great, blood cannot flow in to bring oxygen and nutrients to the cells nor remove toxic metabolic byproducts. If that high contact pressure persists too long, cells die. This is the ischemia model.

We know from long experience that excessive pressures occur where skeletal elements lie close to the skin surface in weight bearing areas. There are three ways to reduce those peak pressures; with cushioning materials; by structural shaping of the supporting surface; and with fluid flotation.

Cushion materials increase weight bearing contact area and thereby reduce peak pressure. However, those vulnerable locations continue to be where the tissue is subjected to the highest pressure. Orthotists and prosthetists know from long experience that shaping of the contact surface is an effective way to transfer forces away from bony, intolerant, areas. Areas of deeper soft tissue are more load tolerant. So, just like in a shoe insole or trans-tibial socket, a very good approach is to use a combination of shaping with only as much cushioning as is necessary to off-load at-risk areas. However, it is difficult to precisely locate, size and shape support surfaces to lower all peak contact loading.

Fluid flotation is the third method listed above but has some negative characteristics and limitations. To truly float the user, the fluid must generate a weight-resisting pressure when in use. If the fluid is air, leakage can reduce user protection to zero, sometimes without the user's awareness. Also, a totally fluid support surface reduces the opportunity to transfer significant load from the pelvis forward onto the thighs.

Finally, with regard to pressure, we must understand the role of the wheelchair footrest. If the wheelchair footrest is too elevated, it will totally negate any efforts to transfer weight-bearing pressures from the pelvis to the thighs. The posterior thighs have no bony prominences and can safely bear higher pressures than the ischial tuberosities. Weight can be shifted from the pelvis to the thighs by shaping a gentle thigh fulcrum into the structural material of the seat cushion in the area of the proximal thighs. See the exaggerated depiction on the left of figure 16. The footrest may then be adjusted lower so that the femurs act like levers. The lower leg weight operates on the lever to partially lift and reduce pressure under the pelvis. The mechanical equivalent appears on the right of figure 16. It is interesting to observe that when we occasionally sit on a table we soon place our hands under our proximal thighs. The weight of our distal thighs and dangling lower legs and feet reduces pressure at the ischial tuberosities. Pelvic unweighting is enhanced even more if we lean our upper body forward a bit. This feature in a wheelchair cushion works the same way to enhance the benefit when a person with SCI leans forward.

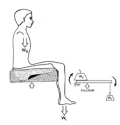

Fig 16

The ischemia model for pressure ulcer generation has been useful and has dominated cushion design almost exclusively. The other three factors have received too little attention from cushion designers. This is unfortunate. Additional strides in prevention of these wounds are possible when we give more attention to technologies that will reduce skin friction, temperature and moisture in at-risk tissue areas.

Friction

Friction, the second in our list of contributors to tissue trauma, is not as easy to visualize as pressure. Friction force is important because it profoundly elevates shear distortions within the soft tissues. Shear is a type of tissue deformation in which neighboring levels/layers of the tissue are dragged or pulled parallel to each other. Friction on the skin surface is a kind of skin traction. The direct result of this kind of loading is shear stress and strain in nearby soft tissue. Some shear conditions are present within the soft tissue under all loading conditions. This is especially the case in close proximity to bony prominences. Bennet's research[13-15] found that surface friction induced shear stress of 100g/cm2 when superimposed on simple pressure, causes capillary blood flow occlusion to occur at much lower pressures than in the absence friction. More specifically, he and his colleagues found that an ulcer could be generated in approximately half the time under those circumstances. Since it is well established that friction-induced shear distortions contribute to the formation of ulcers, it is important to know how we can minimize shear.

There is a common misconception that shear damage can only occur as the skin slides across a contact material. In fact, friction and accompanying shear stress at significant magnitudes do not go away once the person has settled into his wheelchair. As a person settles to a resting position, friction has a role in exactly where movement stops within the seat cushion. Friction is, in fact, traction on the skin directly subjecting skin and soft tissues to a shear distortion. Static friction forces may actually be greater than when sliding is occurring. Friction, and the soft tissue shear it causes, can persist and do its damage all during the many static hours of wheelchair use or bed use.

There are two ways to minimize shear. The first is by reducing the friction needed to keep the client in his/her chair. The tendency to slide is reduced by creating a recess in the cushion that cradles the pelvis and then slopes upward toward the distal thighs. Providing lumbar and other back support to bring the wheelchair user to a more upright, less kyphotic, posture will also help. When the patient is quadriplegic, one must be careful, of course, not to bring the client too close to the forward tipping point unless he has anterior thoracic support.

The second way of minimizing shear is to provide a very slippery interface under the specific at-risk areas. Friction is bad only in ulcer prone locations. In other areas, where the layer of soft tissue is thicker, friction contributes to sitting stability and causes no problems. Unfortunately lubricating agents quickly seep and spread beyond the area of application. In a short time, they cause skin hydration and mix with exfoliants. The result is that the mix on the skin surface becomes somewhat sticky which is a very unhelpful development. Selecting the right materials for the interface at a specific location can almost totally eliminate friction forces without lubrication.

The amount of friction-induced shear trauma is governed by the natural "grippiness" or "slipperiness" of materials between the skin and the support surface. The friction characteristic of a given pair of materials is measureable and known as the coefficient of friction (COF). When materials do not slide easily across one another, that pair of materials has a much higher COF than a pair of materials that glide easily across one another. Most material combinations exhibit a measured COF between 0.2 and 0.9 but a few COF values can be outside that range.

Fig 17

Friction can be managed strategically by locating an area of very low COF material under the bony areas and using a mid-range COF, commonly available fabric or foam material in all the other weight bearing areas (Fig 17). During the hours of sitting, bony area movements remain within the low COF zone. This arrangement allows the skin covering the bony prominence to glide those small amounts along with the bone as the user goes about his/her activities of daily living. The COF and friction in the more extensive, less vulnerable areas, is higher and provides the needed stability.

Temperature

Elevated temperature and moisture are the third and fourth localized surface conditions contributing to pressure ulcer generation. These two are partially interrelated because evaporation reduces both. Temperature is a factor because a one degree centigrade rise in temperature will increase cell metabolic rate by approximately 10%.[16] In other words, if we can keep vulnerable tissue a bit cooler, the onset of cell death will be delayed.

Moisture

Moisture is last on this list but not the least important. In addition to possible unhealthy skin reactions to the contents of urine and sweat, we know that moisture weakens the outermost layers of the epidermis. Moisture also tends to increase at the skin-fabric interface and any other fabric interfaces located between skin and support surfaces.

Materials with good wicking characteristics and/or which allow air to circulate close to the skin may facilitate both reducing heat and moisture. If the cushion and/or the cushion cover are air-permeable, moisture may be evaporated reducing both moisture and temperature at the skin surface. Unfortunately, many cushions are made of materials that insulate, preventing moisture and metabolic heat from escaping. When a client has a demonstrated pressure ulcer risk, the professional caregivers should consider every one of these four contributing factors.

It should also be mentioned that some covers significantly cancel much of the benefit of a well-designed cushion. An ideal cover should be of a material that easily stretches in all directions. Such a material allows the body to immerse into the deeper contours of the cushion with minimal resistance or folding.

Pulmonary Function

Some people with quadriplegic lesions present with shallow breathing and weak cough. Because of very shallow pulmonary function, some cannot speak louder than a whisper. Similar complications were mentioned earlier for MD patients. Pulmonary function issues are encountered so frequently among cervical level SCI patients that it should be routine to perform a quick test. The test consists of applying a moderate amount of passive static abdominal compression to see if it will make a significant difference. When the test is positive the patient should receive a fitted fabric jacket. The improved breathing, coughing and in some cases, voice volume will be remarkable.


Fig 18

A literature search indicated that these clinical findings are consistent with what speech and pulmonary function researchers have reported.[17,18] It is unfortunate that corsets are not more frequently prescribed. The gentleman in (Fig 18) was a classical demonstration of these pulmonary function issues. He had an SCI for many years when referred for improved sitting support. All during the initial interview his left fist was poked a few inches into his midsection. When asked about the reason for this, he seemed hardly aware of that habit but said it just made him feel better. He had found his own solution to being able to breathe a little better. Unfortunately, it cost him the ability to use that arm and hand for other things. A fabric abdominal jacket TLSO or even an abdominal binder would be a better solution.

People living with quadriplegic level SCI have a limited ability to perform the periodic unweighting maneuvers that help prevent pressure sores. They need wheelchair cushions of the very best quality and many also need powered tilt-in-space wheelchairs. The tilt-in-space feature preserves the occupant's entire posture and seated joint angles as it tilts backward to reduce the weight on sub-pelvic surfaces. It is the safest way to mechanically unweight while remaining in a wheelchair.

Wheelchairs, which recline the backrest while leaving the sitting surface horizontal, create large shear-producing friction loads on all weight-bearing skin from head to thighs. Those friction forces are further elevated as, and after, the backrest is moved back toward vertical. There are very few patients for whom this type of wheelchair is appropriate.

Slings are sometimes the best way to transfer a patient between bed and wheelchair. Transfer slings should be carefully removed when the transfer is complete. If the sling is not removed after each transfer, it should be designed to insure that none of the sling material remains between the pelvis and the cushion after the transfer. Sturdy sling fabric remaining under the pelvis could negate the effectiveness of the wheelchair cushion.

MYELOMENINGOCELE

The myelomeningocele malformation causes severe, localized spinal instability because of the severe posterior defect with a resultant angular kyphosis. In addition there is often additional neuromuscular scoliosis or scoliosis related to congenital vertebral anomalies. The incidence of hyperkyphosis and/or scoliosis varies from 52% to 90%.[19] Spinal orthoses have a limited role in the management of spinal deformity in this diagnosis. The area of the myelomeningocele lesion lacks the posterior bony structure and spanning muscle system required to resist kyphotic collapse. Spine support devices must avoid any forceful contact in the area of the kyphotic gibbous where such force would otherwise be mechanically effective. In fact, special modification is often necessary to ensure that area is protected from any forceful contact.

Fig 19

Plastic shell TLSOs are sometimes used to resist deformity progression while the child is very young (Fig19). This can allow some vertebral growth and development before fusion. The TLSO should be a two-piece shell to facilitate gentle, precise placement during donning. The gibbus, when present, must be protected by a non-contacting bulge in the orthosis. The same or a similar TLSO may be used to protect alignment after surgery while the fusion solidifies. The major spine support benefit of the TLSO in this case probably comes from the hydraulic effect of the snug abdominal containment of the plastic shell. The TLSO is not used at night except when needed to protect the area of the lesion or when used for post-fusion stability.

Many older children and adults with myelomeningocele will find a wheelchair to be the most practical means for everyday mobility and daily living. They will have some degree of impairment of lower body sensation and will present skin protection needs similar to those presented by people with SCI.

POLIOMYELITIS

In an unpublished written communication to John Fisk in 2014, Hugh Watts observed that, “Scoliosis as a result of polio paralysis, broadly speaking, is seen in two groups of children.” He observed that the more severe group, who have extensive trunk muscle paralysis and develop scoliosis very early, cannot pull away from pads applying support pressure. The children of the less severe group have more voluntary trunk control and the spinal deformities, which develop more gradually, tend to remain flexible longer. Functional sitting may be possible in spite of a collapsing spinal deformity. The authors of this chapter have encountered a small number of adult polio survivors who are dependent on a wheelchair for movement outside of home but have some ambulation ability within the home in spite of a severe, flexible spine deformity. Those individuals relied on corsets of leather or fabric to provide them with a comfortable modicum of trunk support.

The first author’s limited experience and Watts’ report would suggest that plastic shell spinal orthoses are not appropriate for poliomyelitis patients. Some sitters and marginal ambulators with a flexible, collapsing spinal deformity will benefit from a well-fitted, circumference-adjustable fabric LSO or TLSO. Adjustability of the circumference of the corset is important because pulmonary function is optimized at some mid-range abdominal constraint level. The swing-to crutch ambulators will find that the corset moderately reduces the energy required for ambulation. The abdominal constraint decreases the amount of spinal collapse each time as ambulation transitions from shoulder weight bearing to pedal weight bearing.

Finally, some of the polio patients will present with a neuromuscular condition and functional needs similar to what is encountered by people with MD, spinal cord injury or some combination. See those sections of this chapter for custom orthotic seating information.

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APPENDIX A
APPENDIX B
APPENDIX C

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18

Orthotic Management of Scheuermann Kyphosis

Steven E Koop

DEFINITION

Normal, or typical, thoracic kyphosis is defined by a range of Cobb angular measurement obtained from standing lateral radiographs of a large number of individuals. A study of 121 typically developing children, ages 5-19 years, demonstrated mean thoracic kyphosis of 33°.[1] The films were done with the subjects standing erect with arms placed at right angles to the torso by grasping the crossbar of a ladder. The method was developed through a trial of different arm positions. Kyphosis was measured from T2-T12 in 49%, T2-T11 in 10%, T1-T12 in 10%, T3-T12 in 7%, T2-L1 in 13% of subjects. The range of kyphosis was 17° to 51° with statistical difference between genders or by age groups (5-9, 10-14, 15-19 years). One standard deviation was represented by kyphosis of 25° to 42°, and two standard deviations was represented by kyphosis of 20° to 50°. In addition to the challenges of utilizing standard radiographic techniques, measurements of the Cobb angle vary between observers and across time. This is demonstrated in a study of radiographs for 30 individuals undergoing evaluation for kyphosis.[2] The radiographs were measured twice, at least 16 days apart, by four examiners. The mean intra-observer variance was 4.3° with a 95% confidence interval of ±9.6°. The 95% inter-observer confidence interval was ±8.7°. Curve magnitude did not vary with the variance in measurement.

These studies indicate that thoracic kyphosis in children and adolescents follows a normal distribution in which two standard deviations is 20° to 50°. Radiographic methods and measurement techniques are important. Cobb angle differences ≥8° may be needed to state that change is present as a result of growth or the effects of treatment.

Holger Scheuermann, a Danish radiologist and orthopaedist, described the radiographic characteristics of the deformity that now bears his name.[3] His findings included increased thoracic kyphosis in the skeletally immature with wedging of vertebral bodies and irregularities of vertebral endplates. Sorenson proposed the criteria under which the term Scheuermann's kyphosis could be applied: three adjacent vertebrae with at least 5 degrees of wedging.[4]

INCIDENCE

Publications on Scheuermann Kyphosis (SK) frequently state that the condition occurs in 1% to 8% of the population and slightly more common in males. It is most commonly diagnosed in early adolescence. The etiology of Scheuermann kyphosis is unclear. The prevailing opinion is that some individuals have a genetic predisposition to the condition. This appears to be best described by a dominant major gene diallele model.[5] Survey responses of 34,007 twins from the Odense-based Danish Twins Registry, born in the years 1931-1982, yielded a self-reported prevalence of "Scheuermann disease" of 2.8% (2.1% among women, 3.6% among men).[6] Pairwise concordance was 0.19 for monozygotic twins and 0.07 for dizygotic twins. The odds ratios were 32.92 for monozygotic twins and 6.25 for dizygotic twins. The authors concluded that a major genetic contribution exists for the etiology of Scheuermann disease. Some authors believe that certain physical activities may incite vertebral endplate changes and growth alterations that result in wedging. No study has been able to demonstrate this in a convincing manner.

CLASSIFICATION

Despite the precision of Sorenson's criteria subsequent publications are inconsistent when applying the term Scheuermann kyphosis. Most authors would agree that the term applies to thoracic kyphosis ≥45° with vertebral wedging that meets Sorenson's criteria, endplate irregularities (including Schmorl's nodes), and narrowing of disc height. Cadaveric studies have demonstrated abnormal endochondral growth in the ring apophysis of wedged vertebrae.[7] Disagreement appears when describing patients with diffuse milder wedging, focal severe wedging of one or two vertebrae, or changes in the thoracolumbar or lumbar spine. Therefore no agreed classification system exists for Scheuermann condition. Most authors apply the term "severe" to kyphosis ≥70°. Authors speak of curve stiffness as a measure of severity but a consistent definition does not exist.

NATURAL HISTORY

Many questions exist regarding the long-term consequences of untreated Scheuermann kyphosis. Will the kyphosis increase with age? Will appearance be altered in a way that leads to undesirable social consequences? Will increased kyphosis limit physical activities, including work? Will altered torso shape affect heart and lung function? Will increased kyphosis predispose to neurologic dysfunction? Will individuals experience pain?

A study from the University of Iowa provides some answers to these questions utilizing methods consistent with Level III evidence.[8] From an initial group of 118 individuals who met Sorenson's criteria, 67 were located and agree to participate in an assessment. All completed a questionnaire and pain evaluation tools, 55 were examined, 54 had radiographs performed, and 52 underwent pulmonary function tests. The group included 46 males and 21 females with mean kyphosis of 71° (range 37°-110°). The mean age of the participants was 53 years (range 25-82 years) and mean follow-up was 32 years (range 10-48 years). The results of their assessments were compared to those of 34 volunteers. The individuals with Scheuermann kyphosis did not show a difference in job type or the average number of sick days due to back pain but they tended to be more sedentary in the workplace. They were less likely to report no pain in the preceding month (28% versus 62% of volunteers), more likely to report pain that interfered with activities (38% versus 21% of volunteers), more likely to report thoracic pain (28% versus 3% of volunteers) but reported no differences in activity levels. Individuals with Scheuermann kyphosis demonstrated no difference in education, self-consciousness, or self-esteem unless they had experienced curve progression. There was not difference in marriage rates for curves ≤85°. In general, expressions of concern about any of these factors decreased with age. No clear differences in health that could be attributed to the hyper-kyphosis could be demonstrated. Five individuals (10%) were found to have mild neurologic changes (decreased proprioception, decreased response to pinprick and decreased vibratory sensation). Hamstring tightness was found in sixteen individuals (29%). Pulmonary function tests demonstrated mild reductions in inspiratory capacity and forced vital capacity when kyphosis exceeded 85° or the apex was in the upper thoracic spine. In all cases pulmonary function tests still exceeded 75% of predicted. The researchers concluded that Scheuermann kyphosis did not have major adverse consequences during adulthood.

A study from Finland, with Level IV evidence, had similar results.[9] From an initial cohort of 255 individuals a group of 49 were found to meet Sorenson's criteria with a curve apex in the thoracic spine. There were 37 males and 12 females with a mean age of 59 years and mean follow-up of 37 years. Baseline radiographs demonstrated mean kyphosis of 45° (standard deviation 16°) with an average of 4.9 vertebrae demonstrating ≥5° of wedging (mean = 9.2°). Current radiographs and physical examinations were not done. Pulmonary functions tests were not obtained. The group was compared to a representative sample of 1,851 males and 1,984 females drawn from the Health 2000 study. Age and gender-adjusted odds ratios with 95% confidence intervals for different risk factors were calculated for Scheuermann kyphosis compared to controls. Individuals with Scheuermann kyphosis had an increased risk for constant back pain (odds ratio 2.5), back pain in the last 30 days (odds ratio 3.7) or sciatic pain (odds ratio 2.3) but reported no differences in pain-related disability at work, during leisure activities or while performing domestic tasks. A higher number of individuals with Scheuermann kyphosis reported difficulty carrying a 5-kilogram load at least 100 meters (odds ratio 5.4) or walking up one flight of steps without rest (odds ratio 7.2). There was no correlation between the magnitude of the kyphosis and pain, function or overall quality of life. Neurological deficits are rare in Scheuermann kyphosis but have been reported.[10] When they occur it is the result of anterior spinal cord compression. This can develop as a result of cord compression at the apex of the kyphosis, disc herniation, or extradural cyst formation.

ROLE OF ORTHOTIC TREATMENT

There are two roles for orthotic treatment of Scheuermann kyphosis: resolution of pain during adolescence, and reduction of the magnitude of kyphosis in the hope that long term treatment outcome studies will demonstrate less pain and better physical function when compared to natural history studies.

EVIDENCE-BASED REVIEW

All studies of orthotic treatment of Scheuermann kyphosis have Level IV evidence. Three will be reviewed.

A study from Texas started with 203 individuals.[11] Milwaukee brace (Fig 6) treatment was recommended to 62 individuals and at the time of publication 12 were in active treatment. That left a study group of 50 individuals; eleven (22%) started treatment and abandoned their orthosis while 39 completed treatment. The mean age at starting orthosis wear was 14 years (range 10-19 years), mean kyphosis was 62° (range 43°-87°), mean time in the orthosis was 18 months (range 10-36 months), and the mean kyphosis at the completion of orthotic treatment was 41°. The orthosis was worn "full-time" until maximum improvement of the kyphosis was achieved (usually 6-12 months) at which point "gradual" weaning took place over four to six months. This was followed by an interval of wearing the orthosis while sleeping. Groups based on initial curve size were examined. A pattern of kyphosis


Fig 6

reduction followed by increase was noted in all groups. Twenty-four of 39 patients achieved kyphosis reduction to ≤45° but only 12 stayed ≤45º° at the end of orthosis treatment. Twenty-one patients had follow-up more than 18 months after completing brace treatment; 16 experienced increased kyphosis by an average of 15°. The researchers speculated that more time in the orthosis once maximum correction was achieved might have helped maintain the improvement.

A study of Milwaukee brace treatment in Minnesota had more patients and longer follow-up.[12] The initial group was 274 patients but 136 (47%) were lost to follow-up during active treatment in the orthosis. Eight had <5 years follow-up after completing treatment, 10 refused radiographs, 4 had initial kyphosis <45º° and were excluded, and 2 had undergone surgery, leaving a study group of 120 patients. This group had 44 males and 76 females. The mean age at the start of treatment was 12 years and 5 months, and Risser stage 2 was the typical maturation assessment. The mean time in the Milwaukee brace was 32 months (range 5-111 months) and the mean age at follow-up was 24 years. The researchers determined that 110 patients had worn their orthosis "consistently." Four groups were created from these patients based on initial curve size (45°-54°, 55°-64°, 65°-74° and >75°). All groups demonstrated a pattern of kyphosis improvement in the orthosis, but demonstrated an increase in kyphosis prior to the completion of orthotic treatment, followed by further progression at long-term follow-up. A total of 76 (69%) subjects demonstrated kyphosis at follow-up that was less than the original measurement. Seven patients had undergone fusion surgery including 4 of 14 whose initial kyphosis measurement ≥75°. There was a trend towards reduced vertebral wedging but it was not linked to the long-term results.

CLINICAL CASE (FIGS 1-5)


Fig 1


Fig 2


Fig 3


Fig 4


Fig 5

A third study was completed in Connecticut.[13] A group of 75 adolescents with thoracic kyphosis ≥45° were divided into two groups: those with at least two vertebrae with ≥5° wedging and those without wedging. Within four months 23 patients (31%) abandoned their orthosis. A thoraco-lumbar-sacral orthosis (TLSO) (Fig 7) was used in 36 patients with mean kyphosis of 60°. Kyphosis was 44° at the end of treatment. A Milwaukee brace was used in 16 patients with mean kyphosis of 71°. Kyphosis was 46° at the end of treatment. Compliance, defined as wearing an orthosis >70% of the prescribed wearing time, was 61% for the TLSO 27 of 44 patients) and 29% for the Milwaukee brace (9 of 31 patients). The researchers concluded that a TLSO was a satisfactory method of treatment for kyphosis of <70°.


Fig 7

No study of treatment of Scheuermann kyphosis recorded actual orthosis wear. Therefore, we do not know how many hours of wearing is required for an orthosis to be most effective. A prospective randomized study of orthotic management of adolescent idiopathic scoliosis utilized heat sensors to measure actual wearing of the orthosis.[14] In order to achieve 90-93% success (defined as curvature <50º at the end of treatment) the orthosis had to be worn at least 12.9 hours per day.

CHOICE OF ORTHOSIS

Kyphosis reduction is achieved by a combination three-point stress application and the natural righting mechanism of the brain. A TLSO has a stable base at the pelvis, reduces lumbar lordosis, and applies pressure at the apex of the kyphosis as well as the upper sternum or clavicular area. A Milwaukee brace is a cervico-thoracic-lumbo-sacral orthosis (CTLSO). It encourages the righting mechanism by moving the anterior contact point superiorly with a neck ring that is not meant to apply pressure to the mandible. The visibility of the neck is undesirable but the open frame of the Milwaukee brace is cooler than a TLSO and is more easily adjusted in the early weeks of brace wear.

Treatment studies point to the factors that influence orthotic management of Scheuermann kyphosis. Factors related to the spine include severity and extent of vertebral wedging, the apex and length of the kyphosis, and kyphosis magnitude and initial flexibility. Factors related to the orthosis include the type (TLSO or Milwaukee brace) and the quality of construction and fitting. Factors related to the patient include growth potential, the number of hours of orthosis wear each day and the duration of orthosis wear in relation to growth. The best opportunity for success may be the patient with kyphosis of ≤65° with modest vertebral wedging and at least two years of remaining growth who wears a Milwaukee brace 16 to 18 hours per day until the best improvement is achieved and then continues to wear the orthosis at least 12 hours per day until reaching Risser stage 4 maturation.

FOLLOW-UP VISITS

Clear goals of treatment should be established with each patient and family. When possible, patient-reported outcome measures should be incorporated into the plan of care. It is not realistic to achieve maximum kyphosis reduction with the first brace fitting. Acceptance of the orthosis will improve if the initial correction is modest, followed by several visits and modification of the orthosis over two to four months. Once maximum kyphosis reduction is achieved follow-up visits should occur every four months. Follow-up evaluation should continue until at least two years after treatment ends. During follow-up visits, the orthosis should be assessed to determine if adjustments are required based on growth changes and to insure that proper alignment and force application are maintained during the treatment phase.

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Section 5:
Orthotic Management of Spinal Pathologies

19

Orthotic Management of Spondylolysis and Spondylolisthesis

Tenner J Guillaume

DEFINITION

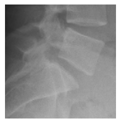
Fig 1

Spondylolysis is defined as a bony defect or stress reaction occurring in the lumbar pars interarticularis (Fig 1).

Spondylolisthesis is defined as a translational displacement of a vertebra relative to its subjacent vertebra (Fig 2) due to any number of causes (see Classification section below).


Fig 2

PREVALENCE

The prevalence of spondylolysis ranges from 3% to 7% in the general pediatric population.[1-7] However, specific populations have been noted to have an increased prevalence such as high level athletes, particularly those involved in hyperextension sports such as gymnastics or cricket fast bowlers (7 to 21%).[8-14] Whereas in their non-athletic peers the prevalence of spondylolysis was noted to be significantly lower (3% to 5%).[10,11] An increased prevalence has also been noted in those with a first degree relative with spondylolysis (15% to 34%).[1,4-7] Furthermore, the prevalence of spondylolysis seems to be associated with certain anatomic factors such as coronal facet orientation, less increase in interfacet distance, and spina bifida occulta.[1,4,11,17-19] In pediatric patients presenting with complaints of low back pain, the prevalence of spondylolysis can approach 50% (13% to 47%).[15,16] The majority of spondylolyses occur at L5 (90%)[1,3] and are bilateral (70%).

The prevalence of spondylolisthesis varies by etiology. The most common etiologies are spondylolysis and degenerative causes. Spondylolysis tends to lead to L5-S1 spondylolisthesis, whereas degeneration tends to lead to L4-L5 spondylolisthesis. Evidence suggests that many persistent bilateral pars interarticularis defects will progress to develop spondylolisthesis (43% to 74%).[7,9] The prevalence of spondylolisthesis due to degenerative causes is rare in individuals less than 50 years of age and overall occurs in about 6% of individuals, with two-thirds (67%) of cases occurring at L4-L5.

CLASSIFICATION

Various classification schemes exist to describe spondylolysis and spondylolisthesis. Ideally classification schemes exist for physician-to-physician, physician-to-therapist, or physician-to-orthotist communication regarding the severity of pathology and likely prognosis.

Spondylolysis

There is a dearth of classification schema commonly used for spondylolysis. However, in the interest of completeness, the Tokushima classification[20,21] for grading spondylolysis has been described in the literature. The Tokushima classification relies on radiographic studies. Acute (early) spondylolysis is defined as a “hair-line defect also referred to as a ‘fissure in the pars’ or ‘focal bony absorption’”. Progressive spondylolysis is defined as a “defect that is moderately wide; the edges are now round”. Terminal (chronic) spondylolysis is defined as a “defect that is wide with sclerotic changes” (Table 1).

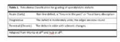

Table 1

Spondylolisthesis

Much focus on classification within the clinical study of spondylolysis and spondylolisthesis is focused on the latter pathology. The most widely used classification scheme as regards the etiology of spondylolisthesis is the system described by Wiltse[22-25] (Table 2).[26] The Wiltse classification system is divided into five main groups. Type I develops secondary to a congenital defect resulting in insufficiency of the superior sacral facet or the inferior L5 facet or both with resultant gradual anterior translation of L5 on the sacrum. This is known as congenital or dysplastic spondylolisthesis.

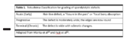

Table 2

Type II, also known as lytic or isthmic spondylolisthesis, involves a defect in the “isthmus” or pars interarticularis. Type II is further classified into three subgroups: Type IIA represents a spondylolysis or stress fracture of the pars interarticularis; Type IIB represents an intact but elongated pars interarticularis due to repetitive stress and bony remodeling; Type IIC represents an acute traumatic fracture of the pars interarticularis resulting in anterolisthesis of L5 on the sacrum. Type IIC is the rarest of these three subtypes. Type III, also known as degenerative spondylolisthesis, is a disease of older adults that develops as a result of degenerative disc pathology and loss of intervertebral disc integrity generally in combination with facet arthritic change. Type III can result in either anterolisthesis (more common) or retrolisthesis.

Type IV, also known as posttraumatic spondylolisthesis, is the result of an acute traumatic injury to the posterior elements other than the pars interarticularis (as seen in Type IIC). Unlike Type IIC, which results in an acute spondylolisthesis from a fracture-dislocation, Type IV is the result of a more gradual event. Type V, also known as pathologic spondylolisthesis, involves the gradual failure of the posterior elements in the setting of a pathologic process such as malignancy, tuberculosis, Paget’s disease, giant cell tumors, or other erosive or cystic processes.

While the Wiltse Classification provides an excellent framework to describe the etiology of spondylolisthesis, it fails as a classification scheme in regards to its ability to predict the prognosis of deformity progression or patient outcome. In an attempt to address this shortcoming of the Wiltse Classification scheme, Marchetti and Bartolozzi proposed an alternative classification scheme for spondylolisthesis in 1982 (Table 3).[27] Spondylolisthesis is divided into developmental and acquired subtypes in the Marchetti and Bartolozzi Classification. Acquired spondylolistheses initially included degenerative, pathologic, and iatrogenic etiologies; whereas, developmental spondylolistheses included elongation of the pars (Wiltse Type IIB), lytic lesions (Wiltse Type IIA), and traumatic events (Wiltse Types IIC and IV). In 1994 Marchetti and Bartolozzi modified their classification scheme to divide developmental spondylolisthesis into high and low dysplastic subtypes, traumatic lesions were incorporated into the acquired group, and the iatrogenic etiology was renamed postsurgical. Developmental spondylolisthesis categorization requires either a lysis of the pars interarticularis or elongation of the pars interarticularis. Thereafter, low dysplastic describes those spondylolistheses that have a largely normal anatomic appear-

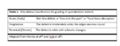

Table 3

ance, whereas high dysplastic describes those spondylolistheses that demonstrate dysplastic changes at the location of the slip. These dysplastic changes include a hatchet shaped L5 vertebral body, superior sacral endplate doming, and sagittally oriented facet joints. By dividing developmental spondylolisthesis into low dysplastic and high dysplastic subtypes Marchetti and Bartolozzi were attempting to create a classification scheme that allowed for both description of pathology while also incorporating prognosis and risk of progression. Those with high dysplastic developmental spondylolisthesis presumably have a higher risk of slip progression than do those with low dysplastic developmental spondylolisthesis.

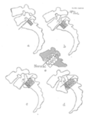
Fig 3

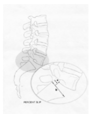
Fig 4

Finally, the Meyerding classification[28] is commonly used to describe the amount of slip associated with a spondylolisthesis. The Meyerding classification allows one to communicate both severity and prognosis of a slip and allows one to differentiate a low-grade spondylolisthesis from a high-grade spondylolisthesis. The Meyerding classification is based upon the distance that a cranial segment has slipped relative to its caudal segment. The posterior-inferior corner of the listhesed vertebra is used to determine the distance of the slip relative to the posterior superior corner of the stable, caudal vertebra (Fig 3A). This slip is then classified based upon the percent (a/b x 100%) slip relative to the total length of the superior endplate of the caudal vertebra (Fig 3B). Grade I (0 to 25%) and Grade II (26 to 50%) slips are considered low-grade spondylolisthesis (Fig 3). Grade III (51 to 75%) and Grade IV (76 to 100%) slips are considered high-grade spondylolisthesis (Fig 4). Grade V is when the vertebral body is completely displaced ventrally and is also known as spondyloptosis.

NATURAL HISTORY

Spondylolysis & Spondylolisthesis

In spondylolysis short-term symptom resolution is expected in most patients. Most pediatric patients are able to continue sporting activities. The large majority of pediatric patients are able to avoid surgical intervention with mild to moderate symptoms in the long term. Infrequently significant symptoms requiring surgical management can develop.[1,29-31]

As regards bony healing rates in spondylolysis, rates of healing are highest for unilateral defects (38% to 100%)[1,30,34] and early (MRI or bone scan) or incomplete (CT) fractures (73% to 87%).[20,21,35] Bony healing of the pars interarticularis can take from three to 14 months. However, evidence also suggests that it is not bony healing alone that predicts return to sport at a similar level of competition, but rather that treatment with symptom resolution is enough. Symptom resolution doesn't seem to be directly correlated with bony healing. However, bony healing may decrease the likelihood of spondylolisthesis development.

Chronic bilateral pars defects will not obtain bony union in the large majority of cases (0% to 3%).[20,21,29,30] It is in these cases that the development of spondylolisthesis is common. Up to 75% (43% to 74%) of persistent bilateral defects will progress to Grade I or Grade II spondylolisthesis. Most of this progression tends to occur in the adolescent years and slows with age. Progression seems to be more common in patients who are skeletally immature and in females.[2,29,30,32,33]

As regards long-term outcomes of spondylolysis, studies suggest that prognosis is less clear, but that most patients will have lumbar symptoms comparable to the general population. Some patients with spondylolysis may develop significant symptoms in the long term requiring surgical intervention. However, many may continue to do well with conservative or no treatment. As of yet there is no way to predict an individual's long-term prognosis.[36]

ROLE OF ORTHOTIC TREATMENT

Orthoses are commonly used in the treatment of spondylolysis, and specifically rigid, antilordotic orthoses are recommended. [See Editor's note at the end of this chapter.] Orthoses are most commonly used in patients with a recent or acute onset of pain, documented pars stress fractures as seen on a positive bone scan or MRI SPECT scan, acute pars fractures or in young patients who are unlikely to be compliant with a recommendation for rest. Oftentimes orthoses are combined with a period of rest and physical therapy.[21,37,38] The most compelling indication for the use of an orthosis is pain relief. The majority of pars lesions do not heal with a bony union, but become stable fibrous unions that remain relatively asymptomatic. In patients with acute pars stress fractures the goal of an anti-lordotic orthosis is for more rapid symptom resolution with prevention of progression from a stress fracture to a true fracture. In the case of truly acute pars fractures, documented by patient history, a positive bone scan or SPECT scan, and possibly a CT scan, an anti-lordotic brace may be utilized to bring about healing of the pars interarticularis. Healing of the pars interarticularis is most likely to occur in unilateral lesions (38 to 100%) or incomplete or early fractures (73 to 87%). Unfortunately, in chronic bilateral pars fractures the rate of healing approaches 0%.

If a physician opts to treat a symptomatic spondylolysis with an orthosis then physical activity is usually limited to activities of daily living. In most cases avoidance of any bending or twisting, running, jumping, impact activity, lifting of more than five to ten pounds, or participation in sports is counseled. Whether or not the brace is worn 23 hours a day versus during the waking hours only, is the choice of the physician and no literature supports any specific recommendation surrounding frequency or duration of brace wear. In most cases bracing is continued for approximately three to six months or until symptom resolution.[20,38-40]

EVIDENCE BASED REVIEW

Though orthoses are a commonly used form of treatment for spondylolysis, and their efficacy has been described in the literature with symptom resolution of greater than 80%;[20, 38-40] on the whole, the evidence for bracing is not particularly strong. All studies on bracing have been Level IV studies and a meta-analysis of level IV studies suggested that bracing does not influence patient outcome.[41] Furthermore, there are no studies looking at comparing treatment with the natural history of spondylolysis, and there are no studies comparing the various non-surgical treatments utilized (rest, bracing, physical therapy, bone stimulators, etc.) with one another.

CHOICE OF ORTHOSIS/DESIGN SELECTION

It is our preference to utilize a rigid antilordotic brace. This is often a Boston-style brace which can either come off the shelf depending on patient size, body habitus and brace availability, or can be custom-made. Many authors prefer to use a total-contact, low profile polyethylene orthosis, which is designed to maintain an antilordotic posture and extends from just below the nipples to 1 inch above the greater trochanter.[38]

FOLLOW-UP VISITS

After initiating treatment for symptomatic spondylolysis it is our practice to see patients back at 6 week intervals. Generally the first 6 weeks of treatment include rest, avoidance of lumbar extension, and are plus/minus orthosis. At the 6-week follow up we perform a clinical examination only. As long as the patient's pain has dissipated somewhat or resolved we progress the patient to start with some physical therapy exercises focusing on isometric core strengthening of the transversus abdominis, internal oblique, and lumbar multifidus. We continue to limit active or passive lumbar extension, and we recommend hamstring-stretching exercises. If a patient has been braced then we continue bracing for the next 6 weeks, permitting patients to remove the brace for physical therapy and bathing only. At this point we are still counseling rest and restraint from physical activity.

Six weeks later another clinical visit is scheduled. This will be twelve weeks after the initiation of treatment. At this visit we will have the patient remove the brace and will test lumbar spine range of motion and determine whether or not lumbar extension results in provocation of pain. We will also check hamstring tightness via measurement of popliteal angles as compared to that determined at the initial consultation. As long as gentle lumbar extension doesn't cause pain and as long as hamstring tightness is improving we will allow patients to progress into light running or jogging over the next two to four weeks. If the patient was braced then we will generally discontinue brace wear at this point. Thereafter we plan for another follow up six weeks later. As long as a patient remains pain free then we let them progress to do all activities as tolerated. For a simple spondylolysis without spondylolisthesis we will plan for subsequent follow up as needed. For a skeletally immature patient with low-grade spondylolytic spondylolisthesis we will recommend annual follow up until skeletal maturity to monitor for the development of spondylolisthesis.

Editors Note:

ALIGNMENT OF THE ORTHOSIS

Symptomatic reduction from Spondylolysis, using a spinal orthosis, is often associated with decreased or diminished lumbar lordosis and an effort to avoid hyperextension or forced alignment (incongruent alignment of the orthosis and the patient's existing alignment). Determining proper alignment is often complicated by what is assumed to be normal lordosis and the wide variance reported in the literature. Lin et al. describes normal Lumbar Lordotic Angle (LLA) as 20-45 degrees with a range of 1 SD.[44] With such a wide range of normal lordosis additional care should be taken to assess the patient's existing lordosis and degree of lumbar flexibility when determining the appropriate sagittal alignment to be built into the orthosis.

Efforts to measure and quantify lumbar lordosis in a reliable and reproducible manner using either a goniometer or flexicurve is complicated by a low inter-rater reliability.[45] Despite this, the utility of these tools appear to be the only realistic method of approximating alignment compared to the conventional practice of not measuring at all. In it's application these tools should be used by the same physician or orthotist as the literature suggests that intra-rater reliability, while not statistically significant, does demonstrate moderate levels of reliability. Measurement of the patient's normal lumbar lordosis and ability to reduce lordosis (flexibility) using these tools are particularly important when attempting to select the correct made-to-measure or off-the-shelf design with pre-existing lordosis already built into the orthosis (i.e. 0°, 15°, 30° lordosis). This is also true of custom molded orthoses (i.e. LSO) where modifications to the positive cast (plaster mold) are reconciled with the assessment of the patient's lordosis and desired alignment during the fabrication of the orthosis. The clinician must consider that degree of lordosis that is most confortable for the patient. Consideration and implementation of these practices should help to minimize arbitrary or harmful alignment and increase the possibility of symptomatic relief for the patient.

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Orthotic Management of Spine Trauma

Robert S Lin, Mark Lee, Thomas Gavin

INTRODUTION

The musculoskeletal burden of thoracolumbar and lumbar spine injury is immense. 79,000 spinal fractures occur in the US each year, that is 64 per 100,000 people. 72.5% of the spinal fractures involve the thoracic or lumbar spine.[1] Of these fractures, approximately 75% involve the vertebral segments from T10 to L2 (thoracolumbar junction).

Most injuries to the thoracolumbar junction and lumbar spine are the result of high-energy falls (35% to 40%), followed by traffic accidents (20% to 30%), and low-energy falls (20% to 25%).[2-5] The peak frequency of these injuries occurs in the 31 to 40 year old age group, although a bimodal distribution exists with a spike in frequency for patients above 60 years of age.[4] Neurological injury occurs in 16% to 25% overall, but in as many as 40% of cervical fractures. There are approximately 12,000 spinal cord injuries each year from injury to the spinal column and such injury is associated with a significant mortality rate.[2,4,5]

ANATOMY OF THE THORACOLUMBAR AND LUMBOSACRAL SPINES

Fig 1

The thoracic spine typically consists of 12 vertebral bodies that articulate via small facet joints oriented almost parallel to the coronal plane (Fig 1). The orientation of these facet joints intrinsically limit flexion/extension motions, but allow lateral bending and rotation. Extrinsic ligamentous supports are critical to the overall stability of the vertebral body segment in the thoracolumbar spine and include the vertebral body ligaments (anterior longitudinal, posterior longitudinal and disc) and posterior ligamentous complex (PLC: ligamentum flavum, facet capsules, interspinous ligaments, supraspinous ligaments) (Fig 2). The thoracic vertebral bodies are further attached via ligaments to the rib cage, conferring additional rigidity to this section of the spine.

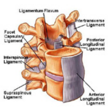

Fig 2

The lumbar spine usually consists of five vertebrae that become progressively larger as one proceeds inferiorly. The facet joints in the lumbar spine are oriented in a more sagittal plane and permit flexion/extension, but limit lateral bending and rotation. Although the vertebral body ligaments and the posterior ligamentous complex also bind the lumbar spine, the absence of rib articulations makes this section of the spine notably more mobile than the thoracic spine in flexion.

The thoracolumbar junction is a unique anatomic intersection between the mobile lumbar spine and the relatively immobile thoracic spine.[6,7] The facet joints in this transitional region are directed obliquely, as an intermediate position between the coronal orientation of the thoracic spine facet joints and the sagittal orientation of the lumbar spine facets. The thoracolumbar junction is also the transition between the sagittal plane contours of thoracic kyphosis and lumbar lordosis. As the discrete structural transition point of motion and posture, the thoracolumbar spine cannot dissipate forces over multiple segments and is anatomically predisposed to structural failure during trauma.

The lumbosacral (L5-S1) zone is another region of high concentrated stresses as it is a transition from the mobile lumbar spine to the immobile sacrum, fused vertebral elements that are wedged securely between the innominate bones of the pelvis. The region is supported by the common ligamentous structures that surround the anterior and posterior elements of the vertebral bodies, as well as the investing thoracolumbar fascia and the ilio-lumbar ligament. The ilio-lumbar ligament serves as an anatomic restraint to anterior translation for the L5 vertebral body and may confer clinical stability to the L5 vertebra in potentially unstable fracture patterns (Fig 3).

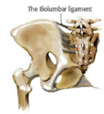
Fig 3

Thoracolumbar spine injuries have the potential to yield spinal cord injuries, as the conus medullaris terminates in this transitional region. The more inferior lumbar and lumbosacral fractures have the potential to cause nerve root injury but typically do not have implications for cord level injury.

CLASSIFICATION OF THORACOLUMBAR SPINE INJURY

The stability of a thoracolumbar spine injury is a controversial concept with frequent inter-observer disagreement and unclear definitions. However, the concept is critical in deciding between surgical and non-surgical options for treatment of traumatic injury to the spine. An unstable thoracolumbar spine after trauma may be defined as a spinal column that no longer supports axial loading without progressive deformity and/or progressive neurologic injury.

Classification systems allow the practitioner to place the patterns of spine injury into a framework that can assist with patient management. Historically, numerous classification systems have been offered and can be broadly separated into anatomic or mechanistic types. However, very few achieve reliable inter-observer and intra-observer agreement, are clinically easy to apply and can reproducibly guide surgical decision-making.

A popular anatomic classification system is that by Denis, who modified the column concept of Kelly and Whitesides by defining three distinct columns of support (anterior, middle and posterior) to the thoracolumbar spine.[6,8] The anterior column consisted of the anterior longitudinal ligament, the anterior annulus fibrosus of the intervertebral disc, and the anterior part of the vertebral body. The middle column is formed by the posterior longitudinal ligament, posterior annulus fibrosus, and the posterior wall of the vertebral body. The posterior column includes the bony posterior arch alternating with the posterior ligamentous complex (supraspinous ligament, interspinous ligament, capsule, and ligamentum flavum) (Fig 4). Denis posited that injury to the middle column was necessary and sufficient to create instability whereas posterior disruption could not alone create an unstable spine.


Fig 4

The Denis classification was useful for solidifying the descriptive vernacular of anatomic injury to the spine and clearly distinguished burst fractures (anterior and middle column involvement) from compression fractures (anterior column involvement alone). However, the system is limited by the absence of discrete parameters for instability in the absence of descriptive involvement of columns, only fair to good inter-observer reliability, a lack of consideration of the patient’s neurologic status in surgical decision-making and a paucity of prognostic information to accompany the column injury descriptors.

The current understanding of thoracolumbar spine trauma has shifted to a mechanistic model that is more consistent between observers and has greater clinical utility. Building on work by McAfee and

Magerl, the Spine Study Trauma Group in 2005 proposed TLICS (Thoracolumbar Injury Classification and Severity Score).[7,9] TLICS is a scoring system based on three distinct components of radiographic mechanism, neurologic status and posterior ligament complex integrity.(Table 1) If the TLICS score is <4, then the spine is stable and a non-surgical approach is advocated. If the score is 4, the clinical approach is indeterminate. If the score is >4, then the clinical approach will be surgical.(Table 2) Contiguous injuries can be scored based on the most severe injury, while non-contiguous injuries along the spine can be evaluated by scoring each injury separately.


Table 1


Table 2

The TLICS score has demonstrated good to excellent inter-observer and intra-observer reliability with excellent, reproducible clinical guidance.[10] It is the prevalent classification system for use in the modern era of spine trauma management. However, limitations to its use must also be understood. The score is only useful in an adult population and cannot be applied to pediatric injury, spinal cord injury without radiographic abnormality or iatrogenic spinal instability. In the setting of a TLICS score, any injury with a score ≤4 is a reasonable option for brace management.

CLINICAL EVALUATION OF PATIENT WITH SPINAL TRAUMA

On-scene Evaluation and Stabilization

Emergency medical team personnel are the first responders. Upon arrival, an accurate description of the scene is obtained including any details on the mechanism of injury, extrication time, associated vehicular fatalities and exposure to the environment. The patient is rapidly stabilized hemodynamically and then transported on a spine board with logroll precautions and appropriate immobilization for the neck.

In Hospital Clinical Evaluation

The evaluation of the patient is a multi-disciplinary endeavor that begins with a standard trauma assessment: Airway, Breathing, Circulation and Disability. Once the patient has been stabilized from a respiratory and hemodynamic standpoint, a history can be obtained from EMT staff and/or family members. The information to be gleaned includes mechanism of injury as well as associated comorbidities for the patient.

The physical examination of the patient proceeds with inspection of the spine, torso and extremities. Ecchymosis along the torso or deformity and swelling of an extremity will guide an evaluation for additional injury. The midline spine is palpated for tenderness and step-offs. A thorough neurological evaluation is performed following hemodynamic stabilization and should include evaluation of sensation and motor function in the extremities, as well as reflexes. A digital rectal exam with a bulbocavernosus reflex should be performed to test the completeness of a potential spinal cord injury. This may not be a valid test until after a period of spinal cord shock has passed so it may need to be done serially. Seventy percent of thoracolumbar injuries do not have neurologic deficits, but deficits can be root level, plexus level or conus level when they occur.[1]

The remainder of the patient evaluation should be guided by the understanding that other major organ injury or limb injury occurs in 28% of cases.[11] Genitourinary injury or gastrointestinal injury most commonly occurs with lumbar spine injuries involving a flexion mechanism. Ileus without discrete bowel trauma is quite common after lumbar spine fracture and should be considered during acute inpatient management. Fractures often associated with spine injury include those of the tibia and calcaneus. Non-contiguous spine fractures or fractures that occur in different regions of the spine are also noted in up to 56% of cases. Therefore, the remainder of the spine should be screened when a fracture in one location is identified.[12]

Radiographic Evaluation

A typical trauma series includes the following studies:

- Lateral cervical spine radiograph
- Antero-posterior and lateral lumbar spine radiographs
- Antero-posterior pelvic radiograph

The initial series of films is extended depending on the clinical presentation. If a patient is obtunded, a skeletal survey is required to exclude additional injury.[13] CT scan evaluation should be performed for all identified bony injuries of the spine as it provides significantly more detail on the fracture morphology than plain radiographs.[14,15] MRI of the spine is performed to evaluate the posterior ligamentous structures, the spinal cord and the intervertebral discs as components of the fracture anatomy.[14] MRI is particularly useful for identifying the position of the conus medullaris and confirming involvement of the cord in thoracolumbar spine trauma.

SPINAL ORTHOSES FOR THORACOLUMBAR AND LUMBAR SPINE TRAUMA

Principles of Orthosis Use

The goals of orthotic management in spine trauma are to immobilize a motion segment and dissipate forces applied to that segment from the patient's transfer, sitting or ambulation activities. In addition, the spinal orthosis can also function as a kinesthetic reminder to limit motion through the segment, potentially improving overall comfort.

All spinal orthoses use some form of 3-point bending force to maintain stability of the spinal column in a desired position. However, it must be understood that no orthosis provides absolute stability. Control of the thoracolumbar spine with an orthosis relies on control of the cephalad endpoint of the thorax and the caudal endpoint of the pelvis. The effect of the device on the spine is generally indirect and must be transmitted through variable layers of subcutaneous tissue as well as viscera. Therefore, the patient's soft tissue envelope significantly impacts the ability of an orthosis to provide even partial control of an injured vertebral segment.

The choice of spinal orthosis for a specific fracture is generally made based on the ability of each orthosis to control motion at specific levels within the spine.(Table 3) In addition, the practitioner must have a general understanding of the advantages and disadvantages of each design in order to offer the most suitable orthosis for a particular patient's spine injury and relevant comorbidities.

Table 3

SPECIFIC ORTHOSES

TLSO (Thoracolumboscaral orthosis)


Fig 5

The TLSO (Fig 5) can be used to control fractures with an apex of T9 to L2. The orthosis may be pre-fabricated or custom-molded. Pre-fabricated varieties are typically sufficient for many body types. However, a body habitus that exceeds a standard spectrum of available sizes will often require a custom fabrication. The question of whether a custom fabricated (from a mold or scan of the patient), custom fit (from numerous measurements), or an off the shelf (OTS) is indicated for a specific patient is largely unresolved. The decision to provide an individual design may be predicated on many factors such as resources; (availability of a qualified orthotist to provide timely care), urgency/instability; (in the best case scenario, a custom fabricated spinal orthosis will take twenty-four hours from evaluation/measurement to final delivery), type of injury; (limited to a single column or plane of motion), and age/body type; (irregular/dysmorphic body shapes are prone to custom fabricated orthoses). There is evidence that a custom molded TLSO can limit lateral bending by 94% and flexion-extension by 69% in the lumbar spine.[16] For the thoracic spine, the device can restrict flexion-extension by 49%, lateral bending by 38% and total rotation by 60%. Therefore, for maximum control, a custom-molded thermoplastic TLSO is desired. In addition, the use of of-over-the-shoulder straps with a TLSO seems to improve rigidity by increasing the overall length of the orthosis. These straps can be attached to the shell of the orthosis or the sternal extension, thus affording additional control superiorly.

In the aggregate, the biomechanical application of fulcrum forces near the site of injury and in the two opposing directions, utilizes the fundamental principles of force couples and lever arms to provide inherent stability to the area of the spine at risk. Control of micro trauma is achieved by the total contact nature of a well fitting, custom design that distributes significant yet well-tolerated forces over a broad surface area.

End point stabilization at the pelvis can greatly reduce pelvic motion to lock the lumbosacral junction and provide the foundation for superior stabilization. Superior stabilization should follow, at a minimum, the plus-two rule which dictates the stabilization of at least two vertebral levels above the at risk vertebral level of involvement. In cases where the at risk vertebrae are susceptible to continued deformation the extended superior lever arm of the TLSO will assist in limiting normal vertebral sway of the spine during activities of daily living. This will help limit large moments (i.e. sagittal flexion) and motion that are likely to put the vertebra(e) a greater risk of instability or deformation. For optimal inferior end point stabilization, the orthosis should extend as low as possible while allowing for comfortable sitting on a firm surface with ninety degrees of hip flexion achievable.

LSO (Lumbosacral orthosis)


Fig 6

A rigid LSO (Fig 6), essentially a TLSO without the thoracic component, can be used for fractures at L3 and L4. Fractures distal to L4 are generally difficult to immobilize with an LSO by itself, as stabilization of the injury with this device will very much depend on the fit around the pelvis. To improve the stability conferred by the orthosis, a unilateral thigh extension is added. A rigid LSO typically allows 32% mean motion at L4-L5 and 70% mean motion at L5-S1.[17] When a unilateral thigh extension is added, allowable motion at these levels decreases to 12% and 8%, respectively.[17,18,19]

Hyperextension Orthoses (Jewett and CASH)

Fig 7

Fig 8

Hyperextension orthoses are designed to exert a three-point contact with distributed pads in order to unload the anterior column. The Jewett orthosis (Fig 7) has two anterior pads and one posterior pad bridged by adjustable struts and is most effective for thoracolumbar injuries (T10-L2). The CASH (Cruciform Anterior Spinal Hyperextension) brace (Fig 8) has a cruciform configuration of pads and is indicated for the same region of the spine. Recent design innovations incorporate a hinge type mechanism that allows for the sternal and suprapubic pads of both these hyperextension systems to pivot, thus enhancing comfort and tolerance for sitting and transitional movement. Spinal hyperextension orthoses may be used to treat stable injuries up to the level of T8 with careful cephalad positioning of the anterior pads. However, the orthoses are meant to manage fractures with a primary deformity in the sagittal plane and are ideal for stable compression fractures. Potentially unstable, multi-column injuries should be managed with a custom molded total contact TLSO to allow greater control of the involved vertebrae.[20] The total contact TLSO will afford greater rotary control then the hyperextension orthosis. Both the Jewett and CASH designs are best suited for the adult/geriatric population with minimal application for the young child (size availability).

Dorsal Lumbar Corset

Fig 9

Dorsal lumbar corsets (Fig 9) are made of various fabrics and used primarily to provide support for elderly patients with osteoporotic compression fractures who cannot tolerate a more rigid orthosis. The corset is contraindicated for management of any fracture with possible instability in a trauma setting. In addition, mild improvement of posterior stabilization can be achieved with the application of posterior stainless steel stays inserted in the garment along side the paraspinal musculature. These can be contoured to accommodate deformity and/or encourage a more erect posture as tolerated.

RISKS AND CONTRAINDICATIONS OF ORTHOTIC MANAGEMENT

Orthotic management is contra-indicated in any setting where surgical intervention is considered the optimal mode of treatment. In general, surgical intervention is recommended for unstable spine fractures (i.e. fracture-dislocation), as defined by the anatomic or mechanistic classification systems. Orthotic management after surgery in adult spine trauma is rarely performed given the advances in rigid internal fixation of the spine, but may be considered in a patient population with questionable bone quality (e.g. pediatric patient).

A soft, dorsal corset, as noted in the above, is ineffective for management of any significant spine trauma, as it provides no appreciable control of the injured spinal column. Hyperextension orthoses are not to be used for management of potentially unstable thoracolumbar injury given their demonstrated inefficacy.

The soft tissue profile of the patient and comorbid conditions must be considered as well when determining the feasibility of orthotic management for thoracolumbar or lumbar spine trauma. A morbidly obese patient will likely not benefit and not tolerate treatment with an orthosis. A patient with multiple cutaneous injuries (burns) would be contra-indicated for orthotic management. Further, patients with overlying restrictive lung disease or pulmonary compromise are likely poor candidates for brace use or require specific design modifications to the orthosis to accommodate chest wall expansion during respiration. Patients with spinal cord injury are relatively contra-indicated for brace use as they lack protective skin sensation and are at high risk of cutaneous complications from orthotic management. If the decision is made to pursue orthotic treatment for this population careful attention should be paid to frequent and on-going skin assessment.

DURATION OF TREATMENT AND TIMING OF EVALUATIONS

Typical spinal column fracture healing occurs over a 6 to 12 weeks period and is influenced by patient age, medical comorbidities and extent of the injury. The treating physician will typically recommend the frequency of follow-up evaluations and the timing of brace removal, basing the decisions on a summation of clinical and radiographic information.

A typical treatment protocol will involve standing orthogonal radiographs in the orthosis following its application to determine if the fracture is controlled to an acceptable degree. If stability in the brace is insufficient, either orthotic modifications are required or a surgical alternative should be considered as the initial in-brace position of the fracture correlates with 1 to 2 year pain and deformity outcomes.[21] The brace fit and function should be checked every 2 to 4 weeks to ensure that the fracture remains well controlled as the soft tissue swelling about the spinal column subsides and patient weight loss invariably occurs. Further, in the setting of altered cutaneous sensation following an associated neurologic injury, the skin integrity should be checked frequently by the patient, orthotist and treating physician.

COMPLICATIONS OF ORTHOTIC USE IN THORACOLUMBAR SPINE TRAUMA

Pressure-induced skin complications are the most common complication encountered with orthoses. The skin is at risk in the setting of altered cutaneous sensation, general immobility and possible diminished cognitive awareness.

In addition, it is well documented that the circumferential containment of the trunk with a spinal orthosis, can restrict chest expansion, reduce efficacy of diaphragmatic movement and result in diminished respiratory function. In cases of spinal trauma with associated respiratory complications, use of a spinal orthosis should be weighed carefully.[36]

Prolonged immobilization in a spinal orthosis is also thought to promote deconditioning of paraspinal muscles, in effect impairing the intrinsic stabilizers of the columnar injury. Data studying the EMG activity of paraspinal muscles in an orthotically managed state are conflicting and can both support or refute the notion of progressive muscular atrophy.[18,22] In addition, prolonged immobilization always has the potential to promote global spine stiffness in an adult and may be a prelude for prolonged pain and disability following a traumatic injury. If the injury pattern allows, an exercise program stressing cardiovascular fitness should be encouraged and the orthosis removed at the earliest time point feasible.

TREATMENT OF SPECIFIC FRACTURE PATTERNS

Use of an orthosis should be tailored to the clinical scenario and must take into consideration the clinical details of each individual patient, along with the morphology of the particular injury. The following provides a general guide to commonly encountered thoracolumbar and lumbosacral injuries that may be treated effectively with a bracing program.

Compression Fractures


Fig 10

Compression fractures (Fig 10) in the thoracolumbar and lumbar spine are, by definition, a stable injury pattern involving only the anterior column of the spine. Management of the injury is symptomatic and orthotic options are extensive. Typically, the least cumbersome orthotic option is utilized with single level fractures. In cases where multiple compression fractures are present or significant loss of vertebral body height confirmed, total contact TLSO designs should be a first consideration over traditional off-the-shelf designs. The total contact TLSO design, although effective in these cases, is not a viable option for pathologic fractures. This is especially true for elderly patients with insufficiency-related fractures of the spine who would not otherwise tolerate more rigid immobilization (see chapter 22).

Burst Fractures

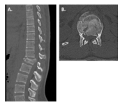
Fig 11

Stable burst fractures (Fig 11) (2 column involvement) without neurologic deficit or posterior ligament disruptions are managed successfully with a non-operative approach. Orthotic design can be either TLSO, LSO or LSO with thigh extension, based upon the level of the injury.[23,24]

Much controversy exists regarding the management of potentially unstable burst fractures (3 column involvement) without neurologic deficit but with posterior ligament complex disruption. Reported benefits of surgical intervention include earlier mobility, possible decreased long-term deformity and decreased long-term pain.[25] Benefits of non-operative treatment include relative success of this approach without significant comparative differences in long-term function or pain and avoidance of the often significant surgical morbidity associated with these injuries.[26] A review of available literature suggested there are no distinguishable clinical differences between operative and non-operative patients treated for unstable burst fractures, save for the difference of surgical morbidity.[27] More convincing, a randomized trial of 47 consecutive patients randomized to orthosis or operative treatment demonstrated no clinical or radiographic difference at 18 years after injury.[28] However, recent literature has arisen to advocate for the use of temporary, percutaneous posterior fixation for a "surgical brace" of a lumbar burst fracture that may minimize overall surgical morbidity with and reap the benefits of earlier mobilization.[29,30] Additional study is required to determine if these alternative surgical techniques will sway the clinical algorithm to a more operative approach.

If an unstable burst fracture is managed with an orthosis, a custom fabricated/fitted TLSO, LSO or LSO with thigh extension is recommended. Unstable burst fractures at the L5 level are relatively rare. However, there is some evidence for successful management of these injuries through a non-operative approach with an LSO utilizing a thigh extension.[31] This design is best tolerated with the hip joint locked at thirty degrees of flexion to facilitate modified sitting and afford maximum stabilization of the injury site. The non-operative approach appears to minimize the relatively high complication rate reported in surgical management of L5 burst injuries.


Fig 12

Bony Flexion-Distraction Injury (Bony Chance)

A flexion-distraction mechanism (Fig 12) that caused a purely bony dissociation can be managed effectively with a bracing regimen.[32] Since the injury is a three-column injury, a custom fabricated/fitted, rigid TLSO or LSO should be used to control this fracture pattern in place of the less rigid Jewett and CASH (Cruciform Anterior Spinal Hyperextension) orthoses. The circumferential containment of the soft tissue surrounding the trunk utilizes the basic principles of volumetric control and fluid mechanics not provided by the Jewett or CASH designs.

Compression, Burst and Bony Chance

In cases where compression, burst or bony chance fractures are present, the orthotist must carefully consider the alignment the orthosis will impart on the patient-particularly in the sagittal plane. Of particular importance is the mechanism of injury of these three fracture types and although different, the collective thread of flexion or hyperflexion is consistent with all three. As a result, and regardless of the orthotic design, the orthosist's goals should be to: 1) avoid flexion, 2) reduce or eliminate deforming moments (flexion), 3) restore vertebral height, and 4) decrease residual and localized kyphosis secondary to the fracture(s). While this can be accomplished with many of the designs described above, the orthotist must be intentional and ready to adjust off-the-shelf designs to reflect proper sagittal alignment and to incorporate this alignment into all custom designs. In these cases, and in order to achieve the above stated goals sagittal extension or hyperextension should be the desired alignment. Examining and recording the patient's current sagittal alignment best determine this. Included in this examination, at a minimum, is assessment of pelvic tilt, lumbar lordosis, thoracic kyphosis, overall posture and if visible the presence of a gibbous secondary to the fracture. This information should be recorded and used as a baseline to determine what alignment is achievable in the orthosis and if enough sagittal extension or hyperextension can be incorporated into the design of the orthosis. In many instances, this information can be obtained by using a surface gauge (i.e. goniometer). Final decisions about desired alignment should be discussed with the physician. When this process or alignment is not adequately considered the patient is ultimately put at risk.

The orthotist should be wary of pre-selected sagittal alignment for all non-custom designs and should expect to make adjustments to optimize alignment. When this is neglected there is a greater risk that the orthosis, at best, simply accommodates the deformity and at worse causes the deformity to progress. In the later, this could signal the abandonment of conservative treatment in favor of surgery and ultimately affect the surgeon's confidence that orthotic management is a viable alternative to surgery.

SUMMARY

The use of spinal orthoses for the non-operative management of traumatic spinal fractures is well documented. Numerous studies have been conducted on non-operative management of thoracolumbar/lumbar fractures in which patients managed with immediate immobilization in casts or orthoses and bed rest statistically performed as well as the cohort managed surgically, at long term follow-up.[33] Seybold et al.[34] compared lumbar burst fractures managed with spinal orthoses with those surgically repaired in a 5 year follow up study which showed the orthotically managed group reporting a higher quality of life and no differences in radiographic gibbous angles between the 2 groups. Other related studies support the orthotic management of neurologically intact thoracolumbar and lumbar fractures over surgical management when comparing long term quality of life and risk factors.[35] Key contributing factors, which impact successful management of spine trauma, include; sound communication between physician and orthotist, skill of the orthotist, timing, co-morbidities and patient compliance.

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21

Orthotic Management of Infectious Disorders of the Spine

Rafael Cruz Bundoc

INTRODUCTION

Infectious spondylitis refers to the gamut of inflammatory processes that take place when the spine and/or its adjacent structures harbor a nidus of infection.[1] They are variably referred to in the literature as: spinal infection, spondylodiscitis, vertebral osteomyelitis, discitis, meningitis, and myelitis. The later two are not truly spinal column infections but instead are infections of the spinal cord or its soft tissue surroundings.

Spinal infections are relatively rare constituting only 1-7% of all cases of osteomyelitis.[2,3,4] There is however an increasing incidence of vertebral infection which can be attributed to a growing susceptible population and the availability of improved diagnostic tools to detect infection of the spine or it's surrounding tissue. Other factors have been credited with the increasing trend of spinal infection and include the HIV epidemic, growing numbers of intravenous drug users, the prevalence of indwelling catheters, aggressive spine surgeries, increasing nosocomial infections, and the resurgence of tuberculosis in industrialized nations.[5]

There is a bimodal age of distribution with peaks at less than 20 years of age and in the age group of 50-70 years. Any age though can be affected with a male to female ratio of 2:1.[6,7] Several studies have identified risk factors; diabetes mellitus, advanced age, intravenous therapy, immunosuppression, malignancy, renal failure, rheumatologic diseases, liver cirrhosis and previous spinal surgery.[5,6,8]

An infection may present with an ill-defined or non-specific pain and tenderness to any of the regions of the spine explaining why delay in diagnosis is very common. Early pain is often attributed to so many other causes than the presumption of an infectious process. Pain may be experienced at either rest or during movement. Systemic signs of fever, weight loss and malaise occur late in many patients.[8,9]

Delayed diagnosis from weeks to several months explains why spinal infections have presented treatment challenges to clinicians for decades. When diagnosed late we may not only worry about controlling the infectious process but also might have to address the involvement of the surrounding tissues as well as a compromise to the structural integrity of the spine.[10-14]

A high index of suspicion usually leads to prompt and accurate diagnosis. Early determination of the causative pathogen and administration of antimicrobial therapy is the mainstay of treatment. More importantly we have to evaluate the extent of collateral damage on the osseous and soft tissues, determine potential instability and address deformities that might ensue from the overall pathology of our patients.

PATHOGENESIS

Spine infection can be acquired through either endogenous or exogenous routes:

Orthotic Management of Infectious Disorders of the Spine

Endogenous

- Hematogenous spread from a distant organ or tissue source
- Contiguous spread from an adjacent organ or tissue infection

Exogenous

- Inoculation from an invasive intervention
- Iatrogenic following spinal surgery

Many organ/tissue systems (e.g. skin, oral cavity, respiratory tract, genitourinary tract, gastrointestinal tract) harbor pathogens, contaminants and normal flora that can give rise to bacteremia. Breach in asepsis during venipuncture, percutaneous procedures and surgical interventions directly transmit pathogens inside our body. Both can lead to a hematogenous and contiguous spread of an infection directly into the spine.[5,6,15]

Vertebrae have a rich arterial network that nourishes its bone marrow close to its endplates. The nutrient artery enters the posterior wall from whence the circulation travels to sinusoids adjacent to the end plates. Here slowing of the circulation allows bacteria to collect and begin to multiply. The pathophysiology of discitis differs in adults and children. In children the discs are vascular resulting in primary discitis. In adults the disc is relatively avascular making discitis a secondary result of a contiguous spread from the vertebral metaphysis.[20, 16]

An extensive paravertebral venous plexus of the spine described by Batson is also felt to be a channel for vertebral osteomyelitis. The Batson's venous plexus is a network of valveless veins that connect the deep pelvic veins and thoracic veins through an internal vertebral venous system. This valveless venous route allows for a large capacity and slow flow directly to the vertebral body. This plexus, found largely over the lumbar region (58%) is felt to be the reason why this area has the highest incidence of infection, more so than the cervical or thoracic region (30%).[17]

Once a septic embolus finds its way to the neighboring vertebra and disc, it creates the characteristic lesion of spondylodiscitis. Inflammation leads to hyperemia and to osteopenia. The body of the vertebra softens, and yields to gravity and muscle forces causing compression and collapse. An extensive infarct ensues within the body because of the accumulation of a fluid abscess. This infarction also leads to the formation of bone and cartilage sequestra.[18] The result is the creation the formation of a viscid fluid abscess that is pushed along the tissue planes resulting in extension between the ligaments, along muscle planes and into cavities like the spinal canal (Fig 1).

Fig 1

Once the spinal canal is invaded, the chances of neurologic deficits become clear. Fluid abscess, necrotic bone and disc debris can create mechanical compression sufficient to alter the neural and vascular physiology of the spinal cord or its nerve roots. Similarly these inspissated substances create enzymatic reactions that lead to vascular thrombosis resulting in a neural infarct. Severe architectural collapse of the spinal column can cause bony ridges that can cause neural compression and/or stretching and fibrosis that can result in paraplegia.[19,20,21]

All of these sequential events of destruction are predictable and can be prevented with early detection. The most common pathology is an anterior compressive collapse because of the destruction and weakening of the anterior column. Early detection, medical treatment and orthotic management can prevent this unfortunate cascade of events.

PATHOGENS

Table 1

Spinal infections are generally distinguished between non-tuberculosis (non-specific) versus tuberculosis (specific) infections. The pathogens associated with spinal infections are bacterial, mycobacterial, fungal and parasitic.[15,22] (Table 1) Staphylococcus aureus is the most predominant pathogen in non-tubercular spondylodiscitis in all age groups accounting for between 20-84% of cases.[15,23,14] Tuberculosis is however the most common type of spinal infection worldwide. Tuberculosis (TB) is second only to HIV as the greatest killer due to a single infectious agent. The statistics regarding tuberculosis are staggering. In 2013, WHO reported that 9 million people fell ill to tuberculosis with a mortality of 1.5 million. Ninety-five percent of TB related deaths are in low and middle income countries and it is always considered among the top 5 causes of death. In 2013, 550,000 children were also estimated to have contracted TB with 80,000 HIV-negative children dying from the disease. Tuberculosis is the leading killer of HIV-positive patients and an estimated 480,000 patients are developing multi-drug resistance to it. The World Health Organization (WHO) is however optimistic because even with this alarming number, the estimated patients falling ill with TB is declining each year which means that the world is on track in achieving the Millennium Development Goal to reverse this trend of TB infections. Between 1990 and 2013, TB related deaths dropped by 45%, with 37 million lives saved through early and proper TB diagnosis and treatment.[25,26]

DIAGNOSIS

Diagnosis of a spinal infection is clinically based on a high index of suspicion. Laboratory exams are carried out to confirm the clinical diagnosis and to determine the causative agents of infection. When spine infection is suspected there would be a variable increase in White Blood Cell (WBC) count. Laboratory tests like Erythrocyte Sedimentation Rate (ESR) and C-Reactive Protein (CRP) are sensitive indicators of inflammation in the body but not specific to a given infection. The ESR is more specific and shows significant increase with tubercular vertebral osteomyelitis. Sequential determination of ESR and CRP during medical treatment helps as a prognostic marker for the response of patients to treatment.[4,6,23,24]

Blood cultures should be a standard procedure even if it is only positive in one-third of patients with pyogenic spondylodiscitis. Spine infections are generally mono-microbial. Blood culture is very simple and cost effective especially since the major route of this infection is hematogenous. Cultures should be taken up to 3 times for definitive identification particularly in the acute febrile phase.[15]

Microbiological diagnosis is critical for a definitive diagnosis. This can be done by CT-guided biopsy of the vertebra, disc space or related abscess formation. CT-guided fine needle aspiration biopsy (FNAB) of the affected spine or paraspinal region, which manifests abscess collection should also be done at the same time. It is essential to identify the pathogen; samples should be submitted for Gram Stain, Acid-Fast Stain, and culture with sensitivity. Adequate samples should also be sent for cytological and histological diagnosis.[27,28] Submitting samples for deoxyribonucleic acid detection via polymerase chain reaction(PCR) is becoming a standard practice. The PCR increases the sensitivity of detection especially in cases where samples are sparse. It also allows for the detection of atypical mycobacteria.[29,30,31,32]

Most of the time the issue is the adequacy of specimen, which might not be enough when fine needle aspiration biopsy (FNAB) is performed. There are also instances when the possibility of a neoplasm or metastasis becomes a differential diagnosis and histological diagnosis becomes a primary concern. In the presence of an obvious osseous involvement and the absence of abscess formation where sample fluid pus can easily be aspirated, larger trocar needles like a Jamshidi needle can be used to get bone sample. Nowadays there are specially designed trocar-cutting needles that can harvest a 3mm x 1mm core vertebral-bone biopsy. This can be done under local anesthesia with the aid of a simple fluoroscopic image intensifier. This method provides us with ample samples for culture/sensitivity, cytology, histology and DNA amplification (Fig 2).

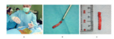

Fig 2

IMAGING IN SPINAL INFECTIONS

Various radiographic examinations can be utilized to confirm a clinical diagnosis and to localize the pathology. It also helps to demarcate the degree of bony and soft tissue involvement and provides an assessment of the stability of the spine. Moreover it provides information needed for treatment planning and monitoring.

Plain Film Radiographs of the spine in anterior-posterior and lateral views are a simple, inexpensive and readily available screening modality that can validate our suspicion of infection. Plain films may reveal bony lytic and sclerotic changes, disc space narrowing, vertebral collapse, and paravertebral soft tissue swelling. These changes typically manifest themselves in the later stages of the infection (Fig 3A).[5,33,34] Plain radiographs have 82% sensitivity and 57% specificity.

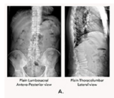

Fig 3A-C

Computed Tomography Scan (CT) enables accurate evaluation of bony destruction. It provides evidence of infection early because the disc shows areas of hypodensity. Similarly it reveals flattening of the disc and clearly shows vertebral endplate destruction. With the addition of contrast medium it can reveal paravertebral and psoas involvement that may lead to CT guided aspiration or drainage. CT scans provide tomographic images that create detailed axial, sagittal, and coronal reconstructions. These give us a complete evaluation of how the disease process might affect all three columns of the spine. These reconstructions also give us a complete picture of spinal canal involvement not seen on simple plain films. Tomographic imaging also allows us to create exquisite and informative 3D reconstructions (Fig 3B).[1,35]

Magnetic Resonance Imaging (MRI) is currently the imaging modality of choice for spinal infections. It is the gold standard modality to detect spondylo-discitis. Signal density changes within the marrow of the vertebrae are picked up early with this modality. Soft-tissue changes and epidural involvement are clearly demonstrated by MRI. It can also provide tomographic images in axial, sagittal and coronal views that give a detailed picture of the pathology in relation to adjacent tissue organ systems. MRI provides a very clear understanding of the contiguous spread of abscesses along ligament and fascial planes as well as its extension into the canal. MRI gives the best visualization of potential meningeal involvement. It is also crucial in revealing non-contiguous vertebral involvement. Gadolinium contrast enhancement improves the accuracy of MRI especially in early stages of infections when marrow changes are still subtle. It also helps in differentiating infection from other differential diagnoses like neoplasm and degenerative changes (Fig 3C).[5,36,37,38,39]

Radionuclide Scintigraphy utilizes various tracers that localize in areas with increased metabolism. Technetium-99m is the most commonly used radioisotope. It has high sensitivity but poor specificity. Gallium-67 scan detects early changes in the spine but still lacks specificity as degenerative changes can show the same uptakes seen in infection (Fig 4A).[70,73]

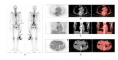
Fig 4A

Positron Emission Tomography (PET scan) can be a very helpful tool when a definitive diagnosis cannot be established using the standard procedures already covered. It has been shown to have good specificity. It allows a fine differentiation of infectious versus degenerative processes but not so with malignant processes. It has less radiation exposure when compared to CT Scan. This is an expensive procedure and is generally only indicated when MRI gives conflicting results (Fig 4B-D).[1,15]

CLASSIFICATION OF SPINAL INFECTION

Classifications of medical conditions are usually designed to serve as tools or guidelines for planning the management of the disease. It usually helps in determining the demarcation between non-surgical and surgical treatment of patients. Most classifications are designed to address concerns regarding tuberculosis of the spine because of its prevalence and the severe complications brought about by late diagnosis and treatment.

Acute versus Chronic Presentations

Previously we have classified spinal infections as non-tuberculosis (specific) versus tuberculosis (non-specific). These two types of infections present quite differently. Non-tubercular infection usually presents with an acute onset, with localized severe back pain and tenderness, severe spasm, inability to walk, general body malaise and febrile episodes. Conversely, tuberculosis infections present with a protracted history of a dull nagging pain variable tenderness and less toxic symptoms. Patients would usually seek care late with weakness and inability to walk, weight loss, body malaise, and a gibbus deformity of the spine. Tubercular spinal infections are more often diagnosed late because of the slow onset of clinical symptoms.[23]

Anatomic Classifications

The anatomical location of the infection is of great importance when considering treatment protocols. Preserving the structural integrity of the spine is important to avoid deformity and neurological insult. There are many classification systems in the literature.[20,24,40,41,42]

BIOMECHANICAL CONSIDERATION OF THE INFECTED SPINE

To understand how infections can affect the stability of the spine it is important to consider three concepts. One of the earliest and simplest references to the concept of spinal stability is the two-column theory of Holdsworth as applied to spinal fractures. He divided the “functional unit” of the spine into the

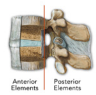
Fig 5

anterior column and the posterior column (Fig 5). The former comprises the whole of the vertebral body and its intervening disc up to the posterior longitudinal ligament. This ligament serves to demarcate the posterior column that includes all the posterior osseous architecture and ligaments attached to it.[43] Holdsworth should also be credited for recognizing the importance of the posterior-ligamentous complex (PLC) and its vital contribution to the stability of the spine. The PLC comprises all the posterior ligaments, the supraspinous ligament, interspinous ligament, the facet capsules, the ligamentum flavum and the inter-transverse process ligaments.

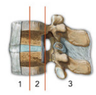
Fig 6

The Denis classification[44] (originally used for fractures) is the second concept and differs from that of Holdsworth in that it describes three columns. For his classification, Denis divided the anterior column to describe a middle column that comprises the posterior wall of the vertebral body, the posterior annulus and the posterior longitudinal ligament. Denis felt that an undamaged middle column renders relative stability to the spine (Fig 6).

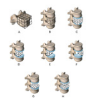
Fig 7

The final concept or classification is described by Benzel and depicts the vertebral body by dividing it into thirds in each plane (for a total of 27 cubic segments) (Fig 7).[45] This theory refers to the post surgical instability brought about by the degree of cubic segments removed during surgical intervention.[7] All three concepts simply dictate that the degree of spine instability greatly depends on how much the anterior elements of the spine are damaged by trauma, infection, neoplasm and even surgical intervention. All might vary in the details of their descriptions of how different columns contribute to the stability of the spine, but they all confirm the importance of the vertebral bodies and the intervening intervertebral discs as the major weight-bearing component of the spine. These concepts also describe how the rest of the posterior elements function to protect the spinal cord and dictate the degree of motion allowed for each of the specific regions of the spine. These concepts are usually discussed with reference to traumatic injuries of the spine but they can be also safely extended to destructions brought about by infections and neoplasms. All of these stability classifications have been corroborated by the in vitro studies of White and Panjabi who showed that about 80% of forces (axial load) in a standing man are born by the anterior elements of the spine and that the posterior elements share the remaining 20% of the load.[46]

It is also important to view the spine as a multi-linked system of joints that constitute static and dynamic stabilizing systems. All osseous and ligamentous structures constitute the static stabilizers and all the intervening posterior muscle attached to the spine from the occiput to the iliac crest make up the dynamic stabilizers. Studies by Panjabi point out the critical importance of the dynamic stabilizers of the spine. They have shown that the dynamic stabilizers contribute to 70% of the stability of the spine and the rest is afforded by the static osseous-ligamentous structures.[17,46] This relationship plays a big role in how the dynamic stabilizers compensate for the predictable damage brought about by infections to the static stabilizers of the spine.

At this point it would be relevant to draw some basic similarities and differences in how the spine can be destabilized by either trauma or infection. Both trauma and infection can destroy the integrity of either the anterior elements or posterior elements individually or in combination. This destruction can either be osseous, ligamentous or in combination. Both can invariably involve the spinal muscles as well.


Table 2

Instability is dictated by the degree and extent of the collective damage to the columns of the spine and supporting tissues. Traumatic injuries to the spine however are acute events that bring outright simultaneous damage to both the osseous-ligamentous static stabilizers and the muscular dynamic stabilizers of the spine. Diagnosis is usually prompt in reference to an immediate traumatic event and management is usually instituted immediately. Neural compression, deformities and instability are immediately evaluated. Thus the progression or worsening of injury is immediately addressed most of the time with prompt diagnosis and management (Table 2).[20,21]

Spinal infections on the other hand are insidious. The initial symptom of pain can be misconstrued as originating from something other than the infectious pathology that is slowly destroying the supporting structures of the spine. Owing to the hematogenous route of infections, an initial inconspicuous stage of anterior column destruction is often undetected. The discs and ligaments are only secondarily damaged because of spread of the infection as the disease process progresses usually because of delayed detection and treatment. The dynamic muscle stabilizers are usually the last to be affected owing to the natural protective barrier provided for by fascial planes. The paraspinal muscles play a significant role in compensating for the subtle events in a spinal infection by splinting the body posture in a position of comfort during waking hours. This resulting support explains the classic “nocturnal cry” in children with tuberculosis of the spine where pain ensues when muscular splinting relaxes during deep sleep allowing movement in the inflamed tissues of the spine.[16,17] Neurologic deterioration, deformity and instability are late complications seen in patients with spinal infection and are complications of delayed diagnosis and treatment. They occur once there is significant destruction of the two anterior columns that Denis described.

An infection has a predictable effect on the vertebral body. Whether the infection is bacterial or tubercular in nature, the common denominator is the lytic destruction of the anterior column rendering it deficient to support axial loads. This loss of support causes most infected spines to go into a certain degree of anterior collapse.[18,47] The axial loading capacity of the spine now shifts to the posterior osseous elements particularly the facet joints. The posterior ligamentous complex acts as a static restraint and the posterior muscles provide the dynamic tensile forces that counter the kyphosing deformation as the anterior column becomes more deficient. However it does not take long before both fail if no internal or external stabilization is provided to compensate for a deficient anterior column.

Deformity becomes a bigger problem if the posterior column is damaged by the contiguous spread of infection. The facet joints and their capsules are the primary restraints against rotational and translational deformations in the spine along its axial and coronal planes respectively.[48]

Damage to both the anterior and posterior elements of the spine produces instability in all of the sagittal, coronal and axial planes of the spine. A complex three-dimensional deformity of the spine will occur if both anterior and posterior elements are destroyed by infection. Such deformities can compromise the continuity of the spinal canal and cause injury to the spinal cord. This highlights the importance of preserving the posterior elements in situations where surgery is contemplated as they may be the only intact structures naturally supporting the spine.[2,41,49,50] Late complications are usually associated with spillage of pus and necrotic debris from the involved anterior column which subsequently encroaches on the spinal canal causing mechanical compression and vascular infarct to the spinal cord. Any progression of a kyphotic deformity squeezes more pus and necrotic debris superiorly, inferiorly, or into the canal carrying the risk of totally indenting the spinal cord. Now it becomes evident how orthotic management of spinal infections can serve to protect the spine from the complications of kyphotic, rotational and translational deformities of the spine.

Children who possess a skeletally immature spine and deformity from an infected spine are expected to worsen until they reach the age of skeletal maturity due to injury to their vertebral growth plates. Deformities secondary to infections in the adult can also progress when not properly treated.[14,51,52] Rajasekaran et al.[66] showed a peculiar pattern in children with post-tubercular spinal deformities. He was able to document that it can improve, worsen or remain static during growth. He documented this growth modulation on 63 children with Pott's disease treated without surgery in a multicenter prospective clinical trial. The study documented varying changes in the infected segment of the spine over a 15-year period. The study used a finite element model to study the development of kyphosis and analyze the relative role of each of the structures of the spine with the primary objective of understanding the basis of biomechanical growth modulation that governs post-tubercular kyphosis. The study shows that in children, the progression of kyphosis depends on the anatomical preservation of the posterior column.[53] Any degree of dislocation in the facet joints indicates growth suppression and severe destruction in the anterior column. For those who showed a preservation of the anatomical relationship of the posterior column, the vertebral body healed and even showed accelerated growth in the long term. The importance of the role of orthotic management in children afflicted with spinal tuberculosis is demonstrated here, to preserve and protect the normal anatomy of the posterior column of the spine.

One last note that deserves attention is the number of levels directly or indirectly involved in the vertebral destruction by a spinal infection. Hyperemia or increase in blood flow ensues at the level of infection resulting from the patho-physiology of the inflammation. These changes bring about a relative degree of osteopenia to the affected level as well as in adjacent vertebrae above and below the infected level washing away the inorganic elements of the bone matrix. This leads to the loss of calcium and phosphorus that can alter the intrinsic strength of these adjacent levels.[17,21] This condition worsens if pus or necrotic materials dissect superiorly or inferiorly between the bones and ligaments or the prevertebral fascia. The acidic medium of this dissecting flegman weakens the unaffected bones making them soft, causing multiple levels of vertebral collapse. The significant progression of the kyphotic deformity is the rationale for a longer use of an orthosis in the infected spine as compared to a post-traumatic spine. Whereas bone and ligamentous healing in trauma is more predictable, it might take longer for the infected levels of the spine to reconstitute their intrinsic strength.

The alteration of the sagittal balance of patients who developed kyphotic deformities needs consideration. An uninvolved spine has sagittal curvatures, both kyphotic and lordotic which places it in equilibrium allowing us to perform our daily activities particularly normal ambulation. Increased kyphosis alters the line of gravity leading to several compensatory mechanisms over the upper and lower segments of the spine as well as to the hip and the knee joints in order to maintain the axial line and center of gravity. When the spine develops severe kyphosis the line of gravity moves more anteriorly. Patients would usually increase their lumbar lordosis to bring this line back to a normal position.[55] The result is a constant muscular strain to maintain a corrected posture which may lead to low back pain. To relieve fatigue in lumbar region, patients tilt their pelvis backwards, extend their hips and flexing their knee to maintain an upright position.[61] In many instances a patient will also extend their neck to maintain a horizontal gaze. All these compensatory alignment mechanisms put a lot of strain in the musculoskeletal system leading to fatigability, intractable muscle pain with a poor quality of life.[56] Because of the intrinsic physical changes on multiple vertebral levels brought about by infection, some patients may lead to a progressive kyphotic deformity even if the infection has already healed. Patients who developed spinal infection are very prone to a severe kyphotic deformities leading to extremes of sagittal imbalance. They need close observation and monitoring and perhaps an extended regimen of orthotic management to prevent such a progression of the deformity (Fig 8).

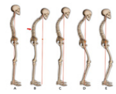
Fig 8

TREATMENT OF SPINAL INFECTIONS

Treatment of patients with vertebral osteomyelitis should be individualized. Treatment should be tailor fit according to their age-related general medical condition, prevailing neurologic status, presence of associated abscess accumulation and the amount of bony destruction assessed from available radiologic imaging. The aim of treatment is to eliminate the infection, preserve the architecture and function of the spine and to relieve pain. Treatment success relies critically on early diagnosis before biomechanical instability is evident. Non-operative treatment is more likely to be successful in younger patients, in patients with an absence of comorbidities (AIDS, diabetes, hepatic or renal failure, steroid medication), and when all radiographic studies show minimal bony destruction.

Non-Pharmacologic

Patients suffering from spinal infection should also be treated with a well-rounded diet and adequate hydration. Patients can be debilitated early in their disease process and can be confined on bed for long periods of time because of the pain they experience. Latter can greatly affect their feeding patterns. Without the proper nourishment, patients can grow weaker and emaciate. The recumbent predisposes patients to develop pulmonary atelectasis that can lead to pneumonia and even pressure sores because of the preferential habitus that they may assume due to the pain they feel. Nursing care is important in these conditions.

Patients should be progressively mobilized according to their tolerance to avoid the development of flexion contractures and to allow them to be independent in their activities of daily living. They should be assisted to enable early mobilization for their daily needs. It would be helpful to expose patients to sunlight early in the morning or late in the afternoon to provide them with their daily requirements for Vitamin D. There is a prevalence of Vitamin D insufficiency even in normal people and much more so for people who may be sick and confined in bed. Supplementation with oral water-soluble vitamins can help for the overall well being of patients. Patients with spinal infections develop severe osteopenia over their infected spine and will need vital vitamin and mineral supplementation to help in the physiology of healing and osteogenesis.

Physical therapy is very helpful in the passive-mobilization of patients who are bed ridden. Progressive assistive-exercise then eventual active-exercises would facilitate patients to get back on their feet. There has been a large shift from prolonged recumbence and rest to early ambulatory care for patients with spinal infection. It is essential that complications of prolonged immobilization be prevented in patients. Once patients are more active, resistive-exercises are introduced to restore performance of routine daily activities.[58,59,68,84] Patients who develop atelectasis or other pulmonary complications during their initial bout of bed rest should be subjected to a regimen of pulmonary therapy. Latter is also applicable for patients who have pulmonary tuberculosis and those with existing restrictive or obstructive lung diseases. A good respiratory status will undoubtedly contribute to the general well being of patients with spinal infections.

Pharmacologic Treatment

Antibiotic therapy is the mainstay of treatment for spinal infections. It is tailor-fit to the culture sensitivity of the isolated pathogen and any other associated infections. In the event that there is a delay in the culture sensitivity of the needle biopsy performed, patients should be started on antibiotics immediately. If non-tubercular infection is suspected, broad-spectrum antibiotics covering both Gram positive and negative organisms, aerobes and anaerobes, including methicillin resistant Staphylococcus aureus, are instituted initially until final culture sensitivity results are obtained. If tubercular infection is suspected, patients are started right away with quadruple antituberculosis combination therapy.[2,8,10,14,51,57] The specifics of antimicrobial treatment are beyond the scope of this text and usually require an infectious disease specialist to manage doses and durations.

Surgical Management

Surgery in spinal infection aims to relieve compression of neural structures, evacuate large pockets of abscess in and around the spine, provide stability to extensive osseous-ligamentous destruction, prevent progression of deformity, and alleviate intractable pain.[2,5,11,12,18,19,65] It is beyond the scope of this chapter to explore all of the nuances for surgical intervention. The absolute indication for surgical intervention in spinal infection is the failure of non-operative management.[2,5,11,19,49]

THE ROLE OF ORTHOTIC MANAGEMENT IN SPINE INFECTION

Bracing is a frequently recommended adjunct to the post surgical and rehabilitative management of spinal infections. With the current trend of limiting the time spent at rest in favor of early ambulatory care for patients with spinal infection, bracing is the most logical mode of providing stability for the infected segment of the spine. The dynamic muscular stabilizers of the spine seek to stabilize an infected segment of the spine by splinting patients in their position of comfort. Sometimes this position involves severe postural listing out of normal axial balance. Muscle splinting normally goes into episodic fatigue and leads to spells of muscular contractions that may cause severe pain.[16,17] The proper immobilization of an infected spinal segment significantly reduces the burden of muscle splinting, maintain proper posture, and also limits gross movements that can trigger spasms helping to alleviate pain.

Bracing should aim to immobilize the affected segment of the spine to heal in its anatomical alignment and proper sagittal balance. Many favor early rigid bracing. It may aid in nursing care when in bed. In acute infections, bracing is usually continued for 6-12 weeks beyond the period of medical management. It should be noted that because of the loss of stability of an infected spine, a kyphotic deformity could progress beyond the acute infection and bony healing period. Even when there is no more pain and radiographs show some evidence of fusion over the affected levels, some degree of vertebral collapse can occur because of the intrinsic weakness of the osteopenic vertebrae. Patients should be closely monitored and might be advised to extend their orthotic management using less rigid orthotic devices.

The physiology of pain and instability in spinal infection is different from that of trauma whether it involves single or multiple spinal units. In spinal infection, the dynamic muscle stabilizers as well as the posterior-ligamentous complex (PLC) are almost always preserved. These two important structures are invariably damaged to varying degrees in spinal trauma causing intense pain and acute architectural instability of the spinal column. The preservation of these two structures in infection is enough to provide internal splinting to auto-stabilize the spine and thus reduce pain. From the discussion of the biomechanics of the infected spine, we have seen that episodic pain ensues when patients' internal muscular splinting bedcomes fatigued. Orthotic management in spinal infections compliments this internal dynamic splinting. Braces provide additional stability to the spine that allows ambulatory care with reduced pain and some degree of freedom to engage in activities of daily living. Cast immobilization and bracing in spinal infections are adjunctive forms of treatment to the medical management are never considered as primary modalities of treatment.

Spinal infections are largely considered a medical problem and should be primarily treated medically. Surgery is reserved as an absolute indication when there are neurologic deficits and severe instability involving the anterior and posterior elements of the spine. Neurologic involvement of the spine is not a common early presentation and is usually a late sequela of a neglected condition. Neurologic involvement varies from 10% to 40% in patients with spinal tuberculosis and even much less in non-tubercular patients. Many authors suggest observing patients with neurologic deficits before contemplating surgery because majority of patients show significant improvement once proper antimicrobial treatment has been started. Approximately 40%-60% of patients with Pott's paraplegia show recovery with multidrug chemotherapy and immobilization with bracing. Whether bracing really contributes to the healing of spine infections remains unanswered by controlled clinical trials.

The closest clinical trials that could have probably addressed the issue of spinal immobilization in spinal infection are those done for spinal tuberculosis. The British Medical Research Council (MRC) Working Party on Tuberculosis of the Spine embarked on a series of randomized controlled clinical trials in different parts of the world to investigate several methods of treating spinal tuberculosis three decades ago.[67.68.69.70] This was primarily conducted to establish a sound treatment protocol based on evidence. These studies are often cited and referred to up to the present day. One of the initial variables that they compared is treatment with bed rest with cast immobilization versus ambulatory outpatient treatment without support. At 18 months the response rate was 66% for the former and 58% for the latter respectively. At three years time the response to treatment was very close to 84% and 88% respectively. There was no difference in the kyphotic and neurological deterioration. These prove that ambulatory care is very acceptable and that patients can be treated with an initial bed rest for 4-6 weeks without immobilization and then encouraged to get up when there is little pain and spasm but wear braces for 6-12 weeks until inflammatory markers normalize and radiographs show evidence of bony healing.

A systematic review and meta-analysis of 35 relevant controlled studies specific to the management of spinal tuberculosis show that there is a paucity of a well-randomized trials that can point to the benefit of orthotic management in spinal infection. This meta-analysis showed that the closest study evaluating the benefits of cast immobilization was still the British MRC trials.[77] The trials that however concluded that plaster jacket immobilization has no benefits were performed 3 decades ago. During that era these plaster jackets were bulky, cumbersome, and heavy plaster cast body literally immobilized patients in bed. Their clinical relevance is difficult to compare with current advances in spinal orthotic fabrication, materials, and designs. Even if one argues that most of the current choices of spinal orthoses are designed for spine trauma, the goal of its prescription for spinal infection is pretty much the same. One paper reported good results with their locally fabricated orthoses based on comfort and tolerance of wear while allowing patients to be treated with chemotherapy on an ambulatory basis but this studies fall short of being randomized clinical trials.[78]

Most clinicians still hail bracing as fundamental in the treatment of spinal infection even if its effectiveness lacks evidence.[2,5,9,41,51,57,79,80,81,82] It is considered as a vital modality in the conservative management of spine infection in many textbooks.[16,17,21] It appears that many practitioners would still prefer to logically "err on the safe side" of treating patients with spinal infections by prescribing an device that would not harm patients at all and yet give them perceived benefits that clinical trials have not significantly proven - a spinal orthosis. In fact many authors suggest that the spine should be immobilized while waiting for the results of laboratory tests and infection identification and sensitivity determination.[2,51,16,83] Initial rest and brace immobilization when there is intense pain or risk of spinal instability appears to be a the norm among many practitioners. One concept that truly became a standard of care that clinical trials have supported is managing patients on an ambulatory basis. It is perhaps the fear that patients might develop complications from instability while being treated on an outpatient basis that pushed practitioners in continuing the use of spinal orthoses.

The pediatric age group afflicted with a spinal infection is the best beneficiary of orthotic management. The average age range of patients afflicted with spondylodiscitis is 2 to 8 years old. These children cannot accurately express themselves making both diagnosis and treatment often difficult. It has been advised by many authors that in pediatric patients, once there is a presumptive diagnosis of spinal infection, they should be immobilized in an orthosis while awaiting the results of their laboratory test, radiographic imaging and culture-sensitivity tests.[9,10,14,16,51] A child's activity level is only held at bay when they feel very sick. Pediatric patients are known for their quick physiologic rebound as soon as they feel well and this natural nonchalance to their medical condition puts them at great risk if spinal instability still exists.

One of the biggest concerns among the pediatric group of patients is their growth potential. It has always been emphasized that they should never be treated as small adults, they have their own unique concerns. Much attention is focused in maintaining the integrity of the end plates and apophyseal ring cartilages in children to preserve their capacity for longitudinal and appositional growth.[52,53,84] Properly fitted orthoses appear to be the best option that can protect the soft and osteopenic vertebral segments that are affected by infection. Commercially available "off the shelf" orthoses should be avoided in children as they are often ill fitting do to the wide range of body soft tissue volume existing in the different age groups of children. These "off the shelf" orthoses are best reserved for adult patients. One of the traits of the pediatric spine is its remarkable capacity to remodel.[84] Children should be closely monitored to assess whether immobilization devices are indeed maintaining the proper anatomic alignment of the spine. A healed spinal infection is half a victory won if it ends up with a residual deformity that could have been averted. Studies by Rajasekaran enumerated spine-at-risk radiologic signs that predispose the pediatric spine to late progressive deformities.[17,53] These should be identified in patients to determine if there is a need to maintain orthotic care beyond the healed stage of the infection or whether surgery is needed to arrest the progression of deformity. Surgery is rarely indicated for children with a spinal infection. Many are poor candidates for surgery. Generally antimicrobial therapy and orthotic immobilization is curative. Orthotic management is the best means by which we can protect a growing and unstable spine in afflicted pediatric patients.

Cervical spine infections in children and adults appear to be an absolute indication for orthotic support. Though some clinicians will still treat this condition with bed rest and cervical traction, the current trend is ambulatory treatment with a cervical orthosis. The cranio-cervical junction vertebral junction is especially problematic but has been shown to heal very well when treated early and immobilized properly in cervical orthosis.[80,81,85] Depending on the degree of instability at the occipito-C1-C2 region, a Halo-Vest apparatus offers the best immobilization. A Sternal-Occipital-Mandibular Immobilization (SOMI) orthosis may also suffice but does not provide the same degree of immobilization that a halo-vest does. The sub-axial cervical spine (C3-C7) can be immobilized with a variety of commercially available devices as long at it accomplishes the desired immobilization. They should offer protection in sagittal, coronal and axial planes and maintain the normal lordosis of the cervical spine. Cervical orthoses should be closely monitored in children especially when skeletal pins are utilized because of chances of early loosening. It should also prevent any pressure on the mandible as it can easily affect the plasticity of other osseous structures and cause mandibular or dental deformations.

Whether one suffers from non-tubercular or a tubercular spine infection, both are considered medical problems whose primary treatment is the specific antimicrobial chemotherapy. Orthoses are then prescribed specific to the region of the spine that is affected. Orthotic recommendations for specific regions of the spine are depicted in Table 3. (Table 3)

Table 3

ALIGNMENT AND FORCE APPLICATION OF ORTHOSES

Most orthoses prescribed for spinal infection are aimed towards restricting sagittal movement in forward flexion to reduce compressive forces on the vertebral bodies since the anterior elements are usually affected by infection. It is only when the posterior elements are also affected that components for coronal restraints are added in the prescription of the orthosis. When the posterior elements are affected it is presumed that the facet joint might be at risk and thus fail in offering physiologic restraints towards lateral bending and rotation. The classic 3-point fixation or force system is employed to secure the orthosis on the body and provide restriction of motion and correction of posture (Fig 9).

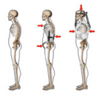
Fig 9

For the cervical spine, 3-point fixation is relatively difficult to employ owing to its short segment. Instead, specific body parts serve as anchors for the orthosis. The upper front chest area with its subcutaneous sternal surface, the broad posterior muscular surface of the upper torso, the rib cage, and the broad surface of the shoulder should serve as a large inferior anchorage for any cervical orthosis. The subcutaneous cranium, occiput and the mandible serve as stable superior anchorage for the head. The cranial component is secured either by skeletal pins, straps or contoured padded components. The superior or inferior components are connected together with rods, posts or plates to provide the restriction and correction needed for the cervical spine. The Halo-vest for example employs this system of fixation and provides the most rigid external fixation of the cervical spine. However, studies have observed inter-segmental snaking phenomenon with the Halo-vest device. A full contact Minerva orthosis addresses this phenomenon but is relatively uncomfortable for most patients particularly for those in tropical countries. This fixation system would also work fairly well with infections at the cervical-thoracic junction (Fig 10).

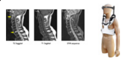
Fig 10

Infections of the upper thoracic vertebra from T1-T8 are in a relatively stable zone owing to the support provided by the rib cage. But when multiple contiguous levels are involved the risks of wedge compression collapse is high. A Risser or a Mehta cast is usually the best choice of supporting the upper thoracic level. It is classically constructed using plaster of Paris making it relatively bulky and heavy. It can also be applied using fast setting fiber composite materials that allow it to be applied thinly making it light, comfortable and relatively breathable. A Risser brace can also be molded using thermoplastics in a bi-valved fashion allowing bathing and hygiene. The most important component is the cervical extension that limits this highly mobile segment whose motion arm transmits physiologic loads to the unstable upper thoracic vertebrae (Fig 11). The Milwaukee orthosis (CTLSO) that is commonly used for spinal deformities also has a role in infectious spondylitis of the thoracic region. When properly fabricated it imposes no restriction to the expansion of the chest and thorax and provides good stabilization to the thoracic spine (Fig 12).

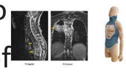
Fig 11


Fig 12

The thoraco-lumbar spine taken collectively is a long segment whereby the principle of 3-point pressure system could be maximized. The superior points can utilize part of all of the rib cage. The most useful part of the thoracic rib cage is the anterior subcutaneous sternal portion and the clavicles. The prominent parts of the pelvis like the pubis and the anterior superior iliac crests serve as the anterior-inferior point of fixation. The last point that completes the 3-point fixation system is located posteriorly usually centering over the affected area of the thoracolumbar spine. This system of fixation is utilized to restrict forward bending and sometimes even to help patients assume a hyperextended posture. Semi rigid to rigid materials should be used for this purpose to maximize the trunk control needed. Lateral restraints are added into the system when there is a need to control lateral bending or trunk rotation particularly when the posterior elements of the spine are affected (Fig 13).

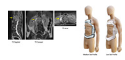
Fig 13

For severe cases with contiguous or multi vertebral level infections along the thoracolumbar spine a total contact body jacket is recommended. These are usually customized patient-specific orthoses that hug the whole body to maximize trunk motion control (Fig 14). Total contact

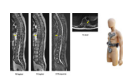
Fig 14

body oryhoses should allow normal chest expansion and should not contribute in unduly increasing intra-thoracic pressures. Similarly, it is important that full contact spinal orthoses not increase the intra-abdominal pressure. An abdominal opening is usually created in a total contact body jacket to prevent any constriction over the abdomen and serve as ventilation for a very constrictive appliance. A good number of patients with spinal infections develop paravertebral pockets of abscess. An increase in the intra-abdominal pressure might push a fluid abscess to areas of least resistance like the epidural space and the spinal canal. Additional windows can be created to facilitate cleaning and dressing of existing sinuses that is also present in some patients with spinal infection. Orthoses made of rigid materials offer better stabilization during the acute phase of the disease. Patients may transition to a semi-rigid orthoses when their clinical condition improves and when they are experiencing less pain.

Fig 15

Infections of the mid lumbar spine may be managed with a TLSO, (Fig 15) whereas infections of the lower lumbar vertebrae and the lumbosacral junction are more clinically challenging. Its location between the lever arm of the torso and the motion of the pelvis and lower extremities predisposes it to a great deal of physiologic loads. It can develop severe instability if it is not properly protected during the acute and healing stages of the infection. Infections in this area elicit a great deal of pain. Patients usually have an associated psoas abscess that aggravates the pain. It predisposes the patient to hip flexion contractures because of hip flexion to splint the pain. The best immobilization device is a pantaloon cast or orthosis or a hip spica brace that extends well onto the thigh. It prevents weight bearing and motion about the hip joint. If properly applied it can correct and counter hip flexion contractures (Fig 16).

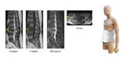

Fig 16

FUNCTION AND ACTIVITIES OF DAILY LIVING WITH ORTHOTIC USE

It has been previously emphasized that the orthotic management of spinal infection should be initiated even while laboratory work ups are being done or even when just a presumptive diagnosis has been made. This is due to the fact that most cases of spinal infection are diagnosed late with patients presenting with clinical and radiographic signs of instability. We have learned that no randomized clinical trial supports the effectiveness of bracing in spinal infection. Yet it is always suggested as a standard of care. It has also been suggested that spinal bracing and activity restriction should be maintained for 10-12 weeks or even longer until there is evidence of clinical, laboratory and radiographic healing.

Orthotic immobilization is recommended when patients assume an upright sitting or standing position. The orthotic prescription should allow patients to engage in all activities of daily living restricting their activities mostly in forward flexion. It should allow them to sit upright with comfort since this will be the position that patients will be assuming most of the time during their waking hours. Any orthosis should allow them to perform activities of daily living with ease.

Orthoses should allow patients to engage in body hygiene and self-care of the perineum. It is thus important that orthotic design employs ease of donning and doffing so patients can easily wear them with little assistance or nursing care. Parental assistance may be necessary with children. If donning and doffing assistance is required it is important for the medical team to properly train the caregiver. Provision of a wearing (dosage) schedule is helpful for patients and allows them opportunities to take their orthoses off to relieve heat buildup under the orthosis especially for those who live in tropical countries. Some patients are allowed to remove their orthosis when recumbent. It would be of great help if the orthotic design would allow ease in donning it in either a lying or sitting position while on bed. Once in an orthosis, many patients find it easier to sit up in bed then stand because of the relative stability provided by the orthosis. Almost all of the orthoses utilized for spinal infection of the cervical and thoracolumbar spine should allow ambulatory activity. Randomized clinical trials have proven that patients with spinal infection can ambulate and should be encouraged to do so to prevent the physiological and psychological complications of prolonged bed rest. It is only when patients are placed in a pantaloon or spica brace for infections of the lumbosacral junction that patients will have to be recumbent for a certain period of time. Even then some pantaloon designs have incorporated locking and unlocking hip joints that can allow patient to sit down. The psychological impact of 10-12 weeks of orthotic wear should not be underestimated. Patient and caregiver feedback should be solicited on a frequent basis to determine if counseling is required. Orthotic designs should allow it to be worn underneath clothing. Orthoses should be perceived as a treatment modality that aims to aid a patient and not as a punishment for one's medical misfortune.

CONCLUSION

Infections involving the spine and its adjacent structures may be relatively rare in some clinical practices but have debilitating consequences if not treated properly. A rising incidence is observed due to the rise of HIV, illegal drug users, increasing nosocomial infections, aggressive spine surgeries and a resurgence of tuberculosis worldwide. Early signs and symptoms may be ill defined and are often attributed to something other than infection. Diagnosis is often arrived at late. A high index of suspicion usually alerts clinicians to investigate further to arrive at the proper diagnosis. Infections can come from an exogenous source as well as an endogenously. Pathogens are classified generally as either non-tubercular or tubercular, which is why it is necessary to aim for an exact microbial, cytological or histological diagnosis. One of the greatest concerns in spinal infection is the degree to which it affects the stability of the spine. When most patients present there is significant damage to the spinal unit because of the delay in diagnosis. It is very important to assess spinal stability with the aide of radiographic imaging procedures. The anterior elements of the spine are often affected predisposing the spinal unit into a kyphotic deformity.

Spine infection is generally a medical condition that responds well to non-surgical medical management consisting of proper antimicrobial chemotherapy and orthotic immobilization. Orthoses are widely used to stabilize the spine to avoid complications that could compromise the neural structures traditionally protected by the spinal column. Proper immobilization can likewise avert the need for surgical intervention. Randomized clinical trials have shown the benefits of ambulatory care for patients with spinal infection. Orthotic management logically provides protection to the spine while allowing patients to engage in their activities of daily living. There is however conflicting evidence as to how spinal orthoses really work. Nevertheless, the medical community would rather "err on the safe side" and still rely on the benefits that spinal orthoses offer. Oftentimes bracing is maintained throughout the medical treatment and sometimes even beyond to prevent the progression of a deformity. The importance of closely monitoring patients with a spinal infection can never be overemphasized. Overall treatment should aim for the resolution of the infection, pain relief, maintenance of anatomical alignment of the spine, prevention of deformity, and to achieve solid bone healing of the affected level.

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Orthotic Management for Osteoporosis

Bryan S Malas, Kevin P Meade

INTRODUCTION

Osteoporosis is a disease characterized by low bone mass and weakening of bone tissue, which can lead to an increased fracture risk for the hip, spine, or wrist. With osteoporosis, mineralized bone density is diminished making the bone structure more susceptible to fractures. Despite being the most common of the metabolic bone diseases, the precursor or causes of osteoporosis are numerous. This includes, but is not limited to connective tissue disorders, endocrine disorders, malnutrition, medications and osteopenia.[1] It is a major public health problem, with 100 million people at risk worldwide and 28 million people at risk in the United States alone (Table 1).[2]

Table 1

Type I osteoporosis is associated with estrogen deficiency occurring after menopause. Vertebral bodies, the distal radius, and the hip are at greater risk for fractures. Trabecular bone is degraded and results in reduced ability to support compressive loads. Type II osteoporosis, related to aging and calcium deficiency, affects males and females. Trabecular and cortical bone are affected. Since cortical bone provides structural stiffness in torsion and bending, areas at higher risk for fractures include the neck of the femur, vertebral bodies, proximal tibia, pelvis, and humerus.

Vertebral compression fractures (VCF) from osteoporosis are common and present with a primary clinical complaint of pain; acute (< 3 months) and/or chronic (> 3 months). There may be comorbidities, e.g., chronic obstructive pulmonary disease (COPD), complicating treatment. The incidence of vertebral fractures internationally is summarized in Box 1.

Box 1

Treatment is divided into pharmacologic, non-pharmacologic, and surgical options that address acute pain from a recent VCF or the chronic pain that may follow.[12] Only a few studies on orthotic management report on the effectiveness of specific orthoses. Thorough patient assessment, distinction between acute and chronic pain and proper measurements, casting, and digital scanning are necessary for selection of the appropriate orthosis. Effectiveness of the orthosis depends on donning and alignment, improving stabilization (acute), improving posture (chronic), decreasing pain (acute/chronic), improving pulmonary function, and improving muscle strength (paraspinal muscles).

ANATOMIC CONSIDERATIONS AND THE AGING SPINE

Normal anatomy and ongoing patterns of change with the aging spine are important to the understanding and management of the osteoporotic spine. Knowledge of normal anatomy offers both a logical starting point and subsequent gauge to the extent of the osteoporotic deformity. Relevant anatomic considerations include spinal alignment, regional vertebral characteristics, and the functional spinal unit. Over time normal anatomic considerations give way to an aging spine with different characteristics such as reduced lumbar lordosis, hyper-kyphosis and forward head posture. The ability to distinguish the aging spine from the osteoporotic spine offers an additional challenge as both share many of the same characteristics. Frequently it is only the level of severity of the deformity that allows a distinction between the aging and osteoporotic spine. Normal aging is typically accompanied by disc degeneration and collapse with loss of lumbar lordosis, increased thoracic kyphosis, loss of sagittal balance and thrusting forward of the head. An overlay of VCFs to an aging spine amplifies these deformities and imbalance in the sagittal plane. A combined knowledge and understanding of, the normal, aging and osteoporotic spine is essential for overall care of this population.

Spinal alignment is identified by region with a distinction across the three anatomical planes (sagittal, coronal, and transverse). The necessity to develop classifications for deformities in the coronal plane make alignment in this plane the most-well understood. Classifications for transverse alignment of the spine exist for the same reason, but to a lesser degree. The sagittal profile in earlier studies was not well understood, but increasingly that has changed with greater agreement of what constitutes normal alignment.

The normal sagittal profile for the thoracic spine kyphosis, ranges from 20°-45° with the average value of 38° for asymptomatic adolescents.[13] Values measured <20° and >45° are described respectively as hypo-kyphosis and hyper-kyphosis.[14] There is less agreement for the lumbar profile in the sagittal plane. Berhhardt and Bidwell described normal lumbar lordosis as -35° to -60°.[15] Lee and colleagues reported similar findings of lordosis in the Korean population with an average of -47.3° +/- 9.8°.[16] Vialle and colleagues studied 300 asymptomatic volunteers and reported lordosis values with a much higher average at -60° +/- 10°.[17] The extensive variation and lack of agreement make it difficult to distinguish normal from pathologic alignment. According to Tuzun and coworkers lumbar lordosis <20° and >40° are described respectively as reduced lumbar lordosis and hyper-lordosis[18] and only the reduced-lordosis with values less than 20° appears to be consistent with other investigators while the high-end value of >40° appears to lack agreement. Alignment challenges with lordosis are not confined to the lumbar spine, but equally problematic in the cervical spine. The normal cervical sagittal profile is described as -30° to -40° of lordosis,[19] however debate still exists about this range.

While variations are apparent within the spine they are not limited to alignment, but include regional characteristics that are different across the lumbar, thoracic and cervical spine. Characteristic differences include the size, shape and variation in mobility based in part on the different facet geometry. However, the Functional Spinal Unit (FSU) or motion segment exhibits biomechanical characteristics similar to those of the entire spine and constitutes two adjacent vertebrae and their complementary surrounding tissue.[20] The two adjacent vertebral bodies and the corresponding intervertebral disc constitute the anterior portion of the FSU which, in the thoracic spine, is subjected to the greatest compressive loads (approximately 80%) while the remaining 20% of axial loading occurs across the posterior column.[20] This includes everything posterior to the posterior longitudinal ligament up to and including the supraspinous ligament. The relevance of the FSU with osteoporosis is observed with the high prevalence of vertebral body fractures and loss of vertebral height that affects the spine's load carrying capacity and ability to withstand normal physiologic loading. This situation invariably leads toward greater thoracic kyphosis and increased risk of fractures to adjacent vertebra. Additionally, there is an increase of compressive loads across the posterior elements leaving them susceptible to osteoarthritis, facet syndrome and disc degeneration.

Aging Spine

Most studies on the aging spine and in particular lumbar lordosis demonstrate that lordosis either decreases or at least remains the same during a person's lifetime.[21,22,23,24,25,26,27] Although a handful of papers suggest an increase in lumbar lordosis over time these investigations are the exception.[18, 28] Reports indicate that loss of lumbar lordosis can be as much as 20% for individuals older than 50 years of age and includes a 12% and 31% loss of range of motion of upper body flexion and extension respectively.[29] Also evident with the aging spine is a progressive loss of cervical lordosis and increase in thoracic kyphosis. The latter has been shown to be associated with increased mortality,[30] diminished physical performance[31,32] and a low quality of life[31,33,34] while the former has been shown to be associated with a forward head posture. Some reports suggest that by addressing impairments related to thoracic hyper-kyphosis, improvements will occur with the cervical spine and forward head posture.[35] As part of the ongoing and continuous aging of the spine it is not uncommon to also see disc and facet degeneration and decreased mobility in later years of life. The combined effects of a deteriorating and aging osteoporotic spine has been shown to affect standing balance which ultimately leads to decreases in health-related quality of life (HRQOL).[36,37,38,39]

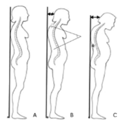

Fig 1

The sagittal profile of the aging spine becomes more noticeable with osteoporosis and the presence of a VCF. The secondary hyper-kyphosis characteristically has a sharper angle of deformity than the aging spine while the forward head posture is often more pronounced and confirmed by an occiput-to-wall distance >5.0 cm (OWD) (Figure 1).

PREVENTION OF VERTEBRAL COMPRESSION FRACTURES (VCFS) FROM OSTEOPOROSIS.

Often the first indication that osteoporosis is present is when a painful VCF event occurs. The treatment team focuses on resolution of the resulting acute pain and resuming activities of daily living (ADLs) of the patient, which can be a lengthy and costly task. This can potentially be circumvented through early screening programs that help to avoid this scenario. Most clinicians agree that increased exercise and calcium consumption, decreased alcohol intake, and cessation of smoking lead to the preventative loss of quality bone.[40]

THE CONSEQUENCES OF VCFS DUE TO OSTEOPOROSIS .

The consequences of VCFs due to osteoporosis include acute and/or chronic back pain, functional limitations, and mood impairment. Clinical signs of VCF include sudden onset of back pain with little or no trauma,[41] loss of height, spinal deformity (dowager's hump), protuberant abdomen, and diminished vital capacity. In patients with thoracic or lumbar VCFs, lung function (forced vital capacity, forced expiratory volume in 1 second) is significantly reduced.

VCFs can present with acute pain or they can be silent and have no associated pain. Nearly one third of the latter will have chronic pain.[42] Increased kyphosis is a common postural deformity secondary to VCF. Involutional muscle loss, called sarcopenia, is common in the elderly and can be an important factor contributing to muscle weakness (Fig 2).[43,44,45]

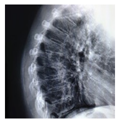
Fig 2

TREATMENT OPTIONS FOR VCFS

Treatment of osteoporosis is divided into pharmacologic, non-pharmacologic, and surgical options that address either the acute pain from a recent VCF or the chronic pain that may follow.[12] The primary types of non-pharmacologic treatments of osteoporosis include exercise, management of pain, orthotic treatment, and gait training. Reduction of the rate of bone resorption, improvement in the strength of bone, pain relief and enhancement of the overall quality of life are the goals of treatment. Improvements in muscle strength, particularly in the lower extremities, have been shown to decrease the risk of falls.[46] Simply stated, preventing fractures is better than treating their complications and consequently, prevention programs and screening for osteoporosis should be stressed.[47]

VCFs and their secondary effects remain a constant challenge for the medical team and should be addressed as quickly as possible. In particular, strategies addressing postural deformity reduction should be a major orthotic consideration because a person's ability to function on a daily basis can be dramatically improved and pain medication reduced.

ORTHOTIC CONSIDERATIONS

Spinal orthoses are used for both short-term management of acute pain from VCFs as well as long-term management of chronic pain. However, in each case they are used differently and have different orthotic goals. The former requires thoughtful stabilization of the fracture while the latter focuses on postural changes to improve resting muscle length. Orthotic management is sometimes complicated by the use of an orthosis intended for acute pain for treatment of chronic pain and vice versa and therefore the orthotist should be mindful of the differences.

Orthotic management options are also often limited by significant spinal deformities, limited pulmonary capacity, or problems involving bony prominences. Concerns have been expressed about the effects of long-term use of spinal orthoses in treating osteoporosis, such as the possibility of muscle atrophy. Indeed, the condition known as sarcopenia (i.e., Involutional loss of functional muscle motor units, a normal process of aging) has been identified as a potentially important condition that may worsen osteoporosis. Therefore, it is essential to include, as part of orthotic treatment, a carefully designed physical therapy routine and to intentionally manage the effects of sarcopenia, when present. A successful non-pharmacologic treatment plan can be achieved through a multidisciplinary team approach working toward similar outcomes of treatment.

A MULTIDISCIPLINARY TEAM APPROACH.

The main challenges the treatment team faces, the VCFs and their secondary effects, should be undertaken as a priority. The primary orthotic consideration is to reduce postural deficits and pain. The patient's ability to function on a daily basis can be dramatically improved and pain medication reduced with the restoration of posture and pain reduction.

Orthotic Management for Osteoporosis

A multidisciplinary team approach to manage the osteoporosis patient can help reduce the likelihood of rejection of orthotic management. Specifically, a "multifaceted approach" is suggested, "to optimize recovery from a VCF secondary to osteoporosis."[48] Interdisciplinary approaches for managing osteoporotic patients may involve orthotic management, proprioceptive dynamic posture training, muscle strengthening and coordination, pharmacotherapy, and/or surgical management.[49] The patient and treatment team should define goals in response to these approaches, including reduction of acute and and/or chronic pain, reduction of risk for falling, and management of VCFs. These goals are meant to increase the patient's quality of life, described as the totality of physical, social, and mental function.[50]

PATIENT ASSESSMENT

The history and physical assessment of the patient with osteoporosis and VCF is critical in determining appropriate and realistic treatment options. Proper decision-making about treatment is predicated on a thorough evaluation of the patient and recognition of an acute or chronic VCF condition. A knowledge and understanding of previous treatment (no treatment, pharmacologic, non-pharmacologic or surgery) are equally important and may impact future decisions about the care of the patient. Determining the patient's cognitive and functional capacity to comply with the recommended orthosis needs careful consideration as well.

History

Current treatment, previous treatment, history of fractures, pulmonary function all represent legitimate areas of concern for establishing a historical picture of the patient with osteoporosis. A logical starting point for physicians is to determine if a history of fractures has been present. Ascertaining whether or not a VCF exists, if other fractures are present and how they have occurred helps to compile a timeline and is useful in determining if a person is susceptible to future fractures. Most initial VCF's occur as a result of a fall, but may occur from something as benign as a cough or sneeze. Because the patient with osteoporosis is often older there is a greater likelihood that complex medical conditions such as rheumatoid arthritis and COPD co-exist. Psychological and cognitive conditions such as dementia or depression should not be dismissed and can adversely affect patient education and the person's ability to follow instructions. Living environment and access to daily care can be easily overlooked, but may ultimately have the greatest impact on whether or not clinical outcomes related to orthotic management are met.

Physical Assessment

While the tendency may be to focus exclusively on the head, neck and trunk, a more global assessment is a better guarantee that all aspects of the patient's presentation are considered and realistic goals set. Proper patient assessment begins with acute observation of the standing and sitting posture and mobility strategies such as the patient's ambulatory capability. The chair in which the person is sitting often exaggerates the sagittal deformity exhibited by this group of patients. Strategies to decrease pain can begin with proper instructions on the best sitting environment. Patients should avoid back supports that tend to push the patient forward in which case they are forced to extend the neck even more to increase their visual field. Chairs that are too high or too low will make sitting to standing more challenging and difficult for both the patient and caretaker. Another important observation to note is the level of independence or dependence and how this will fit into the overall treatment plan for the patient. Manual muscle testing and range of motion-particularly of the upper limbs-offer insight into the patient's ability to don, doff and adjust spinal orthoses. Quality-of-life measures before and after interventions offer additional insight into the effectiveness of the treatment.

Pain assessment includes a distinction between chronic versus acute, location and duration, type and degree of pain and what postural positions, if any, relieve the pain. Pain associated with the VCF is often localized to the fracture and surrounding area while muscular pain maybe located away from the VCF and a result of compensatory balancing efforts. It is important to determine if pain exists in the head and neck, thoracic spine, and lumbar spine and where the pain is maximal. Often the maximum pain is not in the thoracic spine, but in the low back due to the demands on the paraspinal muscles to compensate for the forward flexion moment. As the hyper-kyphosis increases, there is usually an increase in pain around the head and neck as the person tries to extend to increase their visual field of view. While the patient's current level of independence may determine if he or she is a realistic candidate for an orthosis, orthotic management should not be prematurely abandoned if the limited independence is a result of pain.

BIOMECHANICAL OVERVIEW

Acute pain most often arises from the fracture and requires stabilization. Immobilizing the fracture and limiting forward postural sway to decrease the deforming flexion moment can achieve this support. Orthotic management for a VCF must be done with careful consideration of the patient's existing alignment, flexibility, pulmonary function and any bony prominences. Conventional TLSO anterior control designs (Jewett, CASH) should be avoided because of the limited adjustability and inability to accommodate the patient's anatomy and sagittal profile. A custom molded TLSO is the best choice given its ability to accommodate for bony prominences and the patient's sagittal profile. It is the opinion and observation of these authors, that if these factors are neglected, there is a strong probability that the orthosis will only add to the patient's discomfort and result in discontinued use of the orthosis altogether. Therefore, it is imperative that the orthotist consider alternative design modifications to insure the success and acceptance of the orthosis by the patient with a VCF. Design considerations include, but are not limited to:

- Thinner plastic
- Anterior window accommodation for pulmonary function
- (Moderate) increase in in lumbar lordosis to facilitate proper sagittal posture and balance
- Accommodation of bony prominences through cast build ups and pad placement

Chronic pain often comes from paraspinal muscle strain rather than the a fracture itself.[51] Relief of chronic pain can come from changes in sitting and standing posture such as increasing lumbar lordosis. This leads to recommending orthoses such as the PTS, Spinomed, or the posterior shell TLSO.

One of the major design considerations for spinal orthoses with this population is the minimization of its weight. Others include the ease of donning, doffing, and adjusting the orthosis along with the repeatability of these tasks.

While a few studies have considered the effects of the orthosis on changes in postural sway[52,53,54] there is still a need for a more comprehensive study on balance and risk for falls. Moreover, ongoing studies are needed to assess the efficacy of using a spinal orthosis for osteoporosis as part of the treatment plan.

MECHANISMS OF ACTION FOR SELECTED ORTHOSES

Posture Training Support

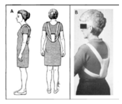
Fig 3

The PTS, which is also called a ''weighted kypho-orthosis,''[53] to bring attention to its proposed mechanism of action, has a weight suspended posterior and inferior to the scapulae (Figure 3). The weight can be increased in 0.25 lb. increments to 2-3 lbs. Patients are encouraged to try different amounts of weight to determine effectiveness. Compliance will deteriorate and the orthosis will not benefit the patient if too much weight is applied. The PTS is indicated in cases of excess dorsal kyphosis possibly involving iliocostal contact or iliocostal friction syndrome.[55]

Two mechanisms of action of the orthosis are hypothesized. Compression forces on the anterior spine are reduced by the counter-moment produced by the posterior weight. Second, the device encourages active back extension through proprioceptive input and helps increase back extensor strength.[12] The PTS aids physical therapy and helps increase the strength of the paraspinal muscles.[52]

The PTS appears to be the least intrusive orthotic recommendation. Its advantages are that it is cosmetically acceptable and has a high level of patient compliance. However, care must be taken in choosing which patients are suitable for using the PTS. Several short-term studies on the PTS have shown some improvement in pain, but large long-term evidence-based use has not been proven.[52,53]

Spinomed (TLSO–sagittal plane control)


Fig 4


Fig 5

The Spinomed is indicated more for management of chronic pain resulting from VCFs. The mechanism of action is similar to the traditional Knight-Taylor orthosis (TLSO–sagittal plane control). However, in contrast to the Knight-Taylor orthosis, the compliance level of the Spinomed is very high. This TLSO weighs approximately 450 gm. It contains a soft, hand moldable metallic posterior section and an array of hook-and-loop straps (Figure 4 and 5). It is donned like a backpack.

The orthotic goal of correcting the unbalanced anterior posture in the sagittal plane is helped by the posteriorly directed forces provided by the shoulder straps. They may also help in retracting the shoulders and increasing back extensor strength. By making adjustments to its shape, the total contact back pad can provide hyperextension of selected spinal segments. Intracavitary pressure likely increases because of the confining pressure of the corset front. The study also showed the potential for improving the strength of the paraspinal muscles.

The Spinomed has several advantages including: (i) ease of donning and doffing the device, (ii) excellent patient compliance, (iii) strengthening of the paraspinal muscles, (iv) lightweight, and (v) a hand-moldable posterior section. Several short-term studies have been done with the Spinomed and have demonstrated some improvement in pain, but similar to the PTS, large long-term evidence-based use has not been proven.[54, 57]

Posterior shell TLSO

Fig 6

The posterior shell TLSO consists of a plastic shell, a soft corset front, and a system of straps (Fig 6). This orthosis has not been scientifically studied to validate or refute its efficacy. However, Gavin et al. fit more than 75 of these orthoses over a 10-year period (1988–1998) and reported good success in pain reduction and posture correction.[58]

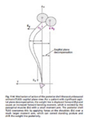

Fig 7

Like the Spinomed, the shoulder straps provide posteriorly directed forces that help correct the unbalanced anterior posture in the sagittal plane (Fig 7). However, unlike the Spinomed, the plastic posterior shell is not designed to be in total contact at the superior portion in the initial phase of orthotic treatment, but it may achieve contact in the later phase of orthotic treatment.

The posterior shell TLSO may help improve sagittal plane standing posture alignment, reduce internal rotation of the shoulders, improve vital capacity, and improve seated posture. The posterior shell TLSO has potential advantages including a soft corset front for comfort, improved appearance, improved mobility and endurance, and ability to accommodate changes in the patient's weight. It may also act as a seating orthosis. The posterior shell TLSO may present disadvantages such as difficulty in donning and doffing and excessive weight. This may be pronounced in patients who have comorbidities such as rheumatoid arthritis, who are of small stature, and/or who may not have a caretaker to help donning and doffing.[59]

The posterior shell TLSO is designed to correct the sagittal plane balance by helping increase lumbar lordosis over time. Caregivers increase the shoulder strap tension daily over 1-2 months to reach this goal. If it is achieved, the patient can typically ambulate for a longer period of time and possibly without a walker. Most patients will continue to wear the orthosis once they have attained a significant correction in balance, however further clinical studies are needed.

EVIDENCE FOR ORTHOTIC MANAGEMENT OF OSTEOPOROSIS

Despite encouraging results from several papers the evidence for spinal orthotic management of osteoporosis continues to remain low. Newman et al. performed a systematic review of spinal orthoses for vertebral osteoporosis and osteoporotic vertebral fractures and concluded that orthotic management of acute VCF is inconclusive due to the limited available evidence.[60] In this same study there appears to be some promising evidence for the use of TLSO-Sagittal Control designs (e.g. Spinomed) and WKO designs (e.g. PTS) for chronic VCFs, but this needs to be explored further. Future studies of sufficient size and emphasis on the long-term effects of orthotic management would be useful for determining a reasonable efficacy for treatment of this patient population.

MEASUREMENT, CASTING, RECTIFICATION PROCEDURE

Once the decision to select an orthosis has been made the next step is to acquire accurate and appropriate information in the form of measurements, casting, and/or scanning. Accurate measurements and other physical data increase the chance of a properly fitting functioning orthosis.[61,62,63] Measurements are typically used for three reasons and include: 1) fitting off-the-shelf devices similar to the Spinomed or PTS; 2) conventional fabrication (usually in combination with a casting/impression) such as the posterior shell TLSO (chronic) or custom TLSO (acute); 3) used in conjunction with image capture (pictures, video) to fabricate a posterior shell or custom TLSO via a CAD-CAM process. When measuring a patient it is important to realize that no one orthotic design will be ideal for every patient and therefore it is important that the orthotist is well-versed with the different orthoses and the measurements that accompany the designs.

Off-the-Shelf

For made-to-measure or off-the-shelf designs such as the Spinomed or PTS, the orthotist should familiarize themselves with manufacturer-required measurements. For the Spinomed the size is determined by the length of the spine and is measured from the sacrum to just below C7 and follows the curvature of the spinal anatomy. To size the PTS, the manufacturer requires a measurement from the inferior angle of the scapula, over the shoulder to the axilla and at the chest level. Proper sizing of these designs is the responsibility of the orthotist. In instances where sizing is problematic and doesn't properly correspond with the patient's anatomy it is recommended that the orthotist speak with the manufacturer's representative. These conversations can prove fruitful and not only provide additional insight into proper sizing, but allows the orthotist to offer suggestions on how the design can be improved.

Measurements for Conventional Fabrication

The posterior shell TLSO and custom molded TLSO require virtually the same measurements. For both designs an impression/casting of the patient is taken in order to fabricate the orthosis. Sagittal, coronal and transverse measurements can be crossed-checked with the positive cast to verify that the anatomy was captured accurately during the impression/casting process. Traditional methods of measurement such as soft tape, M-L gauge, angle finder and goniometer should be part of the orthotist tool kit and, if used correctly, insure that desired alignment is properly transferred to the positive mold. Conventional measurements for the two designs include:

- Circumferential and coronal measurements at the level of the greater trochanter, ASIS, waist, xiphoid, axilla
- Length measurements
    - Gluteal fold → waist → spine of the scapula
    - Pubis→ waist → xiphoid → sternal notch
    - Greater trochanter → waist → axilla
- Inferior angle of scapula, over the shoulder to the axilla (posterior Shell TLSO only).

Confirmation of sagittal alignment such as lumbar lordosis and pelvic tilt is particularly important for designs intent on resolving postural imbalances in the sagittal plane.

In the case of the posterior shell TLSO (chronic pain) a plaster impression is needed in addition to the measurements. The impression is taken with the patient in a prone position and requires 60 to 90 minutes for the entire procedure. The extended duration of the procedure is primarily due to the application of viscoelastic creep in order to capture the appropriate sagittal alignment. The goal is to establish and capture an alignment in the impression that brings the head over the pelvis to reduce sagittal decompensation and decrease the deforming forward flexion moment. After the application of stockinette, identification of bony landmarks and recording of measurements, the patient is asked to lie recumbent on the examination table in a prone position for a period of 20-30 minutes. At intervals of 20-30 minutes the orthotist will place a pillow or pad under the superior and anterior aspect of the chest to increase lordosis. This often takes 2-3 intervals to achieve optimal lordosis. For the process to be effective it must be done gradually. Once the ideal alignment is achieved vertical plaster splints are placed on the posterior aspect of the patient and should extend laterally past the mid-axillary trochanteric line, superiorly to the spine of the scapula, and inferiorly to the level of the sacro-coccygeal junction or gluteal fold for females.[63] (Box 2)

Box 2

For the custom molded TLSO (acute pain) the design and impression/casting process is less aggressive and more accommodative. The impression is best taken with the patient in a recumbent position in order to accommodate the existing alignment. While some consideration should be given to increasing lordosis to insure proper postural alignment it should only be moderate and not nearly as aggressive as the posterior shell casting process.

<u>Measurements for CAD-CAM</u>

Measurements and image capture can be used together as part of the CAD-CAM process for making an orthosis for the osteoporosis population. In this case CAD-CAM might be an alternative approach to acquiring data for the posterior shell TLSO and custom molded TLSO. Depending on the CAD-CAM system that is used, it is important that the orthotist be well-versed in collecting and recording all of the necessary measurements. For example circumferential measurements will help to confirm volume while right and left length measurements (e.g. trochanter to waist and waist to axilla) help to confirm symmetry. Measurements that are not recorded only delay fabrication and increase the risk the orthosis will not fit properly and achieve the intended goals. Despite the advances in technology such as CAD-CAM it may not always be the right solution for this population. Attempting to scan a person's torso that is unable to lift their arms away from their side presents a problem and may not allow for realistic 3-dimensional capture of the person's torso. Ultimately this could affect the fit of the finished orthosis. Other options include a combination of taking pictures and measurements. In this case a thorough clinical evaluation of the deformity and the flexibility or correctability in all three planes is required. From this a computer aided design program is used to develop the patient's new 3D shape or correction. Each measurement or step in the procedure should have an intended purpose and rationale which, as closely as possible, is to replicate the patient's body using anthropometric data.[64]

DONNING/DOFFING AND PROPER ALIGNMENT OF SPINAL ORTHOSES

Donning/Doffing

Conventional donning/doffing practices of orthoses, while appropriate for many patient populations, may not be as effective for patients with osteoporosis and ultimately lead to poor results. Therefore, careful attention to detail and frequent follow-up are important for the successful fit and alignment of the orthosis.[65] Patient upper limb strength/hand dexterity, orthotic design, patient cognition and caretaker status should all be considered to determine the best strategies for donning and doffing. A well-fitting orthosis and one that satisfies all intended outcomes will be of little use if the orthosis is not properly donned and the desired alignment achieved for the patient.

A patient's upper limb strength and hand dexterity can easily be overlooked when much of the attention is focused on the spine. When a patient requires a spinal orthosis for osteoporosis and exhibits upper limb weakness and limited hand dexterity the orthotist should consider alternative closure systems and unconventional, but safe strategies for donning the orthosis such as placing a rigid or semi-rigid orthosis on a chair and having the patient sit back into the orthosis for proper positioning and initial placement of the closures. In some instances, there is not enough adjustability to modify the closure system and a different orthosis altogether must be selected. In these cases it is important to select designs that will still be able to achieve the originally intended goals and also preserve the patients existing independence.[66]

Appropriate closures and design features of the orthosis maybe of little help for a patient with a cognitive deficit. The inability to follow two-step commands (donning instructions) will likely result in an orthosis either being improperly fit or not worn at all. When such cases arise it is important to identify a willing caretaker to assist with this process.[67] In these scenarios the caretaker will assume the responsibility of the patient's orthotic treatment and likely determine the success or failure of the orthosis. Recognizing the role of the caretaker, the orthotist should explain the purpose of the orthosis and dedicate ample time working with the caretaker to develop efficient strategies for donning/doffing of the orthosis. As part of this training, the orthotist should observe and confirm that the caretaker is able to effectively don and doff the orthosis. At the conclusion of fitting it is the responsibility of the orthotist to describe and confirm the caretaker's understanding of proper fit and alignment. If the caretaker is not properly equipped there is a greater likelihood that the orthosis will be donned incorrectly, desired alignment not attained and ultimately lead to unnecessary discomfort for the patient and discontinued use of the orthosis.

Time-Dependent Donning

Understanding the patient's existing alignment and whether the deformity is flexible, rigid or a combination of both will serve the orthotist well when the patient dons certain types of orthoses. Postural spinal stiffness often associated with chronic VCF and a result of soft tissue (muscle) shortening and or weakness is best addressed through the same viscoelastic considerations implemented during the impression (molding) and measuring process of the patient.[67] To properly don the orthosis (posterior shell TLSO), 20-30 minutes should be afforded this process in order to take advantage of the viscoelastic creep of the soft tissue. Allowing the patient to 'relax' into the orthosis over this period of time will improve the chances of obtaining optimal alignment as well as greater patient comfort.

Proper Alignment of Spinal Orthoses

Regardless of the type of orthosis, the method for measuring and determining alignment is the same and should occur prior to treatment, immediately following application of the orthosis and at subsequent intervals throughout treatment. A plumb bob or laser line are both effective tools for measuring postural alignment, but it is the experience of these authors that a laser line is easier to use and better at capturing whole body alignment. In the sagittal plane, the ear, acromion of the scapula and greater trochanter serve as excellent relative points of reference to determine trunk and pelvic alignment in relationship to one another.[64] The added value of including the ear and specifically the tragus landmark allows for the additional comparison of the head to the trunk and pelvis. The need for these three landmarks becomes apparent as one considers the common clinical presentation of the person with chronic VCF where the head (ear) is anterior to the trunk (acromion) and the upper trunk is anterior to the pelvis (trochanter). These points of reference serve the orthotist and physician well when determining the effectiveness of the orthosis and its ability to restore sagittal postural alignment (Fig 8). Based on this type of assessment it is easier to determine what specific adjustments or alignment changes are needed to the orthosis in order to optimize postural alignment based on the given presentation of the patient.

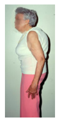
Fig 8

Because the sagittal plane often has the greatest observable deformities it is easy to overlook the coronal and transverse planes. Therefore, fitting and alignment considerations should include these planes as well. The conventional practice of using a plum bob or laser line and dropping that line from C7/T1 down to the spinous process of S1 will confirm that the person's head is properly aligned over the pelvis (compensated) or that it is not (decompensated). Assessing transverse plane is best viewed overhead, but many times is not feasible. In this case attempts should be made to assess and determine if transverse plane deformities exist by viewing them in the other planes or combination of planes. For example, a rib hump could be viewed and confirmed by visually looking from a posterior-lateral vantage point. The utility of using these landmarks to assess overall posture affords the medical team a better way of documenting orthotic effectiveness as it relates to alignment.

CONCLUSION

The degenerative process of osteoporosis and the combined effects of the aging spine are progressive in nature and require a multidisciplinary team that is attentive to the changing and increasingly complex needs of the patient. Treatment done in isolation, whether pharmacologic or non-pharmacologic, is a sure way to undermine the chances for successful outcomes. As in the case of orthotic management of VCF's and secondary deformities, management should be part of a broader treatment plan that encompasses both pharmacologic and non-pharmacologic methods of care. The increasing incidence of osteoporosis along with an aging adult population that is living longer means the demand for care is likely to increase sharply in the future. As such, the need for further evidence to determine the efficacy of orthotic management is at a crucial stage and warranted if the patient is to receive effective and appropriate care.

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Orthoses For Low Back Pain

Michael R Zindrick, Leonard Voronov

INTRODUCTION

Low back pain is a very common condition occurring in modern society. It is estimated that approximately 60% to 80% of the population experience low back pain at some time in their lives. In 2007 alone 27 million US adults age 18-year-old or 11% of the total population reported having back pain according to the Agency for Healthcare Research and Quality.[1] Spinal orthoses are frequently used to manage a variety of spinal disorders despite lacking or conflicting literature supporting use. Nachemson reported different desirable functions of the lumbar support: 1) to correct deformity; 2) to limit spinal motion; 3) to stabilize part of the spine; 4) to reduce mechanical uploading; and 5) to provide miscellaneous effects of massage, heat, placebo.[2] However at present the actual mechanisms of action of the lumbar support remained a matter for debate. Not everyone is physiologically suited to gain benefits from a lumbosacral support. Obesity and deformity may restrict a braces' effectiveness.

In this chapter the authors will review the current highest level literature regarding the effectiveness of lumbosacral brace used for: 1) the prevention of low back pain; 2) the treatment of low back pain; 3) as a prognostic preoperative tool for fusion and 4) use following lumbar fusion.

ORTHOSES USED IN THE PREVENTION OF LOW BACK PAIN

Lumbar orthoses have been used as a means of preventing either initial (primary prevention) or recurrent (secondary prevention) episodes of low-back pain in industrial workers.[3,4] Van Poppel et al. randomized 282 baggage handlers into 4 groups: 1) education and lumbar orthosis, 2) education, 3) lumbar orthosis, and 4) no intervention.[5] Groups 1 and 3 utilized a soft lumbar brace for 6 months while working. There was no decrease in the incidence of back pain reported (36% for braced individuals and 34% for non-braced) or in the number of workdays lost when comparing braced with non-braced workers. The use of a soft lumbar brace was found to reduce the number of days lost due to back pain from 6.5 to 1.2 days per month ($p = 0.03$) in workers with a prior history of back pain. Orthotic compliance was only 43% across the study but there was no difference in the incidence of low-back pain or number of sick days among workers who complied with the protocol and those who did not. Study conclusions were that orthotic therapy does not diminish the incidence of low back pain or time lost from work when used as a preventive strategy. Additionally, the use of a lumbar support by workers with a previous history of low-back injury may reduce days lost due to low-back pain. Due to the high number of noncompliant workers, this study was downgraded to Level II medical evidence.

Reddell and colleagues randomized 642 baggage handlers into 4 groups: 1) education, 2) weight-lifting belt-type brace, 3) education and orthosis, and 4) no intervention.[6] During an 8-month period, the authors collected data on; total incidence of reported low-back injury, lost or restricted workdays due to low back pain, and Workers' Compensation claims related to low-back pain. They found no differences among the groups. Similar to the study by van Poppel and colleagues, only 42% of the individuals in the brace-treated groups were compliant with the use of the brace. However, in this study the noncompliant group (158 individuals) was found to have a higher incidence of lost workdays following discontinuation of the brace, but the difference between the compliant and noncompliant groups was not significant. This study was also considered as Level II medical evidence suggesting no benefit for the use of a lumbar orthosis to prevent back injury.

Kraus et al. randomized 12,772 New York City home health attendant workers to 3 groups: 1) lumbar orthotic wear, 2) safety meeting with information, or 3) no intervention at all.[7] They recorded self-reported back injury rates over a period of up to 28 months. The bracing group was found to have fewer episodes of low-back pain than the participants receiving no intervention (rate ratio 1.36, 95% CI 1.02-1.82). There was a trend toward fewer episodes in the lumbar support group than the information group, although the difference was not significant. This study was classified as a Level II evidence on the use of orthotic management as a strategy for primary prevention of low-back pain in home health attendants due to poor randomization techniques and missing demographic information, the follow-up time points reached, and compliance rates. The authors likewise found that the strongest risk factor for low-back injury was a prior back injury. The study showed a 3.1 risk ratio in this population, suggesting that lumbar orthoses may have an even greater role in secondary prevention of low-back pain.[7,8]

Alexander et al. reported the results of a small prospective randomized study of 60 health care workers divided into 2 groups.[9] One group was assigned to wear a lumbar corset for a 3-month period. No differences in work-related back injuries or perception of back pain were noted. Due to the use of a non-validated outcome measure this study was downgraded to Level II evidence, but does suggest that a corset-type orthosis is not an effective measure to prevent low-back pain.

Walsh and Schwartz reported on a group of 90 warehouse workers who were randomly assigned to 3 groups: 1) no intervention; 2) 1-hour education; or 3) 6-month lumbosacral molded semi-rigid orthosis therapy and education.[10] Outcomes assessed were; work injury incidence, work productivity, and utilization of health care resources. Orthosis-treated workers missed 2.5 days less work ($p = 0.03$) than those not wearing braces (control and education-only groups). There were no statistically significant differences between the groups regarding productivity or utilization of health care resources. A subgroup analysis revealed that the benefit in terms of number of lost workdays was greatest in patients with a previous back injury. The authors concluded that the combination of brace therapy and education were equally effective in reducing lost workdays, especially among patients with a history of back injury. Study limitations include; failure to incorporate validated outcome measures and failure to describe worker compliance with the bracing routine. Due to these shortcomings this study is considered to provide Level II evidence in support of brace therapy as an alternative for prevention of low-back pain.

In post hoc analysis the majority of studies on the efficacy of bracing for the prevention of low-back pain (primary prevention) revealed that the strongest benefit for lumbar bracing was derived from workers with a prior history of low-back pain (secondary prevention).[7-10] Therefore, more recent studies have been designed to look specifically at the utility of lumbar bracing for secondary prevention of low back pain in workers with a prior history of low-back pain.

Roelofs et al. evaluated orthosis use in 360 home health workers with a prior history of back pain. This was defined as current back pain or 2 or more episodes of low-back pain in the previous year.[11] Workers were instructed on healthy working methods with or without use of a brace. Over a 12-month period, the group of workers who were assigned to use of an orthosis had 52.7 fewer self-reported days with low-back pain (95% CI -59.6 to -45.1), but there was no statistically significant difference between the groups in days of sick leave (38.5 vs. 43.5, 95% CI -21.1 to 6.8). Outcome measures included visual analog scale (VAS), Quebec Back Pain Disability Scale measures, and self-reported low-back pain-related sick days at 3, 6, 9, and 12 months. The bracing group demonstrated a lower mean VAS for low-back pain (4.0 vs. 4.6, p = 0.02), better mean disability rating (26.2 vs. 30.3, p = 0.017), and fewer days of low-back pain-related sick leave (3.2 vs. 8.0, p = 0.003). This study is considered to provide Level I evidence on the benefits orthotic use to limit the number of days of low-back pain in home health workers with a prior history of low-back pain.

Oleske and colleagues investigated auto plant workers who had work-related low-back pain. Workers were randomly assigned to lumbar support and education (study group) or education alone (control group).[12] A total of 868 workers were initially screened and 433 workers completed a 1 follow-up visit. Self-reported outcome follow-up was done at 1, 2, 6, and 12 months. Self-reported outcome measures included a low-back pain and "bothersomeness" scale (0-10), the Oswestry Disability Index (ODI), and the physical and mental components of the 12-Item Short Form Health Survey (SF-12); administrative outcomes included medical visits and lost or restricted workdays due to injury or illness. Full randomization for all 868 workers was unclear. Of the 433 participants making up the basis of this report, it is unclear at what time point the follow-up occurred for the self-reported outcomes. Both groups reported significant declines in low-back pain (VAS), disability (ODI), and neurogenic symptoms and improvement in overall physical health (SF-12 scores) over 12 months. There was no significant difference in the number of lost or restricted workdays between the groups. There was a trend toward fewer episodes of low-back pain in the orthosis group (23.1% vs. 31.1%, p = 0.059). Again, a subgroup analysis showed a significant decline in the number of recurrent episodes in the non-assembly line workers receiving an orthosis (34.9% vs. 63.1%, p = 0.016). Because of the uncertainties in the randomization, a dropout rate of 50%, and the lack of clarity regarding the number of workers who achieved 6 or 12 months of follow-up, this study was downgraded to Level II evidence that orthoses have no impact on lost work time, disability, or medical utilization in a general working population.

Jellema et al. looked at a cohort of home health care workers who had previous low-back pain in an observational study.[13] The primary goal was to determine the benefit of back brace use in a cohort of 62 workers with prior low back pain over 6 months. Eighty-one percent of the participants had an episode of low-back pain in the previous week. At the end of 6 months, the authors observed a 44% reduction in both the mean VAS pain score (4.2 vs. 2.3) and the mean disability score as measured by the Quebec Back Pain Disability Scale (29.3 vs. 16.3). Despite a dropout rate of 20% in a relatively small sample size, the study provides Level II evidence that bracing is an option in this population. The authors recommended a prospective randomized trial to further determine the role of bracing in this population.

Several historical cohort studies evaluated the incidence of back pain and days lost to work in groups of workers before and after their employer issued them a brace or lumbar support belt. Analysis of these studies revealed mixed results. In one study bracing made no difference while two studies reported a reduction in these parameters following bracing.[8,14,15] The medical evidence supporting the use of braces for prevention of low-back pain is inconsistent. The authors of several systematic literature reviews have concluded that lumbar support devices are not useful for the prevention of low-back pain in the general working population (primary prevention).[3,16,17] It does appear, however, that braces may be useful as a measure to decrease the number of sick days lost due to low-back pain in workers with a history of low-back injury (secondary prevention).

ORTHOSES USE IN THE TREATMENT OF LOW BACK PAIN

There have been several randomized control trials investigating the role of orthoses as a treatment for low-back pain. A multicenter randomized trial by Calmels et al. evaluated the effect of an elastic lumbar support for sub acute low-back pain.[18] One hundred ninety-seven participants were randomized to best medical treatment or best medical treatment supplemented with the elastic lumbar support. Primary outcome measures at 30 and 90 days were functional recovery by the EIFEL (French version of the Roland-Morris Disability Questionnaire [RMDQ]), change in pain VAS score, and consumption of analgesic and anti-inflammatory medications or muscle relaxants. At 30 days, patients in the study group had greater reduction in functional disability (5.6 vs. 4.0 on RMDQ, $p = 0.02$) and VAS (26.8 vs. 21.3, $p = 0.04$) than the control group. These changes continued at 90 days (7.6 vs. 6.1, $p = 0.02$, and 41.5 vs. 32.0, $p = 0.002$). Use of medications was reduced (34.3% of the study group and 56.8% of the control group took medication at 90 days). This study is considered to provide Level I medical evidence in support of bracing for the short-term management of sub acute low-back pain.

Valle-Jones and colleagues randomized 216 patients with nonspecific low-back pain of varying duration to lumbar brace therapy or activity modification for 3 weeks.[19] Outcome measures evaluated included VAS pain score and disability and pain medication usage. Brace-treated patients were found to have more improvement in pain at rest, pain with activity, and pain at night between days 7 and 21. Brace-treated patients took half the number of doses of Paracetamol during the 21-day trial period than the control group. Return-to-work rates were higher in the brace-treated group (85%) compared to the control group (67%, $p < 0.02$). Because of the inclusion of acute and chronic low-back pain in the patient population studied, non-validated outcome measures (a 7-point VAS), and lack of data downgrade the study level II medical evidence supporting the efficacy of braces for the short-term amelioration of low-back pain.

Pope et al. studied 164 patients with low-back pain treated in a chiropractic clinic.[20] Patients were randomized to 4 treatments: 1) chiropractic manipulation; 2) transcutaneous muscle stimulation (TMS); 3) massage; and 4) lumbar corset. Data collected included VAS and range of motion after 3 weeks of treatment. There were no differences among the groups. Due to small number of subjects (<30 patients in 3 of the 4 groups) and selected patient population (from a chiropractic practice), this paper was considered to provide Level II medical evidence suggesting that braces are no more effective than other modalities used for the treatment of acute low-back pain. Hsieh et al. studied 63 patients suffering from low-back pain for less than 6 months' duration.[21] Patients were randomized into treatment groups of manipulation, massage, lumbar corset, or TMS treatment for a 3-week period. Functional outcomes were evaluated with the ODI and RMDQ. Chiropractic manipulation and corset performed better than massage for both RMDQ and ODI ($p < 0.05$). Due to the small number of patients in each cohort and the lack of a power analysis the authors' conclusions were limited. This paper provides Level II evidence supporting the role of short-term lumbar brace therapy in patients with acute or sub acute low-back pain as compared with massage or TMS. Since chronic low back pain individuals were excluded, no inferences can be drawn regarding the effect of braces for patients with chronic low-back pain.

There were two randomized controlled studies published in 1981 that provide information on lumbar brace therapy for low-back pain. Coxhead and coworkers randomized 322 sciatica patients with or without low-back pain to different treatment modalities, including traction, exercises, manipulation, corset brace, and combinations of these treatments. Outcomes were assessed at 1, 4, and 16 months with VAS, return-to-work status, and patient satisfaction criteria.[22] No short or long-term benefit was detected for the use of lumbar corsets. Because the population was composed of patients with sciatica, no direct conclusions can be drawn with regard to the treatment of low-back pain alone.

Million et al. studied a smaller cohort study of 19 patients with chronic low-back pain that were randomized to either a soft or rigid lumbar brace group for a period of 4 weeks.[23] A 15-item questionnaire regarding pain and functional limitation on a VAS (Million scale) demonstrated a significant improvement ($p = 0.01$) for the cohort of patients wearing a rigid brace at 4 and 8 weeks. Rigid lumbar bracing may therefore have some short-term benefit compared with soft bracing for the short-term treatment of low-back pain. There was no control group in this study, therefore this paper was considered to provide Level III medical evidence regarding the efficacy of brace therapy for low-back pain.

BRACING AS A PROGNOSTIC TOOL FOR FUSION

It would seem logical that if a patient received a benefit from restricted spinal motion with a brace they would likewise benefit from restricted spinal motion from fusion. Unfortunately the medical literature does not support this assumption.

There has been only one published study by Axelsson et al. evaluating prognostic value of preoperative bracing.[24] Fifty patients were studied who had solid radiographic posterior lateral fusion at 1 year. Two years postoperatively the patients were examined for pain relief and satisfaction. Patients to undergo lumbar fusion for low back pain were placed in either rigid or semi-rigid brace for 3 weeks. Pain improvement was noted. Thirty-one patients reported improvement of at least 50%. At the two-year follow-up 20 out of 31 patients had good outcome (pain-free or significant improvement), while 11 out of 31 patients had poor outcomes despite favorable response to preoperative lumbar bracing. Of 19 patients' that did not have significant relief from the corset 13 responded favorably at the two-year mark. The authors concluded that the sensitivity of preoperative bracing as a prognostic test for success after solid fusion was 61% and specificity was 35%. The positive predictive value was 65% and negative predictive value 32%. The use of lumbar bracing as a prognostic indicator for fusion outcome was not recommended due to the poor prognostic parameters. Additionally the study relied on patient satisfaction scores and only patients with solid fusion were studied. There is a lack of standard sensation in the bracing protocol. Dailey et al. concluded that the medical evidence derived from this study is considered level III.[25]

BRACE USE FOLLOWING LUMBAR FUSION

Forty-nine percent of spinal surgeons participating in an international survey responded that they used orthoses after lumbar surgery. Restriction of patient's activities as a result of the orthotic treatment was the main reason for its use. Data to support the use of lumbar bracing following fusion is wanting.[26] Yee et al. randomized 90 patient's undergoing single or multiple level posterior lateral fusion (PLF) procedures to 8 weeks of postoperative bracing or no orthoses.[27] There were no statistical differences in the Dallas pain questionnaire or SF-36 results at 1-2 years. Both groups showed significant improvement compared with baselines. There were no differences noted and fusion rates or postoperative complications. This study was considered to provide level I evidence that post-operative semi-rigid bracing offers no functional or radiographic benefit at 1 or 2 years after surgery for patient's undergoing instrumented PLF. Connolly and Grob concluded that the use of postoperative orthosis in instrumented spine fusions is controversial.[28]

Several authors have advocated the use of postoperative lumbar orthoses based on the fact that that healing of a non-instrumented fusion occurs over a six-month period. Yee noted the patients that were treated with a brace for 6 months following surgery had a higher fusion rate (8 out of 11 patients) at 1 year compared to those who were treated orthotically for 3 months (2 out of 11 patients).[27] No evidence was presented regarding the effect of orthotic management on the rate of lumbar fusion or functional outcome.

CONCLUSIONS

The following conclusions are based on evidence based medical literature review on the topic. Despite these general recommendations, orthosis wear and its specific use needs to be tailored to each individual patient by the treating physician. The authors agree with the conclusions of Dailey et al as listed below.[25]

ORTHOSIS USE IN THE PREVENTION OF LOW BACK PAIN

For primary prevention, the use of a lumbar corset does not prevent the development of low-back pain in the general working population (multiple Level II studies). The prescription of a lumbar orthosis is useful for the secondary prevention of low-back pain by reducing the number of days of self-reported low-back pain and days lost to work in laborers with a history of low-back pain (single Level I study and multiple Level II studies).

ORTHOSIS USE IN THE TREATMENT OF LOW BACK PAIN

For patients presenting with low-back pain, the prescription of a lumbar support in the setting of sub acute pain (< 6 months' duration) reduced the visual analog scale (VAS) pain score and medication usage and improved functional disability at 30–90 days (single Level I study and multiple Level II studies).

ORTHOTIC WEAR AS A PROGNOSTIC TOOL FOR FUSION

A trial of preoperative orthotic wear is not predictive of outcome for lumbar fusion in the setting of low back pain (Level III evidence).

ORTHOSIS USE FOLLOWING LUMBAR FUSION

The use of an orthosis following instrumented posterolateral lumbar fusion (PLF) for lumbar spondylosis is not supported due to equivalent outcomes with and without the use of an orthosis (single Level II study).

EDITOR'S NOTE:

In the opinion of the editors, these authors have effectively reviewed the current literature and have fairly stated what the consensus is for the effectiveness of the Use of Lumbar Orthoses for the Prevention, Diagnosis and Treatment of Low Back Pain. They cited many articles and gave their evidence for scientific effectiveness. There are, however, many clinicians who employ orthoses in the treatment of lumbosacral conditions. Are they mistaken or are their experiences invalid?

This question exemplifies many of the difficulties in conducting controlled orthotic research. Three are mentioned here; the variation in clinical conditions, the adequacy of fit and the non-standard fabrication designs of the orthoses utilized.

Precise diagnosis is difficult enough in treating patients with low back pain. Causes for symptoms may be from trauma, congenital abnormalities or degenerative conditions. Each cannot be expected to respond in the same manner to orthotic support. When clinical conditions are standardized, as much as possible, orthotic fit may vary. Patients will be of different size and shape. Excess adipose tissue is too often present in patients with symptomatic back pain. Adequate fit and consequently adequate support is often impossible. Orthotic design, proper spinal alignment, the location of trim lines and the duration of use is rarely mentioned in journal articles. Without standardization here the comparison of studies is impossible. In conclusion, these authors are accurate in their reporting on the current literature, additional research is, however, needed to support or refute the effectiveness of the frequent use of orthoses in the treatment of low back pain.

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Orthotic Management of the Cervical Spine

Grace Garvey, Riley Ahl, Jennifer Fawcett and Timothy Garvey

INTRODUCTION

This chapter will discuss common orthoses used to treat the cervical spine. Cervical orthoses are typically used in the management of cervical trauma, infection, instability, or in the postoperative setting, whereas other spinal orthoses may generally address deformity.[1] Orthoses for the cervical spine are used to stabilize or immobilize the otherwise mobile cervical region of the spine. There is a wide variety of cervical orthoses, most of which are categorized either by their rigidity or by the region of the spine they immobilize.[2] Types of cervical orthoses include but are not limited to: soft collars, rigid collars, SOMI braces, poster braces, Minerva braces, and halo vests (or casts).

The use of cervical orthoses remains controversial. Different surgeons prescribe different braces for varying lengths of time for varying reasons. A universal rule on the use of cervical orthoses does not exist. Additionally, long-term use of an orthosis can cause many complications and decrease patient mobility. The potential benefit of each brace must be weighed against its possible complications. While we will seek to style this section similarly to the rest of this atlas, the topic of cervical spine orthoses is nuanced and encompasses a multitude of potential treatment options.

BASIC REVIEW OF CERVICAL ORTHOSES TYPES

Most authors break down cervical orthosis types from simple soft cervical collars, to stiffer, more rigid collars, all the way up to poster braces, cervico-thoracic orthoses and halo vests. The biomechanics of each orthosis and specific indications for their use will be discussed in this chapter.

COLLARS

Soft Collars

Fig 1

Soft collars are the least restrictive of cervical orthoses and are normally made of polyurethane foam rubber covered in cloth. They are flexible, easy to wrap around the neck, and are generally secured with Velcro (Figs 1A & B).[1]

As soft collars are not very restrictive of motion, they are frequently worn as a kinesthetic reminder to the patient that he or she just had surgery and needs to be careful with his or her daily activities, to provide gentle support after a soft tissue or ligamentous injury (e.g., whiplash injuries best known as flexion/extension injuries), and to serve as a concrete reminder for patients to follow their treatment regimen. Soft collars can also function as a transition between wearing a more rigid orthosis and not wearing an orthosis at all.[1,2,3]

Orthotic Management of the Cervical Spine

Rigid (Semi-Rigid) Collars

Fig 2

Most authors use the terms "rigid" and "semi-rigid" interchangeably with regard to collars to refer to a cervical collar that is made of a more rigid material than a soft cervical collar; this chapter will treat these collars as one category (Fig 2). Rigid collars are similar in appearance to soft collars, but they are more restrictive and are made of a hard polyethylene material. Rigid collars limit motion more than soft collars do, the biomechanics of which will be discussed later in this chapter.[2]

Rigid collars are frequently used for postoperative immobilization, the treatment of certain cervical spine fractures, and occasionally for the treatment of other cervical diseases such as spondylodiscitis. There are many different varieties of rigid collars; to enumerate and describe them all is beyond the scope of this chapter, though we will address some of the most common types.

Fig 3

The Philadelphia Cervical Collar (Thorofare, NJ) is composed of two pieces of Plastazote® connected with Velcro fasteners and reinforced with ventral and dorsal plastic struts (Fig 3).[1] The collar is also available with a tracheostomy window on the ventral side. This collar has historically been used as an extrication collar in trauma situations.

Fig 4

The Miami J4 (Össur, Paulsboro, NJ), like the Philadelphia collar, is a two-piece cervical orthosis. It is composed of a firm plastic shell with padded inserts (Fig 4A & B). The collar has an anterior extension to increase restriction of cervical flexion.[1]

Fig 5

The Aspen (Newport) collar (Aspen Medical Products, Irvine, CA), similar to the Miami J collar, is a two-piece collar and consists of an adjustable plastic shell with removable padded inserts (Fig 5A & B). The collar also has flexible plastic tabs surrounding the orthosis in order to reflect the edges of the orthosis away from the patient to increase comfort.[1] The Aspen collar can also be utilized as a more restrictive cervico-thoracic orthoses by adding thoracic extensions to increase the overall length (Fig 6A & B). This provides for increased control of the cervico-thoracic junction.[1] In an Aspen 2-post, rigid thoracic extensions are added anteriorly to an Aspen collar, while in an Aspen 4-post, extensions are added both anteriorly and posteriorly.[4]

Fig 6

The Malibu brace is a two-piece orthosis that also utilizes a firm plastic shell with interior padding.[1,3] The front and back pieces of the collar fasten with adjustable straps.

Two other types of rigid collars are the NecLoc collar and the Stifneck collar. The Stifneck collar is a one-piece orthosis that is easily applied during trauma extrications.[1] The NecLoc collar is a two-piece cervical collar that overlaps and attaches on both sides.[5]

Cervico-thoracic Orthoses

Cervico-thoracic orthoses (CTOs) are a type of orthoses that extend further down the trunk of the body, as opposed to orthoses that immobilize the cervical spine alone.[2] This allows for greater levels of stabilization. Minerva braces and the sterna-occipital-mandibular immobilizer (SOMI) are common types of CTOs, as well as the aforementioned Aspen collar with thoracic extensions.

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Minerva Brace/Jacket

Fig 7

Historically, the Minerva brace was an uncomfortable molded cervico-thoracic orthosis that provided moderately rigid control of mid and lower cervical motion. The modern Minerva jacket orthosis provides higher levels of comfort, as it utilizes a padded, plastic vest and padded extensions to the mandibular region and dorsal head (Fig 7A & B).[1]

Originally, the Minerva plaster cast was used to stabilize the spine in patients suffering from poliomyelitis and tuberculosis. The Minerva is thought to be a good option for cervical spine immobilization, because it offers improved end-point control of the head.[2] The Minerva orthosis is used in similar situations to those in which a halo vest is utilized, including cases of spinal trauma or infections.

One of the more current versions of the Minerva is the thermoplastic Minerva body jacket (TMBJ). This lighter jacket provides stabilization by immobilizing the occiput, mandible, and thorax, and it consists of two pre-cut Polyform sections that are lined with Polycushion®. There is also a surrounding headband. Nylon screws and straps across the chest connect these anterior and posterior components in the neck region.6 With the hope that increased comfort would lead to greater patient compliance, the TMBJ was created to be more comfortable than its predecessor.[7]

Sternal-Occipital-Mandibular Immobilizer (SOMI) Brace

Fig 8

A sternal-occipital-mandibular immobilizer (SOMI) orthosis is a rigid type of three post cervico-thoracic orthosis that can be applied to patients in the supine position. A SOMI orthosis has a rigid ventral chest piece, shoulder supports, and a swivel-type occipital pad (Fig 8A & B).[2,3] This type of orthosis is typically used to treat stable fractures with minimal displacement. Because it extends farther down the trunk than collar-type braces, it is used to treat injuries in the cervico-thoracic region. This brace is very effective in limiting upper cervical spine flexion, but is less effective in restricting neck extension.[2,3]

Poster Orthoses

Poster orthoses are not as commonly used now as they have been in the past. These orthoses are known to control the head through the use of padded mandibular and occipital supports. Poster orthoses have two to four rigid metal uprights, which are attached to the front and back components of the brace by adjustable leather straps.[3]

Halo Vests (Casts) - Invasive and Noninvasive

Fig 9

The halo cast was first introduced in 1959 by Perry and Nickel[8], and was initially intended for post-surgical use on patients who were disabled by poliomyelitis. Today, the halo does not commonly involve a cast, but rather a vest, (Fig 9) and is typically used for immobilization in the incidence of spinal trauma, tumors, infections, inflammatory conditions, congenital malformations, spinal deformities, surgical arthrodeses and other various procedures.[1,9,10]

Halo vests allow for the early mobilization of patients, thereby avoiding some of the physical and psychological complications of prolonged bed rest. The halo vest is considered to provide the greatest immobilization of cervical orthoses, and has historically provided the best control for the upper cervical spine (occiput-C1, C1-C2).[9]

Halo vests may have either invasive or noninvasive fixation to the skull. The original halo casts had a metal ring that arched upward dorsally in order to allow for surgical access to the cervical spine. To provide secure fixation of the head, metal pins pierced the outer table of the skull, which were inserted through holes in the metal ring. Two upright posts connected the metal ring to a molded body cast.[1] Presently, halo rings are made of titanium and carbon fiber, making MRI and radiographic studies possible while a patient remains immobilized. In addition the availability of molded plastic body jackets with many sizes of comfortable padded inserts has dismissed the need for body casting.[1]

The Lerman noninvasive halo was developed in order to immobilize the cervical spine in a less invasive manner than the original halo.[11] The Lerman noninvasive halo supports the head with breathable skin-adherent silicone composite pads on the forehead and occiput. Universal ball joints attach these pads to an adjustable vest. This pinless version of the halo vest allows for sufficient stabilization of the cervical spine, while minimizing the chances of developing complications that are typically associated with the traditional halo device. This orthosis is generally used in pediatric patients as it lessens the risk of pin penetration of the skull.[2]

BIOMECHANICS

There is a wide variation in the manner in which biomechanical studies of cervical orthoses have been conducted, leading to reports of a wide range of motion restriction. Some researchers utilize healthy volunteers while others use cadaveric models with simulated injuries. The way in which motion restriction has been measured has varied widely. Some investigations used radiographs or photographs to capture extremes of motion, while other studies used goniometry, live fluoroscopy, or roentgen stereophotogrammetric analysis.[2] Variation in methodology has lead to the inconsistencies in this data reporting, and therefore only general trends can be described. A conglomeration of motion restriction data is shown in Table 1.

Table 1

The amount of contact between a brace and the patient wearing the brace is important. The more contact there is, the more even the pressure will be distributed, resulting in greater stabilization and control of motion.[2] However, the material an orthosis is made of can change the amount of stabilization provided, even if there is a high level of contact. For example, soft collars are made of a soft, pliable material. Though these collars have a high contact level with the neck, soft collars are the least restrictive of all cervical orthoses.

In the vast majority of studies, soft collars are shown to have little to no effect on cervical motion restriction. Rigid collars are more effective at restricting motion than soft collars, though they are less effective compared to cervico-thoracic orthoses. Rigid collars were found to be less effective at controlling the upper and lower cervical spine, but generally effective at controlling the mid cervical spine in the sagittal plane. This design was also found to be less effective at reducing lateral bending and rotation, as they do not provide adequate end-point control of the head and thorax.[2,4]

In comparison to the Philadelphia collar, the Aspen collar was found to provide more motion restriction. The Miami J collar offers even more immobilization than that of the Aspen.[1] Since it projects more inferiorly on the chest and back, the Malibu collar offers more motion restriction in the sagittal plane than does the Miami J and Aspen collars.[1]

Though the Malibu collar may offer improved sagittal plane restriction, the Miami J collar has the least mandibular and occipital tissue-interface pressure, making it less likely for patients to develop pressure sores.[2] Given its greater comfort and comparable degree of stabilization, Agabegi et al. advocates for the Miami J collar over the other cervico-thoracic orthoses and halo vests in the management of stable fractures in the upper cervical spine.[2]

As increasing the length of an orthosis generally increases its restrictive abilities, the addition of a thoracic extension to a rigid collar can effectively provide more immobilization of the lower cervical spine and greater control of the cervico-thoracic junction.[2] The Aspen and Miami J collars can both have anterior and posterior thoracic extensions added, giving them greater control of cervical motion.

Generally, the Minerva orthosis is considered one of the most effective designs for motion restriction. In a study done by Schneider et al., the Minerva was found to be the most effective among seven cervical orthoses in restricting intervertebral motion in the sagittal plane.[13] However, another study found that sagittal plane segmental motion was allowed in the Minerva from level C1 to C2.[1] A third study conducted by Sharpe et al. found that the occiput-C1 region was inadequately restricted with a Minerva brace, but the cervical spine below C1 was controlled well.[2,7] The Minerva, alongside the halo, provides better endpoint control of the head compared with other cervico-thoracic orthoses. Additionally, Benzel et al. found that there was significantly less intersegmental motion in the Minerva, as compared with the halo vest.[14] However, the upper cervical spine (occiput to C2) is still considered to be best controlled by a halo orthosis, while the Minerva orthosis recommended for C2 and below.[2,14] With all this considered, the Minerva brace can be a good alternative to the halo when worries of halo-related complications make choosing this orthosis less appealing.

The halo cast/vest is the only cervical orthosis that has shown true immobilization of the upper cervical spine.[2] However, many studies have reported that the halo cast/vest does not adequately control the mid cervical spine because of a “snaking” phenomenon.[2,3] This snaking is identified as intersegmental motion that occurs when a patient attempts flexion-extension of the neck. Because of this potential instability in the mid cervical spine, some authors believe that a rigid cervical collar is more effective than a halo in this section of the spine.[2] Despite this, the halo remains a staple in the treatment of the upper and lower cervical spine.[7]

COMFORT

In addition to measurable motion restriction, the comfort of cervical orthoses is important. Patients are generally more compliant when the orthosis they have been instructed to wear is comfortable, thereby allowing a treatment to be effective.

Eskander et al. recommend that, in order to increase patient comfort, soft and breathable materials should be used where the orthosis makes contact with the skin.[1] When there is too much contact pressure between an orthosis and the skin, skin breakdown is more likely to occur, which in turn decreases a patient's comfort level. Maintaining good hygiene and having a properly fitted orthosis can decrease this risk. Also, pressure sensors can be utilized during the application of cervical orthoses to lessen pressure and thereby reduce the risk of skin breakdown and patient discomfort.[15]

A general, but not universal, concept found in the literature is that cervical orthoses become less comfortable as the motion restriction of each orthosis increases. In general, soft collars are thought to be the most comfortable cervical orthosis, but they are the least restrictive of motion. The Philadelphia collar is thought to be less comfortable than the Aspen (Nwport) collar, the Miami J collar, and the Malibu collar because it does not have removable components like the others have.[1] In a study done by Plaisier et al. utilizing 20 normal volunteers, the Aspen (Newport) collar and the Miami J collar were considered to be comfortable orthoses, whereas the Stifneck collar was considered to be an uncomfortable cervical orthosis.[16] Schneider et al. produced similar results, suggesting that the Aspen (Newport) collar and the Miami J collar provide the greatest level of comfort. They also concluded that cervical collars provide increased levels of comfort in comparison to cervico-thoracic orthoses.[13] The NecLoc and Stifneck collars are more uncomfortable due to the high skin pressures they wield as their names imply

The modern Minerva jacket provides more comfort than the original Minerva brace, because it utilizes a plastic, padded vest and padded extensions to the mandibular region and dorsal head.[1] The comfort of the Minerva jacket is preferred to that of the halo vest. This is most likely due to the fact that the halo vest includes the use of pins in the skull. Skin breakdown and pressure sores beneath the halo vest can also lead to increased patient discomfort.[1]

ACTIVITIES OF DAILY LIVING

Cervical orthoses can affect the activities of daily living (ADLs) of patients receiving treatment. In a study comparing soft and rigid cervical collars, Miller et al. reported significant differences in only 2 of 15 activities of daily living (ADLs).[17] The fifteen ADLs tested were: standing to sitting position, backing up car, putting on socks, tying shoelaces, reading a magazine in lap, cutting food with knife and fork and bringing food to mouth, rising from sitting position, washing hands in standing position, shaving facial hair (men)/ applying make-up (women), washing hair in a shower, picking up an object from floor using bending technique, picking up an object from floor using squatting technique, walking, walking up stairs, and walking down stairs. The two ADLs that were significantly more difficult to complete in a rigid cervical collar than a soft collar were backing up a car and sitting down from a standing position.

The same study found that typical ADLs do not require the full, active range of motion (ROM) of the cervical spine, in which case a soft collar can serve as a proprioceptive guide just as effectively as a rigid collar.[17] As previously stated, soft cervical collars can serve as a reminder to patients that they just had surgery and need to regulate their motion.

The effect on daily living activities increases alongside the rigidity of different orthoses. For example, the negative impact on ADLs is higher in halo vests, as they are the most immobilizing, with perhaps the exception of swallowing. Patients in a halo vest must avoid heavy lifting, bending, driving, and avoid most activities, besides walking, while they are in the halo vest.[18]

ROLE OF ORTHOTIC TREATMENT

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Trauma

Treatment of traumatic injuries in the cervical spine is one of the most important indications for the use of cervical orthoses. Extrication collars are an example of a typical orthosis use following trauma. Additionally, various types of fractures may indicate the use of cervical orthoses.

Extrication Collars

A common situation in which cervical collars are applied is in the case of traumatic injury. Immediately after trauma, common practice dictates first responders to place a rigid extrication collar, most frequently a Philadelphia collar, on the trauma victim. This practice serves to lower the risk of secondary spinal cord injury during transportation to a medical facility, as it is easy to obtain a secondary injury after trauma that renders the spine unstable. However, several studies have suggested that the movement in the cervical spine caused by the application and removal of the extrication collar could actually be harmful to the trauma patient.[19,20] Prasarn et al. found that there was a statistically significant increase in motion in the spine observed with the application or removal of either a one-piece or a two-piece collar placed on an instable spine.[20] The authors accordingly suggest that only trained practitioners should place collars on trauma patients in order to limit movement and potential secondary injury. Lador et al. found that rigid cervical collars can create pivot points that shift the center of rotation in the cervical spine, which can cause secondary injury to the spine.[21] Extrication collars can also result in abnormal distraction within the upper cervical spine.[19,22-25]

However, the potential benefit that lies in the immediate immobilization of a patient with an unstable spine injury could outweigh the risks of that same mode of immobilization. Ben-Galim et al. argued that cervical collars should not cease to be used, but that more emphasis should be placed on technique and proper application of trauma collars.[19,26] If a trauma patient is found in a position where the head is not in a neutral position, it may be safer for a splint or an X-Collar (EmeGear) to be placed on the patient without changing their position.[26] The use of cervical collars, especially the Philadelphia or a similar collar, remains common practice in the case of traumatic injury.

Flexion-extension Injury

The use of collars to treat flexion-extension injuries [frequently referred to as whiplash though this term is less favored by some because it implies forces that may not have been present] to the cervical spine in the trauma setting is controversial. For those patients with pain associated resulting from this injury, approximately 60% will have complete or nearly complete resolution of symptoms, while roughly 40% may have persistent symptoms.[27] Of the original injury group, about 10-20% will have symptoms of sufficient nature so as to limit their occupational or recreational activities.[27-29] With this natural history in mind, patients presenting with whiplash injuries have traditionally been prescribed a soft collar for two weeks, followed by an exercise regimen. According to some authors though, the soft collar could, at best, produce the same results as not intervening at all or as standard physiotherapy.[30,31] Borchgrevink et al. reported that patients who were instructed to act as usual after sustaining a whiplash injury had better outcomes than patients who took sick leave from work and wore a soft cervical collar for 2 weeks.[32] The patients who did not use an orthosis reported fewer headaches and less neck pain, as well as better memory and concentration during daily activities.[32] Cervical bracing after a flexion-extension injury may not be necessary, though if a patient would feel more comfortable and supported in a soft collar, it may not be harmful for a patient to wear one very short term.

Fractures

According to a recent Norwegian study, the incidence of cervical spine fractures is 15.0/100,000 population per year.[33] The role of orthotic treatment in the case of cervical fractures has been widely researched, though a general consensus of treatment has not been reached among physicians. According to Garvey et al, "treatment principles for patients who have sustained cervical spine fractures or fracture dislocations should include: 1) preservation or improvement of neurologic function; 2) attainment of mechanical stability with an acceptable anatomic position; and, 3) early rehabilitation with the least restrictive external immobilization required to protect spinal stability".[34]

The role of orthotic management in the case of cervical fracture in order to follow these treatment principles is then determined by the location and the magnitude of displacement of the fracture. However, as this is not a definitive chapter on fracture management, it is beyond the scope of this chapter to dictate in every case when and when not to intervene surgically. We will provide some commonly presented fractures and recommendations for their treatment.

In some cases of acute fractures with dislocation and associated posterior ligamentous disruption, anterior decompression with structural bone grafting and internal fixation can be recommended, with adjunct postoperative stabilization increased by orthotic management.[34] Though in the past halo vests have been recommended in the pursuit of postoperative mechanical stability, the halo vest does not ensure this stability, as it is not rigid fixation, and its use does not preclude the recurrence of deformity.[3,34,35]

Occipital Condyle Fractures

An occipital condyle fracture (OCF) is a rare fracture that occurs nearly exclusively in the event of high-energy blunt trauma. Accurate diagnoses for OCFs have historically been difficult to obtain, and the incidence of these rare fractures has been reported from 0.4% to 1.19% in patients with major trauma.[36,37]

Classified by Anderson and Montesano into three types, these fractures typically present with associated injuries, especially severe brain injuries, and they can only be efficiently diagnosed with computed tomography (CT).[36,38] Type I fractures are comminuted fractures of the occipital condyle, type II fractures are an extension of a basilar skull fracture, and type III are transverse fractures with an avulsion of alar ligaments. Mueller et al. reported bony consolidation in almost all patients with type I and type II fractures that were treated for 6 weeks in an Aspen collar. Surgery, typically a dorsal cranio-cervical stabilization operation, is indicated in Type III fractures, as there is confirmed atlanto-occipital dislocation (AOD).[36]

Atlas Fractures

Fractures of the atlas account for 10% to 13% of all injuries to the cervical spine.[39] Nearly all isolated fractures of the atlas can be successfully managed without surgery.

Jefferson's fractures are classified as burst fractures of the atlas ring.[39] Most authors agree that these fractures can be treated with a rigid halo cast or a halo vest if there is only minor displacement of the lateral masses (< 7 mm) and the transverse ligament is intact.[39-42] Dvorak et al. recommends a Minerva brace or similar orthosis for the treatment of these "stable" Jefferson fractures, as the halo vest is very invasive and has additional morbidity.[39]

The treatment of "unstable" Jefferson fractures remains controversial. "Unstable" fractures have an identifying injury to the transverse ligament. According to Dvorak, patients with lateral mass displacement (LMD) of greater than 7 mm have poor long-term outcomes in terms of pain, stiffness, and quality of life with regard to their health.[39] There is no evidence to suggest that early surgical fixation will lead to improved outcomes over non-operative management. Some authors suggest halo traction for up to 6 weeks, then proceeding to immobilization in a halo vest.[43] Bransford et al. suggest C1-C2 trans-articular screw arthrodesis or segmental fixation with C1 lateral mass screws and C2 pedicle or trans-laminar screws connected by plates and rods in the case of an atlas fractures with LMD greater than 7 mm.[42]

Atlanto-axial Fractures

According to Bransford et al. atlanto-axial instability injuries are categorized into three types. A type A injury is rotationally displaced in the transverse plane, a type B injury has transverse atlantal ligament (TAL) disruption and is therefore translationally unstable, and a type C injury is a variant of cervical spine dysfunction (CCD) and is vertically unstable.[42] Reduction and immobilization are utilized in the treatment of type A injuries, as critical CCJ ligaments are intact. Those with type B injuries are typically treated with C1-C2 arthrodesis, if they survive the initial injury. Type C injuries, where C1-C2 distraction is >2 mm, are also treated with C1-C2 posterior arthrodesis.[42]

In the case of an odontoid fracture associated with an atlas fracture, external immobilization in a halo vest can be an effective treatment. Surgery may be necessary if a halo vest fails to maintain alignment in these patients.[44]

Axis Fractures

Fractures of the axis, the C2 vertebrae, can be effectively treated with external orthoses depending on the location and displacement of the fracture. Axis fractures frequently result from high-energy injuries, such as motor vehicle accidents or falls.[39,44]

Axis Fractures - Odontoid

Fractures of the odontoid process, also known as the dens, account for between 10-16% of fractures of the cervical spine.[45] Elderly patients are more likely to sustain this type of fracture, possibly because of an association with osteoporosis in this population.[44,46] Odontoid fractures are classified as Type I, Type II, or Type III depending on where in the dens the fracture occurred.

Type I

An odontoid Type I fracture, a rare avulsion fracture of the apical ligament, is high enough in the cervical spine that it is unlikely to be unstable regardless of healing. This type of fracture can therefore be sufficiently immobilized with either a semi-rigid collar or brace.[44,45]

Type II

A Type II odontoid fracture, the most common axis fracture, occurs at the junction of the odontoid process with the body of the C2 vertebra.[45] Treatment for this type of fracture is considered to be both the most difficult and the most controversial.[44] Greene et al. found that dens displacement of 6 mm or greater was the most significant factor in the nonunion of Type II odontoid fractures after non-operative treatment, and recommended these patients for early surgical intervention.[44] A fracture with this displacement is acutely unstable.

Greene et al. also reported that comminuted dens fractures (Type IIA) were acutely unstable. External orthoses are not successful in maintaining adequate alignment, so patients with this type of fracture should undergo early surgery to mobilize them more quickly.[44]

For patients with a Type II odontoid fracture with less than 6 mm of displacement, early immobilization in an external orthosis, most frequently a halo vest, results in high rates of union.[44] However, the invasive nature of the halo vest must be considered, as this device could be inappropriate in some older or frailer patients.[45] Lennarson et al. reported that the risk of failed treatment in patients over the age of 50 treated with a halo vest was 21 times greater than in younger patients.[47] In this case, a semi rigid collar (like the Philadelphia, Miami J, or Aspen) could be appropriate to provide some immobilization during the healing process.

Type III

A Type III odontoid fracture, a fracture that extends into the body of the C2 vertebra, can also be treated non-operatively with a rigid external orthosis. Greene et al. effectively immobilized the cervical spine enough to allow union using a halo vest for 10 to 20 weeks.[44] Patel et al. used either a rigid collar or a halo vest to treat elderly patients with Type III fractures, with 86% of patients showing bony union, and the remaining 14% showing stable fibrous non-union.[48] There was no significant difference in outcome for those treated with a collar versus a halo vest. Contrarily, Clark and White reported a nonunion rate of 13% for Type III fractures, leading them to conclude that this type of fracture is not benign.[49] They recommended patients to first undergo rigid external immobilization in a halo vest before receiving further treatment.

Axis Fractures - Hangman's

A hangman's fracture is classified as a traumatic spondylolisthesis of the pars interarticularis of the axis,[50] and they account for 38% of axis fractures.[42] Greene et al. found that hangman's fractures treated with external immobilization for 10 to 16 weeks, with very small exception, acquired solid fusions with no evidence of instability. The vast majority of these patients were placed in a halo vest, though a small number were treated with a SOMI brace or a Philadelphia collar.[44]

Axix Fractures – Miscellaneous

For the purposes of this chapter, a miscellaneous axix fracture is considered to be any fracture of the axis that is neither an odontoid nor a hangman's fracture. Greene et al. reported in his study that most of the miscellaneous axial fractures in his patient population involved the vertebral body or lateral mass. In the same study, the authors reported that the external orthosis utilized depended on the specifics of each case, especially if there was other associated cervical spine fractures or a high degree of associated contiguous subluxation. Of Greene's patient cohort, only one patient with a miscellaneous fracture had to undergo surgery, and all achieved union with no evidence of instability; the most frequently used orthosis was the halo vest.[44]

Hadley et al. recommended that patients be immobilized in a halo vest or SOMI brace for 8 to 12 weeks if they had a significant fracture of the vertebral body, pedicle, or lateral mass. If the fractures were less severe or more stable, the authors recommend immobilization in a rigid collar for 6 weeks.[51]

Sub-axial Fractures

Cervical collars can manage multiple types of sub-axial injuries including: isolated minimally displaced lamina and spinous process fractures, single level compression fractures with intact ligaments, and minor ventral column injuries due to a flexion-compression mechanism with intact dorsal ligaments.[40] Sub-axial compression fractures that are mechanically stable can be treated non-operatively, but frequent follow-up is necessary. Unstable fractures, such as in the case of cord compressions from retropulsed bone fragments, frequently require surgical procedures. Prasarn et al. strongly recommend a ventral decompression and fusion in the neurologically compromised patient.[40] However, recommendations for treatment of fractures that are unstable but less severe remain controversial.

Sub-axial hyperextension injuries can result in spinal cord injury in the absence of mechanical instability. These injuries occur frequently in the elderly after a fall. In this instance, a collar can be used for patient comfort, though a surgery may be performed to decompress the cord or prevent further injury.[40] Most facet fractures occur in the sub-axial region of the cervical spine and are unilateral, non-displaced, and do not result in subluxation. These fractures can therefore be successfully managed with a hard cervical collar for 6 to 12 weeks.[52]

If the fracture is unstable, treatment with cervical orthoses has a lower chance of being successful. An unstable facet fracture is generally considered to be a fracture with over 40% of the height of the lateral mass involved or a fracture with an associated injury to the discoligamentous complex.[52] In the case of a sub-axial facet dislocation, the injury should be reduced as soon as is medically appropriate for the patient. After the dislocation is reduced, most patients should undergo surgical stabilization, as up to 40% of patients will remain unstable even if treated with a halo vest.[40]

POSTOPERATIVE ORTHOSIS USE

The use of orthoses after a cervical operation is a common practice for inhibiting motion, thereby encouraging stability of graft material and promoting fusion.

Bible et al. conducted a survey of 98 spine surgeons on their postoperative bracing practices. He found that the majority of surgeons advised brace use for 3 to 8 weeks postoperatively, and that the most commonly reported reason for a surgeon to prescribe postoperative bracing was to “slow down” the patient (51%), followed by improved fusion (48%), and pain relief (38%).[53]

In order to determine which, if any, external orthoses should be used; the goal of the surgery and the expected benefit of bracing need to be considered.[54] For example, if the goal of a certain surgery is to obtain a solid fusion, then a rigid brace can be utilized postoperatively to help stabilize the spine. However, if the expected benefit of bracing postoperatively is simply to keep a patient comfortable and to remind them to “slow down”, then a soft cervical collar is sufficient.[54]

The advent of internal fixation has also affected postoperative orthotic use. After multi-level fusions or operations causing high instability, orthotic use can be appropriate and can lead to better outcomes. However, after some surgical procedures, especially those with rigid internal fixation, postoperative orthotic management is thought to be unnecessary.[54]

For the purposes of this chapter, we will divide postoperative orthosis recommendations according to five surgical categories: fusion with stable internal fixation, fusion with stable internal fixation but poor bone quality, fusion without internal fixation in the upper cervical spine, fusion without internal fixation in the mid and lower cervical spine, and non-fusion operations.

Fusion with Stable Internal Fixation

With the advent of rigid internal fixation, bringing with it high successful fusion rates, more and more surgeons are questioning the necessity of using external orthoses after a fusion using modern instrumentation and techniques.[55]

For an anterior cervical discectomy and fusion (ACDF), the use of an orthosis after surgery depends on the number of motion segments involved in the operation. As this number increases, the frequency of postoperative orthosis use increases as well. Bible et al. found that the frequency of orthosis use for a single-level ACDF was 55%, while frequency of bracing for two-level procedures was 70%, and 82% for 3 or more level procedures.[53] There is a greater rate of pseudarthrosis as the number of levels involved in a fusion increases, which becomes a large factor in the decision to use an orthosis.

Campbell et al. questioned whether a postoperative collar was needed for single-level ACDF procedures. At 24-month follow-up, a comparison of patients using an orthosis and without an orthosis showed that there was no statistically significant difference in outcome.[56] Still, other authors, such as Samartzis et al., have recommended that patients should wear a soft collar for one or two weeks after an ACDF with instrumentation.[57] For a single-level ACDF with internal plate fixation, a postoperative cervical collar might be unnecessary, though a soft collar can be used for comfort.[54,56]

Vaccaro et al. found that after a two or three-level plated anterior cervical fusion (ACF), the vertebral fracture and graft extrusion rate was comparable for patients immobilized in hard cervical collars or in halo vests after the operation.[58]

For a posterior fusion, Bible et al. reported that the majority of surgeons would prescribe a cervical collar. For a fusion involving one or two levels, 66% of surgeons utilize a collar, and for fusion of three or more levels, 78% of surgeons will prescribe a collar. This can be a semi-rigid cervical collar.[53]

In the case of a laminectomy with fusion and posterior instrumentation; patients can utilize a rigid collar for 4 to 8 weeks. However, if the fixation involves more than 4 levels, the time frame can be increased to two to three months.[59]

Using newer surgical methods, postoperative immobilization in a collar can be effective after an upper cervical spine surgery (occiput-C1, C1-C2), where otherwise a halo vest or similar orthosis has been the historical choice.[54]

Fusion with Stable Internal Fixation and with Poor Bone Quality

If a patient's bone quality is osteoporotic, the fixation of instrumentation used in a cervical fusion might be poor. In this case, postoperative bracing should be utilized,[54] and the brace should be worn for a longer period of time than in those with healthy bone. For example, while a patient with healthy bone might be in a rigid collar for 4 to 8 weeks after a laminectomy with fusion and posterior instrumentation, one with osteoporotic bone might be in a collar for 2 to 3 months.[59]

Fusion without Internal Fixation in the Upper Cervical Spine

Traditionally, a halo vest has been the most utilized orthoses after an upper cervical surgery.[54] Halo vests outperform almost all other cervical orthoses in providing stability for the upper cervical spine, though a Minerva jacket or SOMI orthosis can also provide good stabilization.[60]

Recently, studies have tested the newer noninvasive, pinless halo vest as compared to the conventional halo vests.[61] Though the conventional halo performed better in some planes of testing and stability, the noninvasive halo vest provided similar external stability without the need for skull fixation. As pin-related complications are some of the most common complications of halo vests, the noninvasive halo could be a better option for patients who have received upper cervical surgery with rigid instrumentation.

Fusion without Internal Fixation in the Mid and Lower Cervical Spine

Currently in North America, the vast majority of ACDF's are done with internal fixation. Traditionally, until around the early 1990's, they were done without internal fixation, and as such most patients would use of a rigid collar. For example in 1998, Saunders et al. performed 31 four-level ACFs without plates for spondylotic myelopathy. Of these 31 patients, 25 utilized a Philadelphia-type collar for 24 weeks postoperatively. The other 6 wore halo vests.[62]

In the case of a multiple-level corpectomy without internal fixation, some authors have suggested that the patient should be immobilized postoperatively in a halo vest until the fusion shows signs of consolidation.[63]

Non-Fusion

Common operations without a fusion include: decompression surgery (laminectomy, foraminotomy, discectomy), laminoplasty, and disc arthroplasty. If the goal of the surgery is not to obtain a fusion, as in the above operations, then it is not necessarily required to prescribe rigid cervical orthoses postoperatively.[54] Usually, orthoses are used for a short period of time after a non-fusion operation, if they are used at all. This short-term use of orthotics should not be harmful to patients, though it must be added that studies suggest it is not particularly helpful, unless comfort is the only goal. We will address several specific non-fusion operations.

A cervical foraminotomy is a procedure that treats cervical radiculopathy, and does not require a fusion. Bible et al. reported that less than 25% of surgeons brace their patients after a laminoforaminotomy.[53]

A laminoplasty is a common operation that is generally undertaken to treat myelopathy. After this procedure, most surgeons recommend a soft collar for 2-4 weeks after surgery, at least for the patient's comfort.[54,64] Iizuka et al. reported that patients who wore a soft collar for 4 weeks after a laminoplasty had better cervical range of motion postoperatively than those who wore a collar for 8 weeks; so short-term collar use is recommendable.[64] Wearing a brace for a shorter period of time can also reduce the prevalence of posterior neck and shoulder girdle pain following a laminoplasty.[59,65,66]

SPONDYLODISCITIS – SPINAL INFECTIONS

Spondylodiscitis (SD) is a term that encompasses vertebral osteomyelitis, spondylitis and discitis; SD incorporates inflammation generally caused by an infection involving an intervertebral disc and adjacent vertebrae. Spondylodiscitis is not common; the incidence of acute pyogenic SD is given at 5-5.3 cases per million patients per year.[67] Spine infections account for only 1% of all bone infections. Within that 1%, approximately 5% involve the cervical spine.[68] Non-operative treatment with targeted antibiotics and bracing is used to treat the majority of spondylodiscitis cases.[67,68]

The type of orthosis chosen is based on the site of the disease, the extent of bone destruction, and the risk of segmental instability. If the infection is in the lower cervical spine, a rigid collar or cervico-thoracic orthosis should be used to treat the infection.[67,68] There is, however, disagreement in the proper treatment of SD of the upper cervical spine. Di Martino et al. suggest a SOMI brace, while Arkader and Dormans suggest the use of a halo vest.[67-69] Individual patient indications should be considered when choosing which cervical orthosis to utilize. [See Chapter 21 for additional material on this topic.]

TORTICOLLIS

Stedman's Medical Dictionary defines congenital torticollis as, "a contraction, or shortening, of the muscles of the neck, chiefly those supplied by the spinal accessory nerve; the head is drawn to one side and usually rotated so that the chin points to the other side". Torticollis has a reported incidence of 0.084% to 2.1%.[70-73] Orthotic use has had very limited success in treating torticollis and associated plagiocephaly. Cheng et al. successfully used an orthosis after surgical release of the sternocleidomastoid muscle to maintain correction.[70-73] The use of a cervical orthosis alone in the treatment of torticollis is felt to be ineffective.[70]

COMPLICATIONS

Though cervical orthoses can be effective in the treatment of various spinal disorders, there are some potential complications that can arise from the use of these devices. Some of the most common complications include dysphagia and skin breakdown, though other less common complications can also occur. Because of this, cervical orthoses should optimally be used for the shortest possible time duration.

Dysphagia

A common complication with the use of cervical orthoses is dysphagia. Cervical orthoses are known to affect swallowing mechanisms due to the external pressure they may exert and the position in which they place the neck. Stambolis et al. evaluated uninvolved, healthy volunteers placed in a Philadelphia collar, a SOMI brace, and a halo vest, and observed mechanical changes in their swallowing.[74] Mechanical changes in swallowing occurred in 14 of the 17 patients, and they concluded that bracing narrows the pharynx, as well as inducing other changes in swallowing mechanisms. Odderson et al. reported that certain orthoses that utilize mandibular pads, such as the Minerva brace and the SOMI brace, might limit movement of the hyoid bone and thus making swallowing difficult.[75]

Dysphagia can also be attributed to the unusually upright head position that patients must be in while they are eating.[74,76] Normally the neck is held slightly flexed during eating. Cervical orthoses tend to alter this and place the neck in a slightly extended position.[2,9,77]

Patients in halo vests are especially at risk for dysphagia, so special attention should be paid to the degree of hyperextension in which a patient is placed.[78] Garfin et al. found a dysphagia rate of 1% to 2% in patients who utilized the halo vest.[9]

Though dysphagia may be a common complication of cervical orthoses, Stambolis et al. highlighted the importance of distinguishing the source of the swallowing difficulties, as they could result from the orthosis use, from the surgery, or from the injury itself.[74] The cause of the dysphagia should be evaluated before instituting treatment.

Skin breakdown

Skin breakdown is a well-known risk that accompanies the use of cervical orthoses, occurring in 4-11% of patients.[18] One study reported that 55% of patients who wore a collar for 5 or more days developed severe occipital pressure ulcers.[79] This complication usually develops due to increased contact pressures between an orthosis and a bony prominence.[18] These areas include the occiput, chin, mandible, ears, shoulders, and clavicles. In order to decrease the risk of developing skin breakdown, it is important to maintain good hygiene underneath the orthosis, and to frequently check for any signs of skin irritation.[1,18] Additionally, it is important that the orthosis be properly fitted to the patient, with the inclusion of sufficient padding. Patients who are able to perceive painful stimuli well and who are able to act in response to those stimuli are better able to avoid skin break down.[76]

Ill-fitting Orthoses

Additional complications may arise if an orthosis is too small or too large, it allows increased motion in all planes.[80] As one of the major goals of postoperative bracing is adding stability, an ill-fitted orthosis could be detrimental to a patient’s recovery. Patients are also more likely to be compliant with an orthosis if it fits properly.[2] Some clinicians feel that the best-case scenario is a trained orthotist applying all cervical orthoses.

As cervical orthoses seek to immobilize the spine and must do so through a soft tissue envelope, a patient's body habitus becomes a factor in the effectiveness of orthoses. In a morbidly obese patient the soft tissue envelope is deeper and more pliable, making the spine harder to control. This also means that if a patient loses weight the orthoses must be re-fitted accordingly.[2]

Complication specific to halo use

Although the halo vest has historically provided the best immobilization, additional morbidities accompany its use. Van Middendorp found that 60% of patients treated with a halo experienced a complication.[81] Some of the most common complications are pin loosening, pin-site infection, and pin discomfort. Other complications include scarring from pins, nerve injury, pin-site bleeding, intracranial penetration, psychological intolerance, pressure sores, dysphagia, altered cervical mechanics, alteration in gait, respiratory restriction, neurologic deterioration, loss of cervical alignment, and skin breakdown.[9,77] Because of the very invasive nature of the halo pins, a patient's specific health status must be considered before using the halo device.

CONCLUSION

The use of cervical orthoses in the modern world remains controversial. There are many different types of orthoses, such as: soft collars, rigid collars, cervico-thoracic orthoses, and halo vests. Different types of orthoses have varying inherent restriction/support capabilities. If patient support and comfort is the primary desire, then a soft collar is more than adequate for short-term use in an otherwise stable spine. When mid cervical stabilization is indicated, a rigid collar, especially the Miami J, can provide effective stabilization. The Minerva brace can supply good immobilization of the upper cervical spine, though the halo vest remains the optimal orthosis choice when treating the occiput-C2 region. A cervico-thoracic orthosis is indicated when control of the cervico-thoracic junction is necessary.

The use of cervical orthoses has been indicated in many cases, including: the management of cervical trauma, the treatment of cervical fractures, the provision of stabilization during the postoperative period, and the treatment of spinal infections. They have been seemingly less effective in the treatment of torticollis and after certain surgical operations or specific cervical fractures.

There is no universal rule to dictate in every case if and when a cervical orthosis is required. However, if surgeons educate themselves and utilize the knowledge of trained orthotists, the use of cervical orthoses can be very beneficial.

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