Radiology of Spinal Curvature

Arthur A. De Smet

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This book is dedicated
to my wife, Peg,
and my sons, Alan, Mark, and Brian.
Their importance to me and their love
provide the essential balance to the challenges
and pressures of my professional life.

Preface

The idea to write this book was first stimulated by Dr. Donald Resnick of the University of California at San Diego and Mr. Samuel Harshberger of Mosby. They felt that there was a need for a textbook directed toward the radiologic evaluation of abnormal spinal curvature. Their comments reaffirmed my own experience as to the difficulty in achieving expertise in the radiology of spinal deformity. Although there are many excellent textbooks dealing with spinal deformity, their emphasis is on the complex clinical aspects of each condition. As a result, I had found it difficult to determine the role played by radiology from both these textbooks and related articles in the orthopedic literature. Because of the dedicated efforts of Dr. Marc Asher, our institution is a major referral center for spinal deformity problems. With this clinical stimulus and the invaluable assistance of Dr. Samuel J. Dwyer III, Dr. Larry Cook, and Mr. Mark Tarlton of our research section, I had already done considerable research in three-dimensional analysis of scoliosis. Therefore, because of this perceived need and a desire to increase my own knowledge, I enthusiastically agreed to make the considerable commitment of professional time that is required for a project of this kind.

My goal in writing this text was to provide a concise summary of the clinical and radiologic features of thoracic and lumbar spinal deformity for the general orthopedic surgeon and the diagnostic radiologist. With widespread school screening programs for scoliosis, both groups of physicians are becoming increasingly involved in the initial evaluation of patients with abnormal spinal curvature. I believe that both the radiologic and clinical aspects must be learned because of their strong interdependence. The general orthopedic surgeon will be familiar with many of the clinical concepts but may be unaware of the role of the radiographic evaluation in initial diagnosis and the monitoring of treatment. Similarly, the diagnostic radiologist has probably observed many of the described findings but his reports may not have detailed the important points because he was unaware of their clinical significance. I decided not to discuss abnormal curvature of the cervical spine in order to limit the length of the text and because abnormal cervical curvature does not share the rapid worsening with growth and the gravitational forces of trunkal weight that are so important in abnormal thoracic and lumbar curvature.

The first chapter includes a detailed discussion of the epidemiology, prognosis, and pathogenesis of idiopathic scoliosis. The following five chapters deal with the radiographic evaluation of scoliosis, both before and after orthosis or surgical treatment. Chapters seven through nine discuss the less common areas of secondary scoliosis, kyphosis, and lordosis. The last chapter discusses three-dimensional analysis of spinal curvature for both the specialist wishing to investigate this area and the non-research-oriented physician. A review of spinal curvature terminology is found in the Appendix. Although three-dimensional analysis will remain isolated to the academic centers, its use in research should increase. As further investigation is reported using these computer-assisted techniques, physicians will need background information to assess these results critically. Eight of the chapters end with a summary in which I have highlighted those features that I believe should be well known by all physicians evaluating patients with spinal curvature problems.

Although I have often seen extensive acknowledgments in other textbooks, I never previously fully appreciated how many individuals play a role in preparing and writing a major book. Although they are too numerous to mention individually, an important part is played by the technologists, secretarial staff, and file room personnel without whose day-to-day efforts I could not function professionally. I would like to thank Dr. Arch W. Templeton, Chairman of the Department of Diagnostic Radiology, for providing the excellent professional environment that has stimulated my research efforts.

With regard to this book itself, I would like to thank the following individuals for their efforts on my behalf. Our research clerk and department librarian, Mrs. Arlene Berridge, obtained, photocopied, and verified all of the reference material as well as tabulated much of the statistical data. One of our department secretaries, Mrs. Barbara Martin, cheerfully and willingly typed the entire manuscript, including its multiple revisions. Dr. Marc Asher and Mrs. Janice Orrick of the Section of Orthopedic Surgery provided many of the cases that were used for illustration and offered constructive criticism on the manuscript. From our department, Dr. Steven Fritz edited the radiation risk section and Dr. Solomon Batnitzky provided me with several illustrations. Although no longer associated with our institution, Dr. James Goin reviewed the entire manuscript for its clarity of presentation. The photography departments of this institution and Duke University Medical Center contributed their expertise in making the prints of scoliosis radiographs, which are so difficult to photographically reproduce. To all of these individuals, I owe a great debt of gratitude.

Arthur A. De Smet

Contents

Chapter One

An Overview of Idiopathic Scoliosis

Scoliosis is a common deformity of the spine that has received considerable attention in the orthopedic literature but has been discussed only infrequently in the radiologic literature. This situation is unfortunate because scoliosis is both verified and quantified primarily by radiographic techniques. Interaction between orthopedists and radiologists can only improve evaluation of this complex condition. This text will emphasize idiopathic scoliosis because it is the most common and most thoroughly studied abnormality of spinal curvature. As such, it is an ideal prototype for understanding the principles of radiography of abnormal spinal curvature.

Scoliosis can be defined very simply as a lateral curvature of the spine. When a person is viewed from behind, the normal spine should be in a straight line. Any lateral deviation from that straight line is by definition a scoliosis. Although there are multiple causes of scoliosis,[78] 80% to 90% of the cases are idiopathic.[84] The terminology, patterns, epidemiology, and natural history of idiopathic scoliosis will be discussed as background for this important and common condition.

Terminology

The basis of all scientific study is the precise definition and measurement of the phenomenon under investigation. Evaluation of scoliosis research prior to the last two decades is handicapped by the lack of consistently defined and adequately detailed data for subsequent investigators to compare and validate earlier work. The Scoliosis Research Society was founded in 1966 to address this problem. The terminology committee of this society presented the first standardized list of terms relevant to scoliosis in 1978 and revised that list in 1981.[101] Because it is the only officially proposed terminology, the approved glossary will be used throughout this text and is presented in its entirety in the Appendix.

In order to describe fully a scoliotic curve, a number of descriptive terms must be used. The description of a scoliotic curve should routinely include etiology, age at presentation, curve direction, and curve level, for example, an idiopathic, adolescent, right thoracic scoliosis.

Age at Presentation

Idiopathic scoliosis is classified according to the age at which the scoliosis is first detected (with the realization that the age at presentation may not be the same time that the curve began). In most cases, the exact age that the scoliosis began is unknown, so the examiner can only guess at the age of onset. On the other hand, the age at presentation is known precisely. Curves should be differentiated according to patient age because of the differing prognosis and treatment options in the various age groups.

INFANTILE SCOLIOSIS

Infantile scoliosis refers to lateral spinal curvature beginning during the first 3 years of life. These patients are a distinctive subgroup of idiopathic scoliosis as emphasized by the fact that the condition is relatively rare (0.5%) in North America[93,107] but represents 9% to 13% of idiopathic scoliosis in Great Britain.[50,102] Also, unlike the other forms of scoliosis, there is frequent spontaneous resolution of infantile scoliosis in 28% to 92% of patients.* A recent fascinating study from Great Britain reported a decrease in infantile scoliosis from 41% of idiopathic scoliosis patients in 1970 down to 4% in 1981.[75] The author attributed the decrease to a change from positioning infants supine and tightly bundled to the current prone positioning without restrictive covers. This positioning difference may well have accounted for the frequency differences between North America and Great Britain.

These curves are single left thoracic 76% to 90% of the time and are one-and-one-half times more common in boys than in girls.† Untreated curves that do progress usually become very severe, exceeding a Cobb angle of 70 degrees.[53,102]

Unlike juvenile and adolescent scoliosis, prediction of subsequent progression is frequently possible by using the rib-vertebral angle of Mehta,[76] as described in Chapter Two. These patients also have associated congenital abnormalities including plagiocephaly (100%), mental retardation (13%), hip dislocation (3.5%), heart disease (2.5%), and inguinal hernia (7.4% of boys).[19,66,128] No incidence studies of spinal deformity have been performed in patients of this age, so the frequency of this condition is unknown.

JUVENILE SCOLIOSIS

These curves are defined as those first noted between 3 years of age and the onset of puberty. In its terminology, the Scoliosis Research Society did not give a definition for the onset of puberty, but it is commonly taken to mean thelarche (onset of breast development) in girls and pubarche (development of pubic hair) in boys. Since thelarche usually begins at age 10 years in girls and pubarche begins about age 12 years in boys,[5] the age range for juvenile scoliosis should be different for the two sexes. However, even recent studies[37,114] have used a range of 4 to 9 years of age to define juvenile scoliosis. Because the age range is similar to the physical development standards the distinction is not critical, but the inconsistency will hopefully be resolved in the future.

Juvenile scoliosis represents 12% to 16% of the cases of idiopathic scoliosis.[51,58,77,90] It affects both sexes equally and usually presents with a right thoracic pattern (41% to 48%) or a combined right thoracic and left lumbar

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*See references 19, 50, 52, 53, 66, 75, 76, 113.

†See references 19, 50, 53, 66, 75, 113, 128.

pattern (22% to 32%).[37,114] Juvenile scoliosis is familial and commonly progressive, so it is more closely related to adolescent than infantile scoliosis. Undoubtedly some of the curves first detected during the rapid growth period of early adolescence are due to previously unrecognized juvenile scoliosis. Prognosis and treatment considerations are similar to those of adolescent scoliosis. This subgroup has been studied only infrequently, presumably because few children have physical examinations for spinal deformity at this age. Because population surveys of this age group have not been performed, the prevalence of juvenile scoliosis is unknown.

ADOLESCENT SCOLIOSIS

Adolescent scoliosis refers to those patients presenting with scoliosis at or after the onset of puberty but before completion of skeletal maturity. Most patients with idiopathic scoliosis present clinically during adolescence due to the rapid curve progression that occurs during accelerated growth. Skeletal maturity has not been defined in this context, but common usage has taken this to mean that skeletal growth has stopped. Adolescent scoliosis has been extensively studied and will be discussed in detail later in this chapter.

Curve Description

After specifying the age at presentation, each curve should be described by its direction and location. Supplementary terms such as *major* and *minor, primary* and *secondary,* and *structural* and *nonstructural* can also be used to describe other features of the curve.[42]

CURVE DIRECTION AND LOCATION

Curve direction is either right or left and denotes the direction in which the curve is convex, for instance, the common *right* thoracic scoliosis. Some physicians modify this terminology by adding the word *convexity* after the direction to emphasize how the direction is defined, but this addition is not necessary.

The curve location or level refers to the specific region of the spine that is curved and is defined by where the apex of the curve is located. The apex is the vertebra that is the most rotated or most deviated from the vertical axis. It is usually the most horizontal vertebra within the curve. After locating the apex, curve level is then defined as follows:

Cervical curve: apex between C1 and C6
Cervicothoracic curve: apex at C7 or T1
Thoracic curve: apex between T2 and T11
Thoracolumbar curve: apex at T12 or L1
Lumbar curve: apex between L2 and L4
Lumbosacral curve: apex between L5 and S1

SUPPLEMENTARY TERMS

Other terms can then be added to subcategorize the curves. The terms *structural* and *nonstructural* refer to the flexibility of the curve. A structural scoliosis is a lateral curvature of the spine that does not demonstrate normal segmental mobility on lateral bending or distraction. A structural scoliosis will not disappear on supine radiographs, when the patient bends toward the convexity of the scoliosis. A nonstructural scoliosis, such as that due to limb-length discrepancy, will correct completely with lateral bending.

A *major curve* is the largest curve in the scoliotic spine in contrast to the *minor* or smaller curves. Two curves of equal size in the same spine are termed a *double major* scoliosis. Since there is a well accepted standard deviation of 2.2 to 3.0 degrees[54,84] in measuring scoliosis, Willner recently defined *double major scoliosis* as consisting of two curves within 5 degrees of each other.[124]

A *primary* curve is the first structural curve to appear, with all other subsequent curves being *secondary* curves. This notation is seldom used because most patients are not seen until two curves are present, so radiographs are not available from the time when there was only one curve. Although the larger of two curves is usually the primary curve, a secondary curve can become larger than the primary, as has been illustrated by Moe.[78]

A *compensatory curve* develops above or below a structural curve to maintain body balance. A compensatory curve can become structural with time. Since it develops after a primary curve, every compensatory curve is by definition a secondary curve. The term *compensatory* is unnecessarily complicating because most secondary curves serve to restore balance.

If used only to indicate relative size, the terms *major* and *minor* are useful in emphasizing whether one curve is more deforming than the other. For instance, a patient with both thoracic and lumbar curves could have a double major thoracic and lumbar, a major thoracic and minor lumbar, or a minor thoracic and major lumbar curve pattern.

Therefore, it is suggested that each scoliotic spine be classified according to etiology, age at presentation, curve direction, and curve location. If two curves of different sizes are present, one should be labeled the major and the other the minor. If supine bending films are available, each curve segment can be classified as being structural or nonstructural.

Epidemiology

PREVALENCE

The frequency of scoliosis is not clear despite the fact that 39 studies have been reported.* The difficulty in interpreting these studies lies in lack of consistent epidemiologic techniques. The studies vary in their methods of case selection and criteria for defining a scoliotic curve. Almost all studies

*See references 1-4, 7, 9, 14, 15, 23, 27, 30, 31, 33, 39, 41, 44, 45, 49, 55, 68, 70, 71, 74, 82, 86-88, 92, 98, 104-106, 109, 110, 112, 118, 124, 125, 127.

have investigated prevalence (proportion of the population affected at a given time) rather than incidence (rate of occurrence of new cases).

Two methods of estimating the prevalence of scoliosis, tuberculosis (TB) screening chest radiographs[7,106,109] and retrospective analysis of referral center patients,[55] are less reliable than prospective screening. The TB screening chest radiographs are not optimally exposed for spine detail, and they evaluate only thoracic curves. Retrospective series from scoliosis referral centers are always biased in favor of more severe disease so that mild cases are not included in the studies, thereby giving a lower-than-actual prevalence.[63]

The most useful studies are those that screen large numbers of adolescent children without a case selection bias. A large number of studies have been reported in which a school nurse or physician performed a screening physical examination of a specific age group of children.* Unfortunately, many of these studies then reported a prevalence of scoliosis without obtaining a spinal radiograph or specifying whether or not the scoliosis was of a certain minimal magnitude. These studies have been summarized and are presented in Table 1-1. Although the popular forward bending test[70] was used by all the investigators as clinical evidence for possible scoliosis, there is considerable variation, with the reported prevalence varying from 0.07% to 8.5%. Either the different examiners had varying sensitivities for calling minimal asymmetries of the thorax abnormal or there might be population differences in the frequency of scoliosis. Even when the scoliosis is confirmed radiographically, there is considerable variation in the prevalence of small curves. If a 5 degree curvature is used as the minimal size for a scoliosis, the prevalence rate is still in a widely varying range from 1.2% to 16.0% (Table 1-2). The data in the original articles were carefully reviewed and frequently recalculated for Tables 1-2 through 1-8 to allow comparison between studies with consistent presentation of the data. With a minimum Cobb angle of 10 degrees for scoliosis as recommended by the Scoliosis Research Society, the prevalence is a more consistent 1.5% to 2.7% for ten studies, but five other studies have a range of 0.03% to 10.3% (Table 1-3). Only for the clinically more significant curves (over 20 degrees) is the prevalence a more consistent 0.3% to 0.6% (Table 1-4).

This variation in scoliosis prevalence might reflect differing methodologies but is more likely the result of different frequencies of scoliosis among population groups. Several small studies indicate that racial differences do exist, with a 0.5% prevalence for Lapps and 1.5% prevalence for non-Lapps in Norway,[109] a 2.5% prevalence for whites and a 0.03% prevalence for blacks in South Africa[104] and a 6.2% prevalence at one site (more than twice that at three other locations) in Greece.[111] In contrast, the large study of Shand and Eisberg[106] found no significant difference in the prevalence of scoliosis between whites and blacks. Since scoliosis has a definite familial tendency, it is not surprising that studies in different geographic regions give different frequencies of scoliosis.

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*See references 2, 4, 9, 14, 23, 27, 30, 39, 41, 43-45, 49, 65, 68, 74, 82, 86, 92, 98, 104, 105, 110, 112, 115, 118, 125, 127.

TABLE 1-1
Scoliosis prevalence based on positive screening physicals

Authors	*Year*	*Place*	*Age group (yr)*	*Number screened*	*Prevalence (%)*
Cronis and Russell	1965	Delaware	6-18	68,301	0.07
Wynne-Davies	1968	Edinburg, U.K.	8-18	7,894	0.22
Baker and Zanyger	1970	Arizona	10-14	125	2.40
Grant et al.	1973	El Paso, Texas	5-18	6,058	0.83
Weiler	1974	Pennsylvania	12-14	8,096	2.80
Sells and May	1974	Seattle, Washington	12-15	3,096	1.60
Golomb and Taylor	1975	Sydney, Australia	10-15	3,299	8.50
Hensinger et al.	1975	Delaware	6-18	316,002	0.15
Flynn et al.	1977	Florida	13-15	38,710	1.80
Benson et al.	1977	Sacramento, California	10-14	7,815	1.50
Asher et al.	1980	Kansas	10-13	379,034	3.20
McCarthy et al.	1983	Little Rock, Arkansas	10-14	11,700	1.96

TABLE 1-2
Scoliosis prevalence: curves over 5 degrees

Authors	*Year*	*Place*	*Age group (yr)*	*Number screened*	*Prevalence (%)*
Brooks et al.	1975	California	12-14	3,492	13.6
Newman and Dewald	1977	Chicago, Illinois	14-18	861	16.0
Drennan et al.	1977	Denver, Colorado	11-12	15,904	3.4
Rogala et al.	1978	Montreal, Canada	12-14	26,947	4.5
Smyrnis et al.	1979	Athens, Greece	11-12	3,497	5.0
Goldberg et al.	1980	Dublin, Ireland	9-14	604	15.3
O'Brien	1980	Oswetry, England	11-14	903	3.3
Cooke et al.	1980	London, England	12-15	125	12.3
Willner	1982	Malmo, Sweden	7-16	17,181	2.8
Lonstein et al.	1982	Minnesota	10-14	1,393,553	1.2