Osteopathic Family Physician (2013) 5, 158–168

ELSEVIER

acofp Osteopathic Family Physician

A review of the evaluation, diagnosis, and nonsurgical treatment of adolescent idiopathic scoliosis

Brandon Raudenbush, DO,[a] Ashley Simela, DO,[a] Hans Joseph, DO[b]

From [a]Orthopedic Surgery Resident, University Hospital's Richmond Medical Center, Cleveland, OH; and [b]Orthopedic Surgery Resident, Millcreek Community Hospital, Erie, PA.

KEYWORDS:
Scoliosis;
Idiopathic;
Nonoperative treatment;
Assessment;
Adolescent;
Brace therapy

Adolescent Idiopathic Scoliosis is a relatively common orthopedic condition, affecting approximately 0.5%-3.0% of the pediatric population. Although the condition is often self-limiting, the consequences of a late or delayed diagnosis, coupled with the potential for rapid progression of the deformity, make the detection and treatment of AIS critical for a satisfactory patient outcome. The scope of this article is to review the natural history, etiology, diagnostic workup, and nonoperative treatment options available for Adolescent Idiopathic Scoliosis.

Introduction

Idiopathic Scoliosis (IS) is defined as a lateral curvature of the spine greater than 10^0, measured via the Cobb method. To be defined as idiopathic, the vertebral rotation must occur in the absence of any congenital spinal anomaly or an associated neuromuscular condition.[3-7] Although defined as a lateral or coronal curvature, scoliosis is in fact a 3-dimensional phenomena and deformity. Through spinal motion coupling, not only is scoliosis a lateral spinal curvature, but it is also associated with vertebral rotation as well as flexion and extension.[8-10]

A lordosis or hypokyphosis at the apical vertebra in the thoracic spine is seen as the initial insult. Adams, an English physician and surgeon, was the first to describe this in 1865 while performing autopsies on patients with scoliosis.[10] He observed that the rotational prominence, or rib hump, was made worse by forward bending (Adams Forward Bend Test).

Corresponding author: Brandon Raudenbush, DO, Orthopedic Surgery Resident, University Hospital's Richmond Medical Center, Cleveland, OH 44143.

E-mail address: brandonraudenbush@yahoo.com.

1877-573X/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.osfp.2013.01.009

Scoliosis: Classifications

Scoliosis is divided into 3 broad categories: *Idiopathic*, *Congenital*, and *Neuromuscular*.[11,12] IS was classified according to the age of onset by James in England in 1954.[13] These include *Infantile* (birth to 3 years), *Juvenile* (4-9 years), and *Adolescent Idiopathic Scoliosis* (AIS) (>10 years old).[5,13,14] IS is the most common form of scoliosis, comprising close to 80% of cases. It is distinguished from the other 2 major types of scoliosis, congenital and neuromuscular, by its unknown etiology.

Congenital scoliosis occurs as a result of abnormal growth and development of the vertebral column, likely due to intrauterine events at or about the sixth week of gestation.[15] Neuromuscular scoliosis is often identified in pediatric patients with neurologic and myopathic diseases, such as cerebral palsy, among others.[16] It is characterized by an early onset with rapid progression even after skeletal maturity. The curves are often long, extend into the sacrum, and have an associated pelvic obliquity[11,16-18] (Figure 1).

A fourth category of scoliosis is occasionally referred to in some texts, called a *functional* scoliosis. This encompasses conditions causing a *relative* scoliosis including postural changes secondary to muscles spasms and short leg

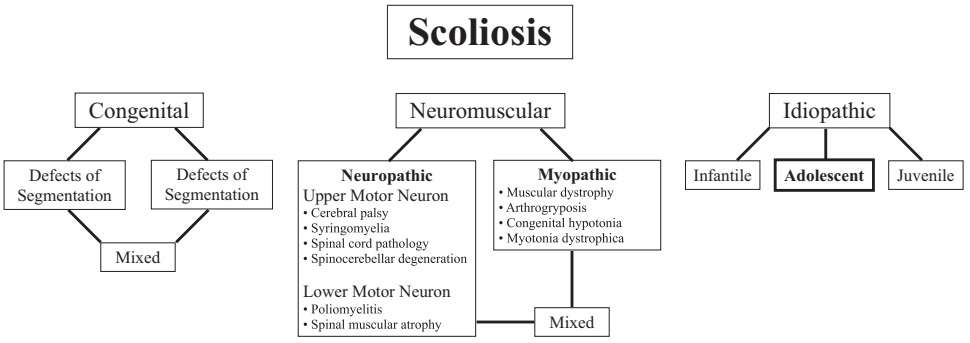

Figure 1 Scoliosis classification.

syndrome, among others, and is not truly due to an abnormality of the spinal column.[1,19,20]

In recent years, the classification for IS has changed slightly. More emphasis has been placed on pulmonary development in relation to the onset of scoliosis, with the threshold of 5 years being critical for lung development.[7,21-23] This has led to reclassifying IS as either *early onset* (before age 5) or *late onset* (after age 5), with AIS falling into the latter category.[23]

Etiology, epidemiology, and natural history

Several theories exist as to the etiology of AIS, however none have been proven definitively. The role of genetic factors has been widely accepted, but the exact mode of inheritance and specific gene locations have not been determined.[24-26] Due to an increased risk among first-degree relatives of patients with IS, as well as the high concordance rate among monozygous twins, it appears some form of autosomal inheritance pattern with incomplete penetrance is occurring.[27] A positive family history for scoliosis is observed in anywhere between 10%-30% of patients referred for medical evaluation.[1,14,27]

A DNA-based test that incorporates 53 genetic markers has recently become available in late 2009 to help determine those patients who are at higher risk of curve progression.[28] The test is not fully incorporated into most orthopedic practices, however, but hopes are that it would help avoid costly follow-up visits and excessive radiation exposure to those at a lower risk of progression.[29] More research is being conducted in hopes to perfect future treatment algorithms using genetic testing such as this.

AIS comprises the vast majority of the 'idiopathic' cases of scoliosis. It is estimated that Infantile Idiopathic Scoliosis accounts for only 0.5% of all cases, and that for Juvenile Idiopathic Scoliosis, it ranges from 8%-16% of cases. Interestingly, the male-to-female ratio of mild curves in AIS is approximately 1:1. However, for larger and more significant curves, females predominate males by a ratio of 6:1, and according to some literature, upward to 8:1.[30,31] Although there is no complete agreement, most clinicians view *significant curves* as those that are greater than 40^0 at skeletal maturity, or greater than 20^0 if the patient is skeletally immature.[1,31]

The term *progression* in scoliosis refers to an increase in curve magnitude of greater than 5^0 from the original presenting curve. This is due to the measurement error of $3\text{-}4^0$ that can occur with the Cobb method. With the prevalence of IS estimated to be only 0.5%-3%, the actual number of patients that would go on to develop a significant curve is even smaller, roughly 0.1% or 1 in every 1000 AIS patients.[1,2] This is a substantially lower risk than that seen in Juvenile Idiopathic Scoliosis, which carries approximately a 70% chance of requiring some form of treatment.[5]

Risk factors that have been well associated with curve progression in IS deal primarily with indicators of skeletal immaturity. It has been documented that periods of rapid growth in adolescence, specifically the *peak height velocity* of the growth phase, can potentially lead to great increases in curve magnitude, thus requiring strict and periodic observation by the physician.[1,30-34] Other risk factors for progression include the initial Cobb angle at presentation, curve pattern, vertebral rotation, and most importantly, female gender[1,30-33,35,43] (Figure 2).

School screening programs

In the last fifty years, screening programs for scoliosis have been implemented in the hopes of early diagnosis and treatment to decrease curve progression and severity. These programs were first instituted in the 1960s.[31] The utility of these screenings has been called into question.[44,45] Specifically, the United States Preventive Services Task Force issued an update in 2004, giving a grade D recommendation for routine screening (recommends against routine screening),

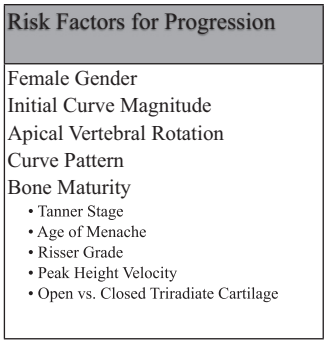

Figure 2 Risk factors for curve progression.

feeling that there has been an overreferral to specialists.[46] This was a change from the United States Preventive Services Task Force 1996 recommendation that was inconclusive and did not favor for or against screening.[46]

However many experts and expert panels disagree, including those from the American Academy of Orthopaedic Surgeons, the Scoliosis Research Society, the Pediatric Orthopaedic Society of North America, and the American Academy of Pediatrics.[47-49] These societies admit that more standardized research is needed, but recommend continued screening, especially during periods of rapid growth.[31,48] Screening allows for referral of high-risk patients, and early intervention that can potentially avoid operative treatment and spinal fusion. For this reason, focused or selective screening is recommended at least twice for females (at the age of 10 and 12 years, or in grades 5 and 7), and at least once for males (at the age of 13 or 14 years, or in grades 8 or 9).[48]

Clinical assessment

The clinical assessment of patients with AIS begins with a thorough and detailed history. Close attention should be paid to the patient demographics, including current age, gender, menses status, and the original reason for seeking medical evaluation. The presence of significant back pain, which is not typical in IS, should raise concern.[50,51] This must be distinguished from the routine aches and pains of musculoskeletal fatigue and mechanical low back pain, the presence of which is only slightly increased in AIS than in the general population of adolescent patients.[50,52,53] Signs of pathologic back pain require further investigation to rule out potentially devastating conditions such as tumor, infection, or neurologic abnormalities.[51] One must remember that adolescent IS is a diagnosis of exclusion.

Following a thorough history, the physical examination should commence with inspection of the patient, noting any dermatologic findings such as café au lait spots or axillary freckling seen in neurofibromatosis, abnormal hair growth or distribution as seen in spina bifida, or abnormal skin dimpling seen in other spinal dysraphisms (neural tube defects such as syringomyelia).[51]

A thorough neurologic examination should be performed and compared with the contralateral side, including gait evaluation, heel-and-toe walking, deep tendon reflex testing, and muscle strength testing. Additional neurologic testing includes the abdominal reflex, Babinski reflex, and other upper motor neuron tests looking for spinal cord pathology.[14] Positive findings with any of these tests require further workup with an MRI of the spine to rule out spinal cord pathology.[51]

Inspection of the patient from the posterior to anterior view is performed next. The Adams forward bend test is a quick, easy, and sensitive method that has been used in school screening programs for many years.[31] This test is used to assess both truncal rotation and sagittal contour. The patient bends forward with the knees fully extended, feet together, and the palms opposed until the spine is horizontal.[14,19,54] Truncal rotation can be visualized in this position as well as measured with an inclinometer or scoliometer. Approximately 7^0 of angle trunk rotation equilibrates to about 20^0 of coronal deviation (Cobb angle) and justifies referral to a spine specialist with relatively few false-positive results and a reduction in overreferring[3,31,55] (Figure 3).

Other key areas of the patient that should be assessed during the physical examination include determining the level and position of the occiput, scapula, iliac crests, posterior superior iliac spines, anterior superior iliac spines, greater trochanters, and maleoli. These areas can alert a physician to somatic dysfunctions such as leg-length inequality and short leg syndrome, psoas syndrome and contracture, lumbosacral dysfunction, or sacral shear. All of these conditions can mimic or give the appearance of a lumbar scoliosis, but are not commonly found in AIS.[20,46]

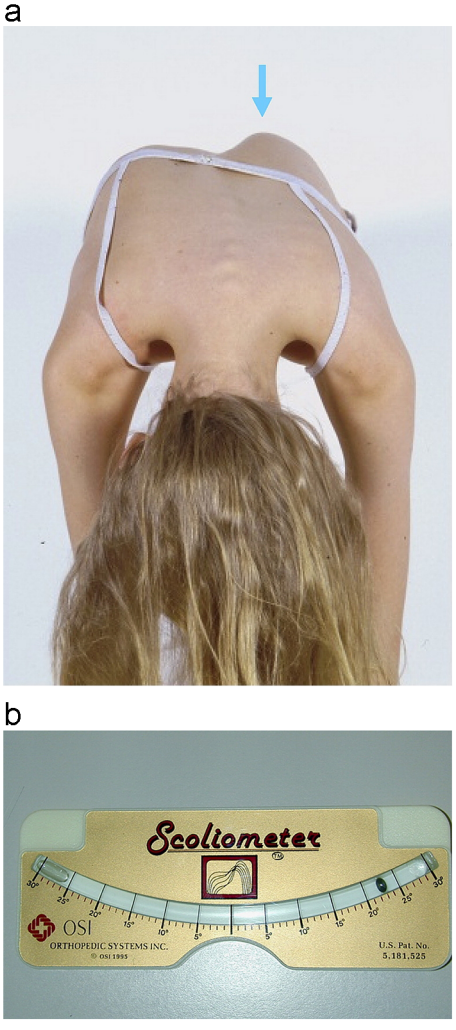

Figure 3 Adams Forward Bend Test (A) The patient bends forward at the waist with the arms relaxed and legs fully extended while the physician inspects from a posterior to anterior view. (B) Scoliometers can be used and are placed at the location of the rib hump; 7^0 = clinically significant curves that require follow-up.

Radiographic assessment

The definitive diagnosis of scoliosis lies within the imaging studies. Many radiographic measurements are used to assess scoliosis, with more than fifteen parameters having been described in the past.[42] Most commonly, the radiographic assessment begins with full-length standing PA and lateral radiographic views of the spine on a 14 × 36-in film with the image intensifier positioned 72 in away from the patient and the patient standing erect with the elbows and knuckles rested into the supraclavicular fossa[56,57] (Figure 4). More commonly, with digital imaging, two 14 × 17-in films are used and 'stitched' together electronically.[56]

The Cobb method for measuring the extent of coronal plane deformity is similar to the earlier Ferguson method described in 1930.[3,58,59] Despite their similarities, the Cobb angle is most widely used today.[58] This involves finding the angle formed by the intersection of perpendicular lines that are parallel to the superior end plate of the most superior vertebra, and to the inferior end plate of the most inferior vertebra of the curve.[3,60] It is important to remember to be consistent with all future measurements, and to assess the same vertebral bodies each time (Figure 5 A and B).

The standard PA radiographic view not only allows for the Cobb angle to be determined, but also allows for the curve to be described based on the coronal plane deformity and the extent of the vertebral rotation. Curves are named in the direction of their respective convexity with multiple curve patterns existing, including thoracic, lumbar, thoracolumbar, cervicothoracic, cervical, and lumbosacral. Apical vertebral rotation has been described well in the past, by Cobb, Nash and Moe, as well as Perdriolle, and also signifies the aggressiveness of the curve and potential for progression[3,32,43,61,62] (Figure 5C).

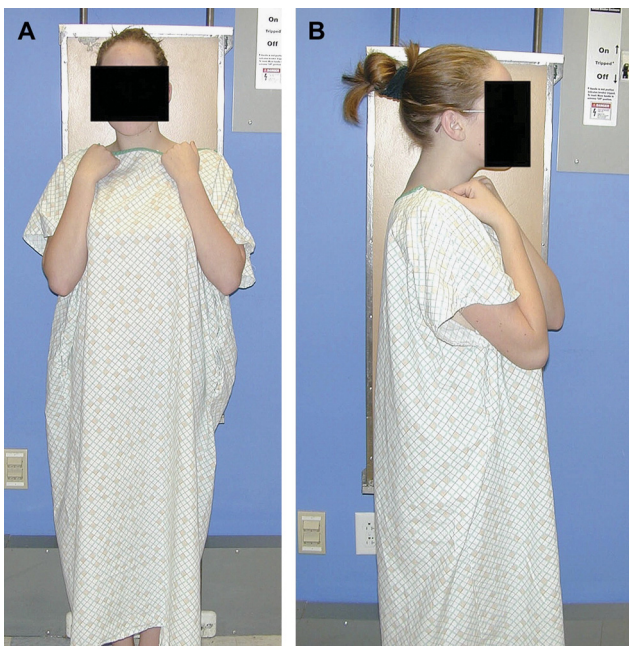

Figure 4 Full-length PA and lateral radiographs of the spine (A) The PA view was traditionally taken with 36-in film with the image intensifier at a distance of 72 in. (B) The lateral view is obtained in the same fashion, with the patient's hands in the supraclavicular fossa.

In the recent past, the classification system describing curve types and patterns has been changed. The curve characteristics as well as the amount of arthrodesis required for surgically treating AIS has been revolutionized by the introduction of the Lenke classification.[63] This newer classification is based on multiple curve characteristics and replaces the older and less reproducible King classification[63,64] (Figure 6).

The full-length lateral radiograph is used to assess any sagittal plane deformity and for assessing spinal balance.[14,54] The sagittal plane depicts the amount of kyphosis or lordosis that is in the vertebral column. In AIS, a lordosis or hypokyphosis of the thoracic spine is usually present, particularly at the apex of the curve or apical vertebrae.[54,65] If there is increased thoracic kyphosis, further evaluation is warranted as this is atypical for AIS and is one of the most sensitive indicators for underlying neuronal disease.[51,54]

The term *spinal balance* refers to the even distribution of weight over the sacrum and pelvis. This applies to both the sagittal and coronal planes, and is determined by drawing a plumb line in both vertical axes. To determine the coronal spinal balance, a plumb line is suspended from the inion or vertebra prominens to the sacrum. The line should lie within 1 cm of the middle of the sacrum. Plumb lines lying to the left of the center of the sacrum are said to have *negative coronal balance* and those to the right are said to have *positive coronal balance*.[56]

To determine sagittal spinal balance, also called the sagittal vertical axis (SVA), a plumb line is suspended from the center of C7 inferiorly through the sacrum on the lateral radiograph. This line should lie within 2.5 cm of the posterior superior corner of S1. If the line is posterior to the L5-S1 disc space, it is considered *negative sagittal balance*; if it lies anterior to the L5-S1 disc space, it is considered *positive sagittal balance*. The sagittal vertical axis (SVA) should be neutral in the balanced spine[56,66] (Figure 7).

Skeletal maturity

The iliac apophysis, or Risser sign, has been studied extensively in the past, and is used as a relatively good indicator of skeletal maturity.[1,30,34,36-40,42,55,67-70] Skeletal maturity guides treatment and is used as an indicator for the risk of curve progression. The iliac apophysis is the secondary ossification center of the iliac crest. Ossification begins at the anterior superior iliac spine and continues along the iliac crest from an anterior to posterior direction. Ossification is completed most posteriorly, at the posterior superior iliac spine. Skeletal maturity can be assessed by reviewing the radiographs already obtained for the Cobb angle measurement and finding a Risser score. The average chronologic age when the apophysis is completed is 14 years in females and 16 years in males[67,71] (Figure 8).

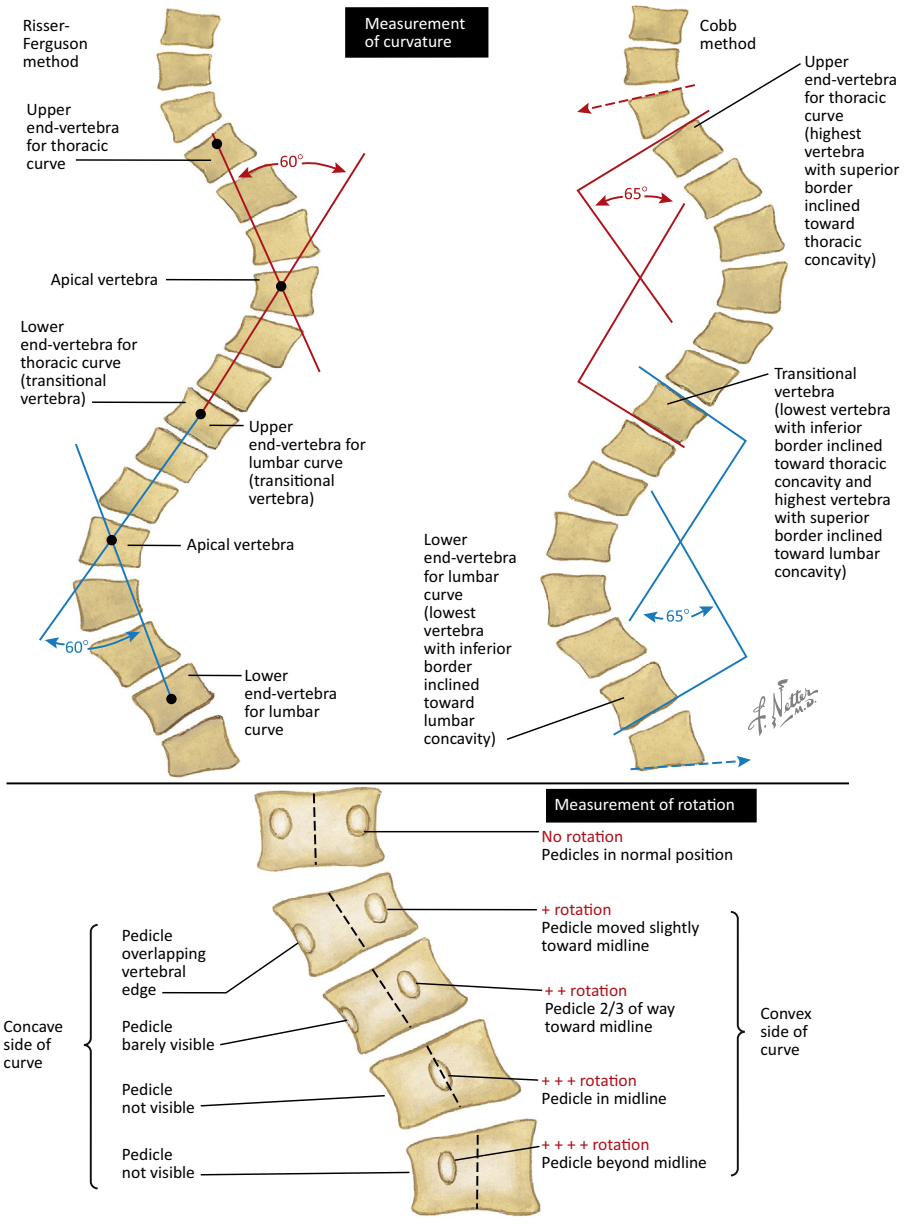

Figure 5 Measuring the curvature and the rotation of the spine (A) The Ferguson method that is no longer typically used. (B) The Cobb method, most popular among clinicians worldwide. (C) Vertebral rotation increases with increasing curve magnitude; it can be noted that as rotation increases, less of the pedicle is visible.

However, the utility of the Risser sign has been called into question as the majority of curve progressions occur at a Risser sign of 0-1, during the patient's peak height velocity. During this time of rapid growth, the scoliosis can progress dramatically and the Risser sign has been faulted as being too late an indicator of skeletal maturity. Regardless, Risser sign is still considered by many to be a useful radiographic marker of skeletal maturity.[70]

The radiographic appearance of the triradiate cartilage (TRC) is also an indicator of skeletal maturity.[14,41,42,72] The triradiate cartilage is an epiphyseal growth plate cartilage complex of the 3 secondary ossification centers of the acetabulum; the ilium, ischium, and pubis.[73] On average, the TRC fuses between the ages of 11 and 13 years, and is usually closed shortly before the Risser 1 is first apparent[72] (Figure 9).

Other methods of determining skeletal maturity, or *bone age,* are used as well.[74] The Greulich and Pyle method was developed in the late 1950s and is a radiographic atlas of standardized hands and wrists of both sexes, but was limited to Caucasian subjects only.[75] A newer Tanner-Whitehouse-III RUS method has been published, which studies the radiographic features of the distal Radius, Ulna, and Small bones of the hands, similar to the Greulich and Pyle method.[76]

Some researchers find this method too complex, with the need of an experienced pediatric radiologist to interpret the findings.[76,77] Sanders et al. developed a

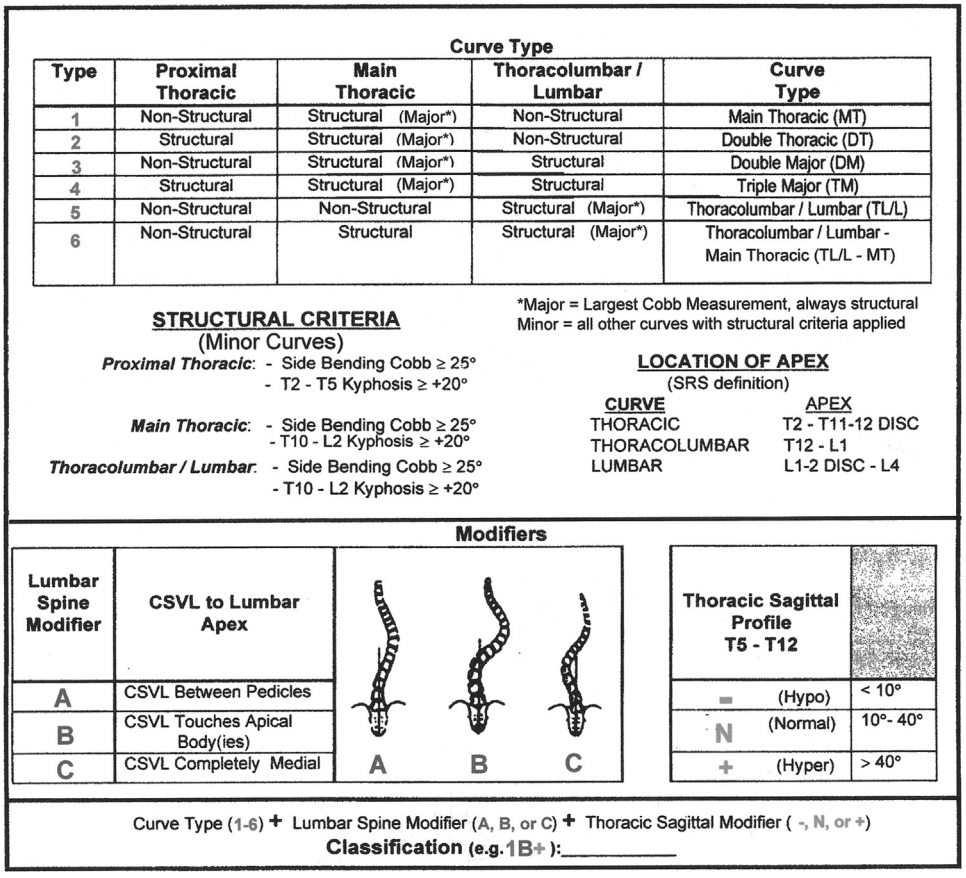

Figure 6 The Lenke classification. (The classification that has been adopted by spine surgeons for determining the amount of arthrodesis needed for adequate curve correction, stability, and balance.) Used with permission from Lenke LG, Betz RR, Harm J, et al. Adolescent Idiopathic Scoliosis: A new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg Am*. 2001;83-A(8):1169-1181

simplified version of using the Tanner-Whitehouse method in 2008 that has been found to be both fast and reliable.[76] The search for a better radiographic marker of skeletal maturity continues, with research into using a variation of the radiographic appearances of the olecranon first described by Sauvegrain, as well as other methods[41] (Figure 10).

Treatment options

Guidelines for treating AIS are based primarily on the initial curve severity and the amount of remaining skeletal growth. It is important to note that scoliosis, unlike spinal asymmetry, does not improve with time. Curves greater than 20^0 in those who are skeletally immature should be observed with radiographs on a routine basis, typically every 6 months until skeletal maturity. Alternatively, if no progression occurs and if other testing confirms a low likelihood of progression (DNA testing) or the patient is approaching skeletal maturity, x-rays can be discontinued.[28,29] Although there still remains controversy, most experts agree that patients with curves more than 25^0 in the skeletally immature patient should be offered some form of an orthosis and brace treatment.[5,14,78-80]

Orthotics

Scoliosis treatment has been performed for more than 2 millennia, with Hippocrates describing a distraction apparatus for deformity correction in the fifth century BC.[10,81] Brace treatment and design has exploded during the last 30 years, with more orthotic devices on the market than ever before.[80,81] The theory of brace treatment is to overcorrect the coronal plane deformity in an attempt to stop further progression. This corresponds to a direct type of Osteopathic Balanced Ligamentous tension technique and is obtained with various brace devices depending on the location of the curve apex. The time required for theoretical correction varies depending on each device (Figure 11).

Some argue, however, that a 2-dimensional orthosis is not effective for correcting a 3-dimensional spine deformity.[26] The decision to brace can be quite troubling for both families and physicians. This is due to the psychological effect of wearing a brace, as well as the conflicting evidence of brace efficacy and the possible need for later surgery despite brace compliance.[79,82-88]

Brace-effectiveness studies are quite hard to control in terms of randomization, brace wear time (night time vs 23-hour bracing), and patient compliance.[89] Because of a universal lack of consistency, a new criteria for AIS bracing was

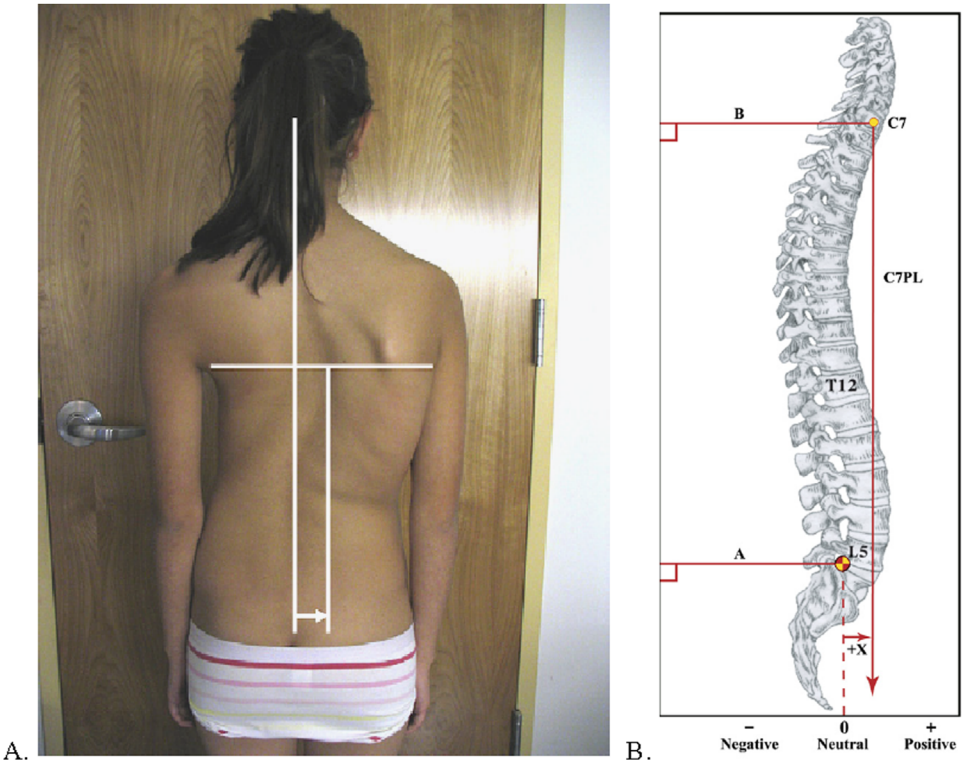

Figure 7 Spinal balance (A) Coronal balance is maintained in this patient because of a compensatory thoracolumbar curve, allowing the patient's occiput to rest over the sacrum and in line with the natal cleft. (B) Sagittal balance refers to the position of the C7 vertebrae in relation to the sacrum, and can be negative, neutral, or positive.

introduced in 2005 in a hope to help standardize future studies.[90] A multicenter partially randomized prospective study that is finishing data collection in August 2012 hopes to finally determine if bracing is effective in AIS.[91] The ***Br****acing for* ***A****dolescent* ***I****diopathic* ***S****coliosis* ***T****rial*, or BrAIST, will attempt to clarify the efficacy of orthotic treatment for AIS.[91]

Manipulation and modalities

The concept of manipulative medicine and other physical therapy or modalities to correct scoliosis has been promoted by some groups and nonoperative practitioners, especially in the European literature.[92-96] Similar to bracing treatment,

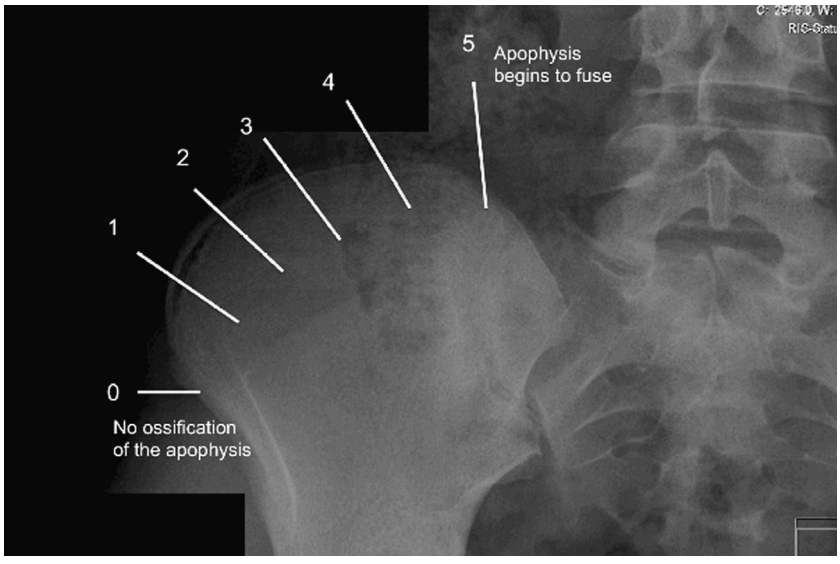

Figure 8 The Risser grading system. (The appearance of the iliac apophysis is referred to by a grade of 1 and signifies skeletal immaturity; fusion of the apophysis is a grade of 5 and signifies skeletal maturity.)

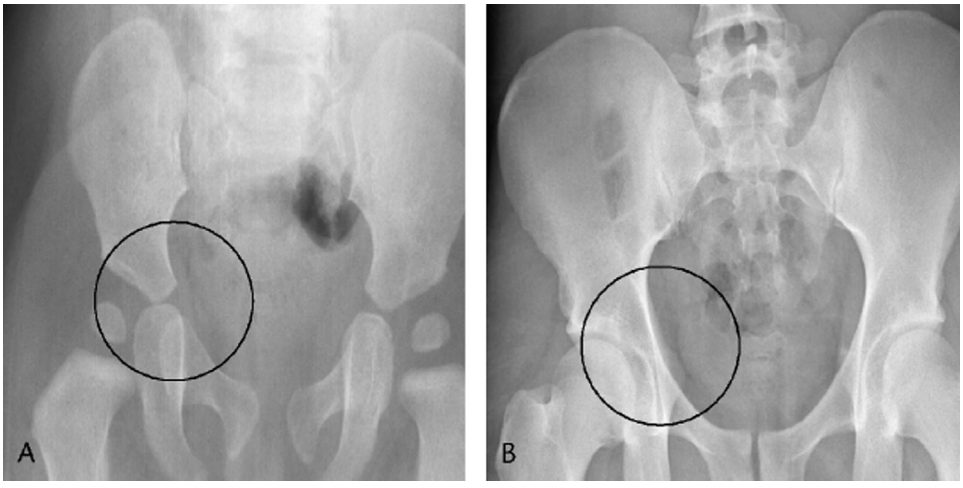

Figure 9 The triradiate cartilage (A) An immature TRC. (B) A mature and fused TRC.

there are limited high-quality studies to substantiate therapy or modality use to prevent further progression of scoliosis. Several studies have found little benefit with these treatments; however the use of such therapies may be of benefit for overall health, fitness, core strengthening, or symptom relief.[19,78,97-99]

Surgery indications

It is seen that the early onset subgroup of IS has the greatest risk of progression and likely need for surgical intervention. This is done to prevent associated cardiopulmonary complications that occur with curves greater than 70^0.[21,22,100] In AIS patients, curves that are $>50^0$ are usually recommended for surgery because of the likely progression throughout adulthood.[14] Surgical indications cannot be taken lightly, as there can be approximately a 15% nonneurologic complication rate (bleeding, wound infection, and ileus) as well as the potential for new neurologic deficits after surgery[101-103] (Figure 12).

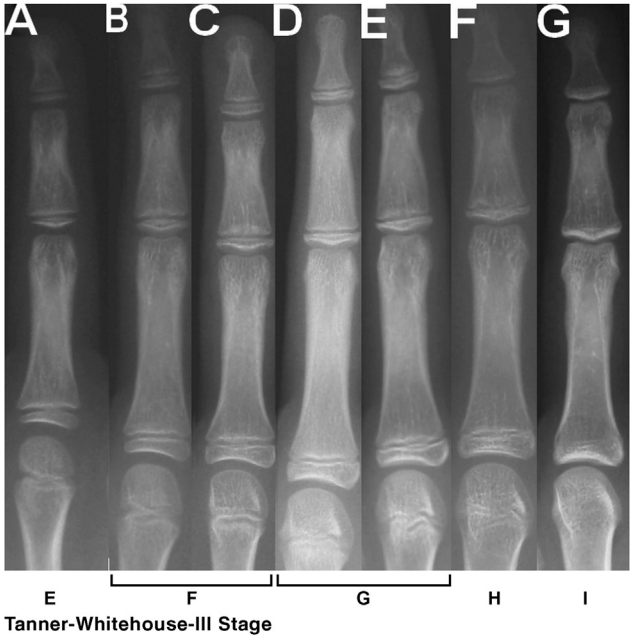

Figure 10 Tanner-Whitehouse-III stage. (Examples of digital skeletal maturation is seen here in the middle phalanx. Please refer to the original article for a complete description.)

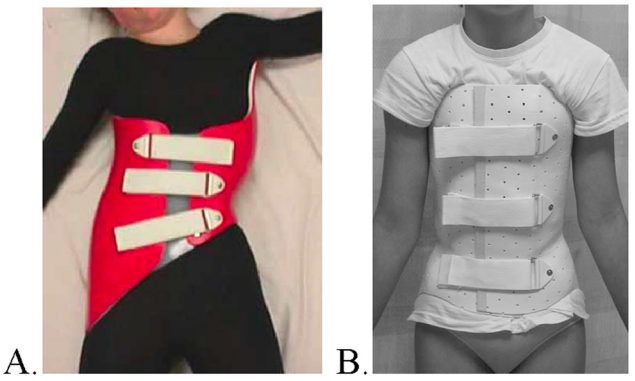

Figure 11 Spinal orthoses (A) The providence night time brace; by overcorrecting the curve it is believed that orthotic wear can be limited to the night. (B) The Wilmington Brace.

Curve Magnitude	Skeletal Maturity	Treatment
0-24°	Immature	Observation
25-40°	Immature	Bracing
>45°	Immature	Surgery
>50°	Mature	Surgery

Figure 12 Treatment guidelines.

Conclusions

AIS is relatively common in the pediatric population. The guiding factors for the diagnosis, initial nonsurgical treatment, and possible surgical treatment of AIS are based on many factors, primarily those concerning skeletal maturity and the potential for the risk of rapid and future progression. Although there is limited level I evidence for bracing or other nonsurgical treatment options, current and future studies hope to elicit treatment algorithms to separate those patients at highest risk of progression.

References

1. Bunnell WPMD. The natural history of idiopathic scoliosis. *Clin Orthop Relat Res*. 1988;229:20–25
2. Weinstein SL. Idiopathic scoliosis. Natural history. *Spine*. 1986;11(8): 780–783
3. Cobb JR. Outline for the study of scoliosis. *Instr Course Lect*. 1948;5:261–275
4. Cobb JR. Scoliosis; quo vadis. *J Bone Joint Surg Am*. 1958;40-A(3): 507–510
5. Lenke LG, Dobbs MB. Management of juvenile idiopathic scoliosis. *J Bone Joint Surg Am*. 2007;89(suppl 1):55–63
6. *Scoliosis Research Society*. Scoliosis research society Adolescent idiopathic scoliosis: causes. http://www.srs.org/professionals/conditions_and_treatment/adolescent_idiopathic_scoliosis/causes.htm. Updated 2012 Accessed May 21, 2012.
7. Dickson RA. Basic principles of scoliosis treatment. In: Newton PO, O'Brien MF, Shufflebarger HL, Betz RR, Dickson RA, Harms J, eds. *Idiopathic Scoliosis: The Harms Study Group Treatment Guide*, 1st ed. New York, NY: Thieme Medical Publishers Inc.; 2010:17–27
8. Deacon P, Flood BM, Dickson RA. Idiopathic scoliosis in three dimensions. A radiographic and morphometric analysis. *J Bone Joint Surg Br*. 1984;66(4):509–512
9. Deacon P, Archer IA, Dickson RA. The anatomy of spinal deformity: a biomechanical analysis. *Orthopedics*. 1987;10(6):897–903
10. Dickson RA. History of the treatment of scoliosis. In: Newton PO, O'Brien MF, Shufflebarger HL, Betz RR, Dickson RA, Harms J, eds. *Idiopathic Scoliosis: The Harms Study Group Treatment Guide*, 1st ed. New York, NY: Thieme Medical Publishers Inc.; 2010:1–16
11. Aronsson DD, Stokes IA, Ronchetti PJ, Labelle HB. Comparison of curve shape between children with cerebral palsy, friedreich's ataxia, and adolescent idiopathic scoliosis. *Dev Med Child Neurol*. 1994; 36(5):412–418
12. Goldstein LA, Waugh TR. Classification and terminology of scoliosis. *Clin Orthop*. 1973;93:10–22
13. James JI. Idiopathic scoliosis; the prognosis, diagnosis, and operative indications related to curve patterns and the age at onset. *J Bone Joint Surg Br*. 1954;36-B(1):36–49
14. Kim HJ, Blanco JS, Widmann RF. Update on the management of idiopathic scoliosis. *Curr Opin Pediatr*. 2009;21(1):55–64
15. Hedequist D, Emans J. Congenital scoliosis. *J Am Acad Orthop Surg*. 2004;12(4):266–275
16. McCarthy RE. Management of neuromuscular scoliosis. *Orthop Clin North Am*. 1999;30(3):435–449. [viii]
17. Tsirikos AI, Chang WN, Dabney KW, Miller F, Glutting J. Life expectancy in pediatric patients with cerebral palsy and neuromuscular scoliosis who underwent spinal fusion. *Dev Med Child Neurol*. 2003;45(10):677–682
18. Lonstein JE, Akbarnia A. Operative treatment of spinal deformities in patients with cerebral palsy or mental retardation. An analysis of one hundred and seven cases. *J Bone Joint Surg Am*. 1983;65(1): 43–55
19. Kuchera ML. Postural considerations in coronal, horizontal, and sagittal planes. In: Ward RC, Hruby RJ, Jerome JA, eds. *Foundations for Osteopathic Medicine*, 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2003:603–632
20. Irvin RE. Reduction of lumbar scoliosis by use of a heel lift to level the sacral base. *J Am Osteopath Assoc*. 1991;91(1):34–44
21. Dickson RA, Deacon P. Spinal growth. *J Bone Joint Surg Br*. 1987;69(5):690–692
22. Dimeglio A. Growth in pediatric orthopaedics. *J Pediatr Orthop*. 2001;21(4):549–555
23. Dickson RA. Conservative treatment for idiopathic scoliosis. *J Bone Joint Surg Br*. 1985;67(2):176–181
24. Wajchenberg M, Lazar M, Cavacana N, et al: Genetic aspects of adolescent idiopathic scoliosis in a family with multiple affected members: a research article. *Scoliosis*. 2010;5:7
25. Qiu XS, Tang NL, Yeung HY, Qiu Y, Cheng JC. Genetic association study of growth hormone receptor and idiopathic scoliosis. *Clin Orthop*. 2007;462:53–58
26. Dickson RA. Pathogenesis of idiopathic scoliosis. In: Newton PO, O'Brien MF, Shufflebarger HL, Betz RR, Dickson RA, Harms J, eds. *Idiopathic Scoliosis: The Harms Study Group Treatment Guide*, 1st ed. New York, NY: Thieme Medical Publishers Inc.; 2010:28–50
27. Cheng JC, Tang NL, Yeung HY, Miller N. Genetic association of complex traits: using idiopathic scoliosis as an example. *Clin Orthop*. 2007;462:38–44
28. Ogilvie J. Adolescent idiopathic scoliosis and genetic testing. *Curr Opin Pediatr*. 2010;22(1):67–70
29. Ward K, Ogilvie JW, Singleton MV, Chettier R, Engler G, Nelson LM. Validation of DNA-based prognostic testing to predict spinal curve progression in adolescent idiopathic scoliosis. *Spine*. 2010; 35(25):E1455–E1464
30. Bunnell WP. The natural history of idiopathic scoliosis before skeletal maturity. *Spine*. 1986;11(8):773–776
31. Bunnell WP. Selective screening for scoliosis. *Clin Orthop*. 2005;434:40–45
32. Perdriolle R, Vidal J. Thoracic idiopathic scoliosis curve evolution and prognosis. *Spine*. 1985;10(9):785–791
33. Tan KJ, Moe MM, Vaithinathan R, Wong HK. Curve progression in idiopathic scoliosis: follow-up study to skeletal maturity. *Spine*. 2009;34(7):697–700
34. Sanders JO, Browne RH, McConnell SJ, Margraf SA, Cooney TE, Finegold DN. Maturity assessment and curve progression in girls with idiopathic scoliosis. *J Bone Joint Surg Am*. 2007;89(1): 64–73
35. Modi HN, Suh SW, Song HR, Yang JH, Ting C, Hazra S. Drooping of apical convex rib-vertebral angle in adolescent idiopathic scoliosis of more than 40 degrees: a prognostic factor for progression. *J Spinal Disord Tech*. 2009;22(5):367–371
36. Wang Q, Yong M, et al: Histologic, risser sign, and digital skeletal age evaluation for residual spine growth potential in chinese female idiopathic scoliosis. *Spine*. 2007;32(15):1648–1654
37. Wang WW, Xia CW, Zhu F, et al: Correlation of risser sign, radiographs of hand and wrist with the histological grade of iliac crest apophysis in girls with adolescent idiopathic scoliosis. *Spine*. 2009;34(17):1849–1854
38. Liu XC, Thometz JG, Lyon RM, Klein J. Functional classification of patients with idiopathic scoliosis assessed by the quantec system: a discriminant functional analysis to determine patient curve magnitude. *Spine*. 2001;26(11):1274–1278
39. Kotwicki T, Negrini S, Grivas TB, et al: Members of the international society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT). Methodology of evaluation of morphology of the spine and the trunk in idiopathic scoliosis and other spinal deformities—6th SOSORT consensus paper. *Scoliosis*. 2009;4:26
40. Kong CK, Tse PW, Lee WY. Bone age and linear skeletal growth of children with cerebral palsy. *Dev Med Child Neurol*. 1999;41(11): 758–765

41. Charles YP, Dimeglio A, Canavese F, Daures JP. Skeletal age assessment from the olecranon for idiopathic scoliosis at risser grade 0. *J Bone Joint Surg Am*. 2007;89(12):2737–2744
42. Kotwicki T. Risser sign: the value of the lateral spinal radiograph to assess the excursion of the iliac apophysis. *Stud Health Technol Inform*. 2008;140:44–47
43. Mehta MH. Radiographic estimation of vertebral rotation in scoliosis. *J Bone Joint Surg Br*. 1973;55(3):513–520
44. Bunge EM, Juttmann RE, van Biezen FC, et al: Netherlands evaluation study on screening for scoliosis (NESCIO) group. Estimating the effectiveness of screening for scoliosis: a case-control study. *Pediatrics*. 2008;121(1):9–14
45. Goldberg CJ, Dowling FE, Fogarty EE, Moore DP. School scoliosis screening and the United States preventive services task force. An examination of long-term results. *Spine*. 1995;20(12):1368–1374
46. Calonge N. Screening for idiopathic scoliosis in adolescents: update of the evidence for the U.S. Preventive Services Task Force. Agency for Healthcare Research and Quality. 2004. Available at http://www.preventiveservices.ahrq.gov.
47. Richards BS, Beaty JH, Thompson GH, Willis RB. Estimating the effectiveness of screening for scoliosis. *Pediatrics*. 2008;121(6): 1296–1297
48. Richards BS, Vitale MG. Screening for idiopathic scoliosis in adolescents. An information statement. *J Bone Joint Surg Am*. 2008;90(1):195–198
49. Richards SB. School screening programs for the early detection of scoliosis. SRS/AAOS position statement web site. http://www.srs.org/professionals/advocacy_and_public_policy/SRS-AAOS_position_statement.htm. Published 2007. Updated 2007 Accessed May 21, 2012.
50. Ramirez N, Johnston CE, Browne RH. The prevalence of back pain in children who have idiopathic scoliosis. *J Bone Joint Surg Am*. 1997;79(3):364–368
51. Davids JR, Chamberlin E, Blackhurst DW. Indications for magnetic resonance imaging in presumed adolescent idiopathic scoliosis. *J Bone Joint Surg Am*. 2004;86-A(10):2187–2195
52. Sato T, Hirano T, Ito T, et al: Back pain in adolescents with idiopathic scoliosis: epidemiological study for 43,630 pupils in Niigata city, Japan. *Eur Spine J*. 2011;20(2):274–279. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=medl&AN=21165657.
53. Bradford DS, Hensinger RN. Back pain in children. In: Hensinger RN, ed. *The Pediatric Spine*, 1st ed. New York, NY: Thieme; 1985:41–60
54. Diab M. Physical examination in adolescent idiopathic scoliosis. *Neurosurg Clin N Am*. 2007;18(2):229–236
55. Bunnell WP. An objective criterion for scoliosis screening. *J Bone Joint Surg Am*. 1984;66(9):1381–1387
56. Kuklo TR. Radiographic evaluation of spinal deformity. *Neurosurg Clin N Am*. 2007;18(2):215–222
57. Crawford AH, Oestreich AE, D'Andrea LP, Heller JE, Cahill P. Clinical and radiographic evaluation of the scoliotic patient. In: Newton PO, O'Brien MF, Shufflebarger HL, Betz RR, Dickson RA, Harms J, eds. *Idiopathic Scoliosis: The Harms Study Group Treatment Guide*, 1st ed. New York, NY: Thieme Medical Publishers Inc.; 2010:60–80
58. Stokes IA, Aronson DD, Ronchetti PJ, Labelle H, Dansereau J. Reexamination of the cobb and ferguson angles: bigger is not always better. *J Spinal Disord*. 1993;6(4):333–338
59. Cobb JR. The problem of the primary curve. *J Bone Joint Surg Am*. 1960;42-A:1413–1425
60. Mehta SS, Modi HN, Srinivasalu S, et al: Interobserver and intraobserver reliability of cobb angle measurement: endplate versus pedicle as bony landmarks for measurement: a statistical analysis. *J Pediatr Orthop*. 2009;29(7):749–754
61. Nash Jr CL, Moe JH. A study of vertebral rotation. *J Bone Joint Surg Am*. 1969;51(2):223–229
62. Mehta MH. The rib-vertebra angle in the early diagnosis between resolving and progressive infantile scoliosis. *J Bone Joint Surg Br*. 1972;54(2):230–243
63. Lenke LG, Betz RR, Harms J, et al: Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg Am*. 2001;83-A(8):1169–1181
64. Hosseinpour-Feizi H, Soleimanpour J, Sales JG, Arzroumchilar A. Lenke and King classification systems for adolescent idiopathic scoliosis: interobserver agreement and postoperative results. *Int J Gen Med*. 2011;4:821–825
65. Upendra B, Meena D, Kandwal P, Ahmed A, Chowdhury B, Jayaswal A. Pedicle morphometry in patients with adolescent idiopathic scoliosis. *Indian J Orthop*. 2010;44(2):169–176. http://ovihttp://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=prem&AN=20419004.
66. O'Shaughnessy BA, Ondra SL. Measuring, preserving, and restoring sagittal spinal balance. *Neurosurg Clin N Am*. 2007;18(2):347–356
67. Risser JC. The iliac apophysis; an invaluable sign in the management of scoliosis. *Clin Orthop*. 1958;11:111–119
68. Risser JC. Scoliosis: past and present. *J Bone Joint Surg Am*. 1964;46:167–199
69. Kim YJ, Noonan KJ. What's new in pediatric orthopaedics. *J Bone Joint Surg Am*. 2009;91(3):743–751
70. Nault ML, Parent S, Phan P, Roy-Beaudry M, Labelle H, Rivard M. A modified risser grading system predicts the curve acceleration phase of female adolescent idiopathic scoliosis. *J Bone Joint Surg Am*. 2010;92(5):1073–1081
71. Greiner KA. Adolescent idiopathic scoliosis: radiologic decision-making. *Am Fam Physician*. 2002;65(9):1817–1822
72. Ryan PM, Puttler EG, Stotler WM, Ferguson RL. Role of the triradiate cartilage in predicting curve progression in adolescent idiopathic scoliosis. *J Pediatr Orthop*. 2007;27(6):671–676
73. Ponseti IV. Growth and development of the acetabulum in the normal child. Anatomical, histological, and roentgenographic studies. *J Bone Joint Surg Am*. 1978;60(5):575–585
74. Acheson RM. A method of assessing skeletal maturity from radiographs; a report from the oxford child health survey. *J Anat*. 1954;88(4):498–508
75. Greulich WW, Pyle SI. *Radiographic Atlas of Skeletal Development of the Hand and Wrist*, 2nd ed. Stanford, CA: Stanford University Press; 1959
76. Sanders JO, Khoury JG, Kishan S, et al: Predicting scoliosis progression from skeletal maturity: a simplified classification during adolescence. *J Bone Joint Surg Am*. 2008;90(3):540–553. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=medl&AN=18310704.
77. Proos LA, Lonnerholm T, Jonsson B, Tuvemo T. Can the TW3 bone age determination method provide additional criteria for growth hormone treatment in adopted girls with early puberty? A comparison of the tanner-whitehouse 3 method with the greulich-pyle and the tanner-whitehouse 2 methods. *Horm Res Paediatr*. 2010;73(1):35–40
78. *Scoliosis Research Society*. Scoliosis research society Adolescent idiopathic scoliosis: treatment. http://www.srs.org/professionals/conditions_and_treatment/adolescent_idiopathic_scoliosis/treatment.htm. Updated 2012 Accessed May 21, 2012.
79. Nachemson AL, Peterson LE. Effectiveness of treatment with a brace in girls who have adolescent idiopathic scoliosis. A prospective, controlled study based on data from the brace study of the scoliosis research society. *J Bone Joint Surg Am*. 1995;77(6):815–822
80. Sponseller PD. Bracing for adolescent idiopathic scoliosis in practice today. *J Pediatr Orthop*. 2011;31(1 suppl):S53–S60
81. Fayssoux RS, Cho RH, Herman MJ. A history of bracing for idiopathic scoliosis in North America. *Clin Orthop*. 2010;468(3):654–664. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=medl&AN=19462214.
82. Sponseller PD, Jain A, Lenke LG, et al: Vertebral column resection in children with neuromuscular spine deformity. *Spine*. 2012;37(11): E655–E661
83. Noonan KJMD, Dolan LAMA, Jacobson WCMD, Weinstein SLMD. Long-term psychosocial characteristics of patients treated for idiopathic scoliosis. *J Pediatr Orthop*. 1997;17(6):712–717

84. Korovessis P, Kyrkos C, Piperos G, Soucacos PN. Effects of thoracolumbosacral orthosis on spinal deformities, trunk asymmetry, and frontal lower rib cage in adolescent idiopathic scoliosis. *Spine*. 2000;25(16):2064–2071
85. Janicki JA, Poe-Kochert C, Armstrong DG, Thompson GH. A comparison of the thoracolumbosacral orthoses and providence orthosis in the treatment of adolescent idiopathic scoliosis: results using the new SRS inclusion and assessment criteria for bracing studies. *J Pediatr Orthop*. 2007;27(4):369–374
86. Clayson D, Luz-Alterman S, Cataletto MM, Levine DB. Long-term psychological sequelae of surgically versus nonsurgically treated scoliosis. *Spine*. 1987;12(10):983–986
87. Fallstrom K, Cochran T, Nachemson A. Long-term effects on personality development in patients with adolescent idiopathic scoliosis: influence of type of treatment. *Spine*. 1986;11(7): 756–758
88. Olafsson YMD, Saraste HMD, Soderlund VMD, Hoffsten MOI. Boston brace in the treatment of idiopathic scoliosis. *J Pediatr Orthop*. 1995;15(4):524–527
89. Dolan LA, Sabesan V, Weinstein SL, Spratt KF. Preference assessment of recruitment into a randomized trial for adolescent idiopathic scoliosis. *J Bone Joint Surg A*. 2008;90(12):2594–2605
90. Richards BS, Bernstein RM, D'Amato CR, Thompson GH. Standardization of criteria for adolescent idiopathic scoliosis brace studies: SRS committee on bracing and nonoperative management. *Spine*. 2005;30(18):2068–2075
91. Bracing in adolescent idiopathic scoliosis trial (BrAIST). http://clinicaltrials.gov/ct2/show/NCT00448448. Updated 2012 Accessed May 21, 2012.
92. Karski T, Madej J, Rehak L, et al: New conservative treatment of idiopathic scoliosis: effectiveness of therapy. *Ortop Traumatol Rehabil*. 2005;7(1):28–35
93. Beilke MC. Roentgenological spinal analysis. 1936.
94. Brooks WJ, Krupinski EA, Hawes MC. Reversal of childhood idiopathic scoliosis in an adult, without surgery: a case report and literature review. *Scoliosis*. 2009;4:27
95. el-Sayyad M, Conine TA. Effect of exercise, bracing and electrical surface stimulation on idiopathic scoliosis: a preliminary study. *Int J Rehabil Res*. 1994;17(1):70–74
96. Morningstar MW, Woggon D, Lawrence G. Scoliosis treatment using a combination of manipulative and rehabilitative therapy: a retrospective case series. *BMC Musculoskelet Disord*. 2004;5:32
97. Hasler C, Schmid C, Enggist A, Neuhaus C, Erb T. No effect of osteopathic treatment on trunk morphology and spine flexibility in young women with adolescent idiopathic scoliosis. *J Child Orthop*. 2010;4(3):219–226. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=prem&AN=21629373.
98. Romano M, Negrini S. Manual therapy as a conservative treatment for adolescent idiopathic scoliosis: a systematic review. *Scoliosis*. 2008;3:2
99. O'Donnell CS, Bunnell WP, Betz RR, Bowen JR, Tipping CR. Electrical stimulation in the treatment of idiopathic scoliosis. *Clin Orthop*. 1988;229:107–113
100. Goldberg CJ, Moore DP, Fogarty EE, Dowling FE. The natural history of early onset scoliosis. *Stud Health Technol Inform*. 2002;91:68–70
101. Lenke LG. The Lenke classification system of operative adolescent idiopathic scoliosis. *Neurosurg Clin N Am*. 2007;18(2):199–206
102. Coe JD, Arlet V, Donaldson W, et al: Complications in spinal fusion for adolescent idiopathic scoliosis in the new millennium. A report of the scoliosis research society morbidity and mortality committee. *Spine*. 2006;31(3):345–349
103. Carreon LY, Puno RM, Lenke LG, et al: Non-neurologic complications following surgery for adolescent idiopathic scoliosis. *J Bone Joint Surg Am*. 2007