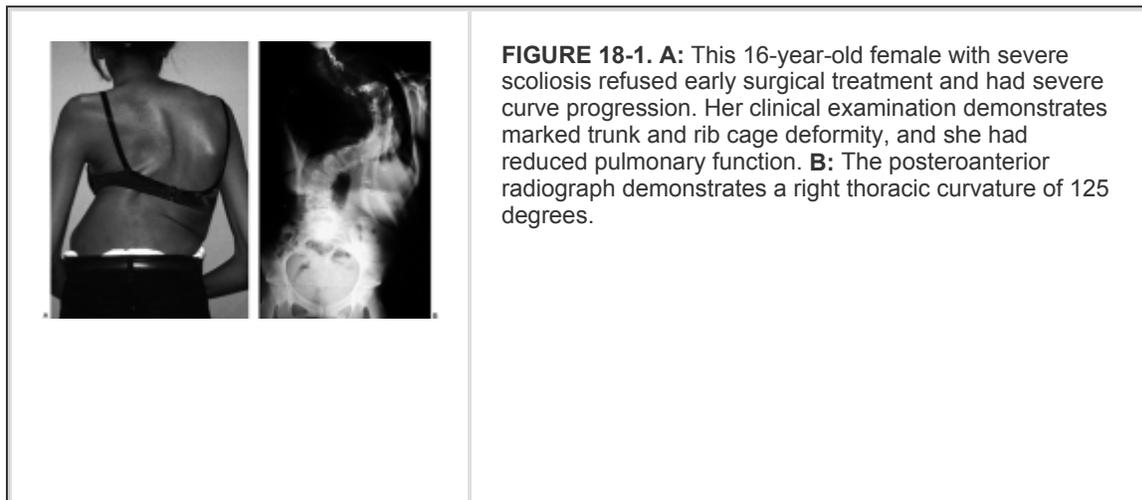


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CHILDHOOD AND ADOLESCENT SCOLIOSIS

Part of "18 - IDIOPATHIC AND CONGENITAL SCOLIOSIS"

"Idiopathic scoliosis" defines a common and potentially severe musculoskeletal disorder of unknown etiology, the diagnosis and treatment of which have been central in the development of orthopaedic surgery as a specialty. In its milder forms scoliosis may produce only trunk shape change, but when severe, can be markedly disfiguring as well as producing cardiac and pulmonary compromise (Fig. 18-1). The goal of this chapter is to present the key elements in diagnosis, natural history, and treatment of both idiopathic and congenital scoliosis.



The etiology of typical adolescent scoliosis remains unknown; thus, the term "idiopathic" remains appropriate. Scoliosis can also be classified based on associated conditions, since it occurs in many neuromuscular disorders (cerebral palsy, muscular dystrophy, and others) as well as in association with generalized diseases and syndromes (neurofibromatosis, Marfan syndrome, and bone dysplasia). Congenital scoliosis, caused by failure in vertebral formation or segmentation, causes a more mechanically understandable type of scoliosis.

The etiology of a scoliotic deformity (idiopathic, neuromuscular, syndrome related, and congenital) largely dictates its natural history, including the risk for and rate of curve progression, as well as the effect the curve will have on the cardiopulmonary function, mobility, and appearance. Although scoliosis includes both sagittal plane and torsional malalignment of the spinal column, the deformity is most readily noted as frontal plane deformity. Better understanding

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of the three-dimensional nature of scoliosis has led to many recent advances in its

treatment.

Definitions

The normal spine is straight in the frontal plane, but has sagittal plane contours including thoracic kyphosis averaging 30 to 35 degrees (range 10 to 50 degrees, T5–T12) and lumbar lordosis averaging 50 to 60 degrees (range 35 to 80 degrees, T12–S1) (1,2 and 3). The scoliotic spine deviates from midline in the frontal plane, and rotates maximally at the apex of the curve (4). The vertebral rotation toward the convexity of the curve, through the attached ribs, produces the typical chest wall prominence (Adams sign) that allows early diagnosis (5,6) (Fig. 18-2).

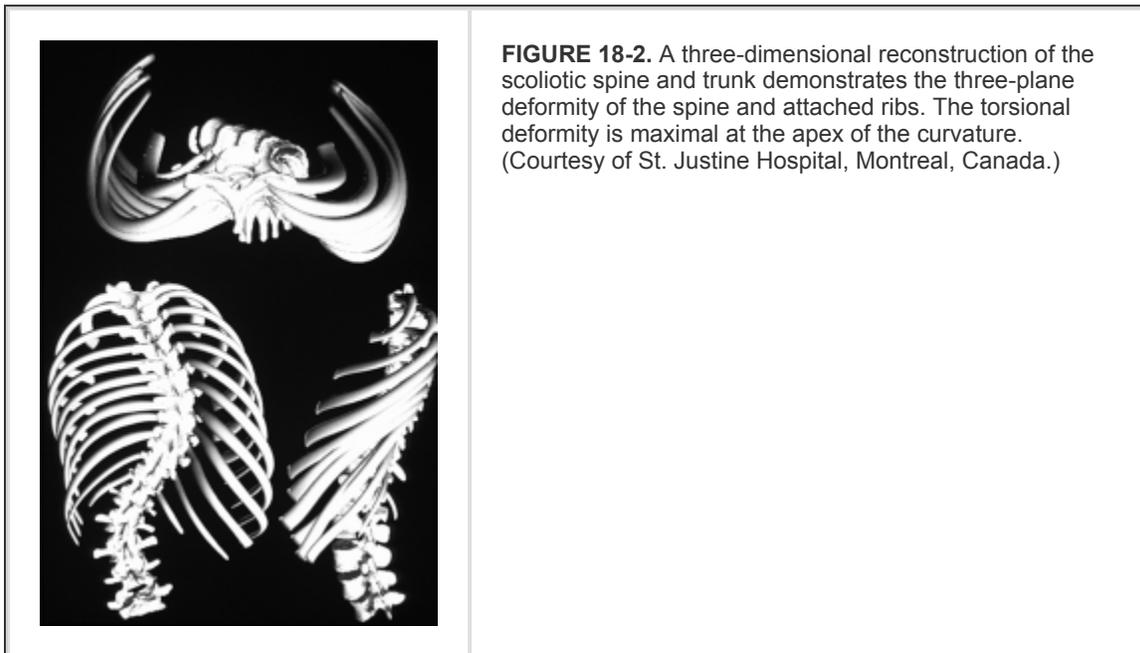


FIGURE 18-2. A three-dimensional reconstruction of the scoliotic spine and trunk demonstrates the three-plane deformity of the spine and attached ribs. The torsional deformity is maximal at the apex of the curvature. (Courtesy of St. Justine Hospital, Montreal, Canada.)

In the past, it was thought that the lateral curvature of scoliosis was also kyphotic (increased roundback). It is now understood that the apparent “hump” on the back is due to rib prominence secondary to the rotational deformity of the vertebrae and rib cage, and that most thoracic idiopathic scoliosis is associated with a *decrease* in normal thoracic kyphosis (7,8). Dickson and others have postulated that an early evolution to lordosis in the normally kyphotic thoracic spine leads to an unstable mechanical environment, leading to rotational collapse (9,10) (Fig. 18-3). This is not to say that all thoracic scoliosis is hypokyphotic, since many congenital, neuromuscular, and a few idiopathic cases have a true kyphotic component.

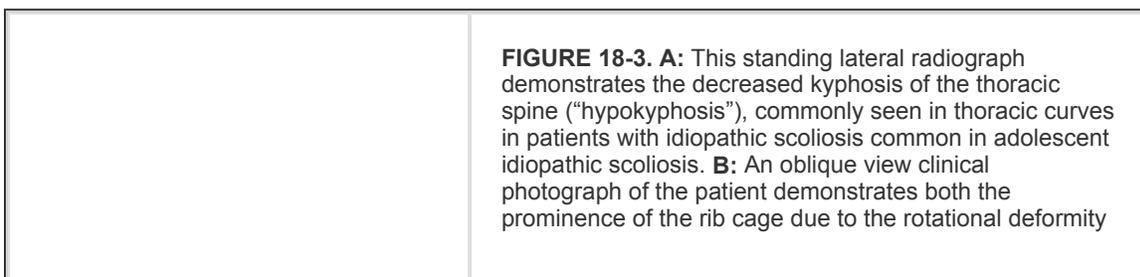
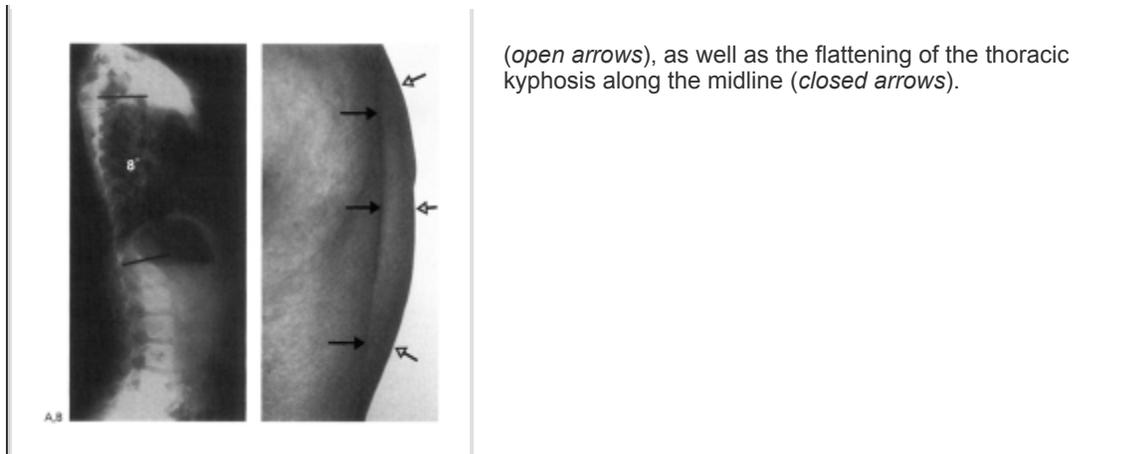
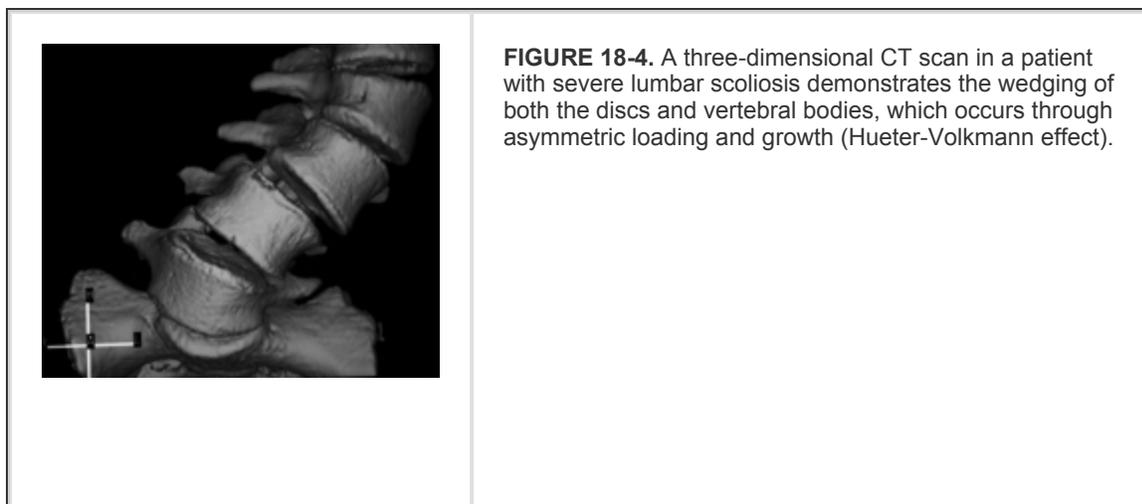


FIGURE 18-3. A: This standing lateral radiograph demonstrates the decreased kyphosis of the thoracic spine (“hypokyphosis”), commonly seen in thoracic curves in patients with idiopathic scoliosis common in adolescent idiopathic scoliosis. **B:** An oblique view clinical photograph of the patient demonstrates both the prominence of the rib cage due to the rotational deformity



In addition to global deformity of the spine and trunk, wedging of individual discs and vertebral bodies develops, due to the Hueter-Volkman effect (suppression of growth on the concave side of the curve) (11) (Fig. 18-4). This includes asymmetric growth and/or remodeling of the vertebral bodies, pedicles, laminae, and facet joints, as well as the transverse and spinous processes.



Etiology

Although the etiology of idiopathic scoliosis remains unknown, substantial research has been performed with many theories proposed. These range from genetic factors to disorders of bone, muscles, and disc, as well as growth abnormalities and central nervous system causes.

Genetic Factors

Several studies have demonstrated an increased incidence of scoliosis in the family members of affected individuals,

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confirming a genetic etiologic component to the etiology of scoliosis (12,13,14,15 and 16).

Risenborough and Wynne-Davies found scoliosis in 11.1% of first-degree relatives of 207 patients with idiopathic scoliosis (16). These familial studies suggest a polygenic inheritance pattern.

Examination of scoliosis in birth twins has led to further confirmation of genetic etiologic factors. In a meta-analysis of scoliosis in twins, Kesling and Reinker demonstrated 73% concordance in 37 pairs of monozygotic twins. They found that in 37 pairs of identical twins in which at least one twin was identified with scoliosis, 27 of the pairs had both twins affected. However, only 36% of the 31 dizygotic twins were concordant. In addition, the severity of the scoliosis was statistically similar for the monozygotic twins, but not for the dizygotic twins (17). Inoue et al. demonstrated even greater concordance in twins. DNA fingerprinting confirmed the zygosity, and found concordance of idiopathic scoliosis in 92% of monozygotic and 63% of dizygotic twins (18). Despite this confirming evidence of a genetic etiology, the genes and gene products responsible for the development of idiopathic scoliosis remain unknown.

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Tissue Deficiencies

Competing theories propose that the primary pathology of scoliosis is centered in each of the structural tissues of the spine (bone, muscle, ligament/disc). There are known conditions in which each of these tissues are pathologic and associated with scoliosis. For example, fibrous dysplasia (bone collagen abnormality) resulting in dysplastic, misshapened vertebrae (19); muscle disorders such as Duchenne muscular dystrophy leading to a collapsing scoliosis; and soft tissue-collagen disorders, such as Marfan syndrome, each have a clear association with the development of scoliosis.

In Marfan syndrome there is a defective gene coding for fibrillin. Fibrillin is found in many soft tissues including ligament, cartilage, and periosteum (20). The fibrillin abnormality found in Marfan syndrome is associated with scoliosis in 55 to 63% of cases (21,22). Although fibrillin has been ruled out as a cause of idiopathic scoliosis (23), similar subtle deficiencies in any of the tissues of the spine could result in idiopathic scoliosis (24). For instance, several (25,26 and 27) have suggested that adolescent idiopathic scoliosis (AIS) may be related to osteopenia. They found the vertebral bone mineral density to be lower in girls ages 12 to 14 years with scoliosis compared to matched controls, with the density lower not only in the vertebrae, but also in the proximal femur (25). The mechanism by which osteopenia alone leads to scoliosis, however, remains undefined.

Vertebral Growth Abnormality Theories

Abnormalities of spinal growth mechanisms also provide an attractive etiology theory because scoliosis development and

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progression are temporally related to the time of rapid adolescent growth (28,29). Differential growth rates between the right and left sides of the spine could generate an asymmetry that would be accentuated with asymmetric biomechanical loading and the Heuter-Volkman effect (11,30,31). Milner and Dickson (32), as well as others (10,31,33,34 and 35), have postulated that the etiology of scoliosis relates to the development of relative

thoracic lordosis. Dickson believes that anterior spinal growth outpaces posterior growth, producing hypokyphosis with subsequent buckling of the vertebral column, leading to the rotational deformity of scoliosis; however, the cause for this theorized "mismatch" of anterior and posterior spinal column growth has not been presented, and may be secondary rather than primary. Interestingly, it has been documented that thoracic kyphosis tends to decrease in normal children during the normal adolescent growth spurt (36). Thus, irregularities in the changing sagittal shape of the spine during the rapid period of adolescent growth may be important in the development of scoliosis.

Several studies suggest that adolescents with scoliosis are taller than their peers (37,38,39,40,41 and 42). Increased levels of growth hormones (43,44) and characteristic body morphometry (thin, physically less developed appearance) (45,46,47,48 and 49) may also relate to scoliosis development.

Central Nervous System Theories

Clearly, disorders of the brain, spinal cord, and muscles may result in scoliosis with the role of the central nervous system in idiopathic scoliosis having been studied in detail (50,51,52,53,54,55,56 and 57). Goldberg et al. noted greater asymmetry of the cerebral cortices in scoliotic patients (55). Also, abnormalities in equilibrium and vestibular function have been noted in patients with scoliosis (50,58,59,60,61,62 and 63); however, it is difficult to know if these findings are primary or secondary (64). Woods et al. have suggested a neurologic etiology to scoliosis based on the surprising finding that hearing-impaired children seem to have a lower incidence of scoliosis (63). Syringomyelia is associated with an increased incidence of scoliosis (65,66) possibly due to direct pressure on the sensory or motor tracts of the spinal cord. Alternatively, there may be no relation to the dilation of the central canal, but instead, brain stem irritation from an associated Chiari malformation or enlargement of the fourth ventricle of the brain as the cause.

Recently, it has been postulated that melatonin and the pineal gland may be related to scoliosis. This is based on research of pinealectomy in chickens that resulted in a high incidence of severe scoliosis (67,68 and 69). In these studies, presumably melatonin deficiency led to scoliosis in the chicken (70). Melatonin receptors are located in the brainstem and spinal cord dorsal gray matter, areas associated with postural control. Subsequent studies of human melatonin levels have been conflicting and inconclusive. Machida et al. found lower than normal melatonin concentration in the serum of patients with progressive scoliosis compared to those with stable curves (71). In contrast, Hilibrand et al. (72) and Fagan et al. (73) found no difference in urine melatonin levels between patients with scoliosis and normal control subjects. In addition, Bagnall et al. found no difference in serum melatonin levels of patients with scoliosis (74). Thus confirmation that melatonin deficiency in humans is associated with scoliosis, as seen in chickens, is lacking.

Histologic analysis of paraspinal muscles has revealed denervation changes suggestive of a neuropathic cause (75), as well as ultrastructural changes in the sarcolemma at the myotendinous junction, supporting the concept of a primary muscle disorder (76). As in the findings relating to equilibrium, it is difficult to determine a causal relationship, and the findings in muscle could be secondary, reflecting the muscle's response to asymmetric

spine loading (77).

In summary, the etiology of scoliosis remains puzzling. From a biomechanical standpoint the vertebral column is a naturally unstable construct, made of multiple mobile segments. As Stagnara has noted, one should not be surprised that a minor disturbance in the structure, support system, or growth of the spine could lead to scoliosis, particularly in a complex structure where the “normal” state includes multiple curves (sagittal plane), and is based on an oblique foundation (the sacrum) (78). There are likely several causes of idiopathic scoliosis, and active research continues in an attempt to find a unifying theory as to its cause.

Classification

Curve Location

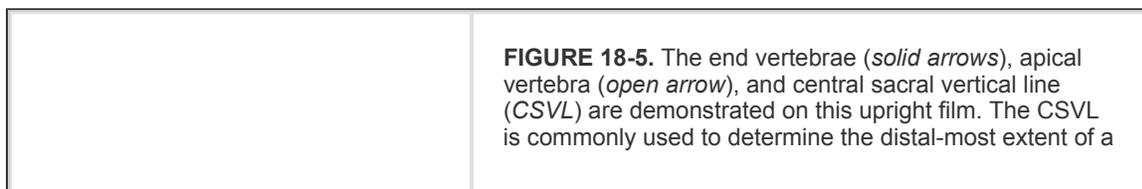
Scoliotic deformities assume a variety of curve patterns, and several useful classification systems have been developed. The terminology committee of the Scoliosis Research Society (SRS) defines the following technical description of curve locations (this is in contrast to curve pattern descriptions developed for the purpose of planning surgical correction; see “Surgical Correction of Idiopathic Scoliosis”):

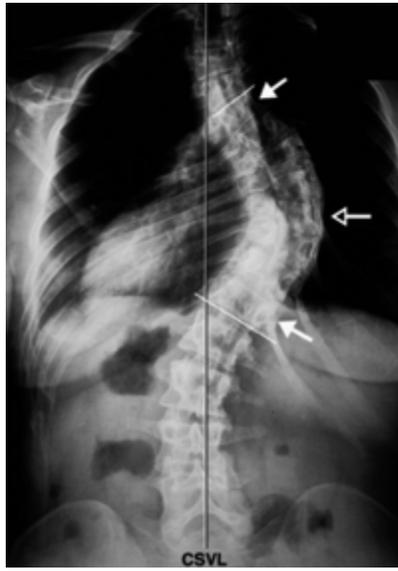
- Cervical: apex between C2 and C6
- Cervicothoracic: apex between C7 and T1
- Thoracic: apex between T2 and T11
- Thoracolumbar: apex between T12 and L1
- Lumbar: apex between L2 and L4
- Lumbosacral: apex at L5 or below

The apex of a curve defines its center, and is the most laterally deviated disc or vertebra of the curve. Usually a single vertebra can be defined, but in other cases a pair of vertebrae are at the apex (in this case the “apical disc” is used to define the level of the apex). The apical vertebra(e) are also the most horizontal. The end vertebrae of a curve define the proximal and distal extent of a curve, and are

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determined by locating the vertebrae most tilted from the horizontal (these vertebrae are used to make the Cobb measurement). The central sacral vertical line, a vertical line which bisects the sacrum, is used to assess the balance of the spine in relation to its base (the pelvis) (Fig. 18-5).





spinal fusion that classically extends to the "stable vertebra." In this radiograph, the stable vertebra is arguably L1 or L2.

Age at Onset

Age at diagnosis is also used to define idiopathic scoliosis groups as follows:

- Infantile (ages 0 to 3 years)
- Juvenile (age 4 to 10 years)
- Adolescent (11 to 17 years)
- Adult (≥ 18 years)

The age when idiopathic scoliosis develops is one of the most important factors in determining the natural history of the disorder, with early onset cases more likely to be progressive. Scoliosis onset before the adolescent growth spurt is more likely to have an underlying spinal cord abnormality as the cause of the deformity with the incidence of abnormality approximately 20% in the juvenile group and as high as 50% in the infantile group (79).

Primary and Secondary, Structural and Nonstructural Curves

Curves may also be described as primary or secondary. The primary curve is the first to develop; however, at times two or even three curves of equal severity exist that make the determination of a primary versus secondary curve difficult. Secondary or compensatory curves develop after formation of the primary curve as a means of balancing the head and trunk over the pelvis. Similar compensation occurs in the sagittal plane in which the typical lordotic thoracic curve may end both cranially and caudally with a junctional kyphosis. Sagittal plane abnormalities have only recently been well understood and considered when

screening examination (either in school or at a routine primary care visit) often leads to referral. History-taking should include questions about family history of scoliosis, recent growth, and the physical changes of puberty (onset of menses). When an affected sibling or parent has scoliosis, prevalence increases seven times (sibling) and three times (parent), respectively, compared to the general population (14). A record of height increases over the prior few years is important in predicting remaining spinal growth and the risk for curve progression (80). This information may be available from the primary care physician or, at times, from measurements on the wall/door marked in the family's home. The onset of menses forms an important maturational time point in females (81). The family history, as well as the review of systems, should identify disorders known to be associated with scoliosis (Table 18-1).

The presence or absence of severe back pain is important, because most idiopathic scoliosis patients have only mild discomfort. Patients seen after scoliosis has been diagnosed (in a screening setting) commonly develop "pain" that continues until the exact diagnosis, and particularly the prognosis, have been clarified by an orthopaedic consultant who can provide reassurance. Despite the common belief that mild idiopathic scoliosis is not painful, a recent study suggests that adolescents with mild curves often report discomfort of a mild fatigue variety. Ramirez et al. noted back pain in 23% of 2,442 patients with "idiopathic" scoliosis. Only 9% of those with pain were subsequently found to have an underlying pathologic condition to explain it (diagnoses such as spondylolysis/spondylolisthesis, Scheuermann kyphosis, syringomyelia, herniated disc, tethered cord, and intraspinal tumor) (82).

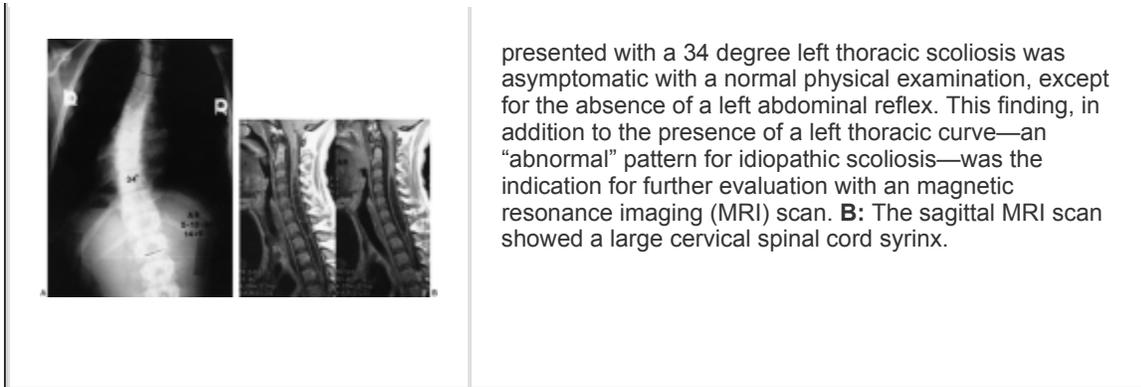
In evaluating a child with scoliosis, a significant complaint of back pain is a clue that should raise one question, "Is this truly an idiopathic curve?" A child or adolescent who presents with severe back pain, and is subsequently found to have scoliosis requires a very careful history, physical examination, and radiographic study (a bone scan and MRI study may be required), because an underlying etiologic cause is more likely (82,83 and 84). However, the clinician must distinguish between "severe pain" (requiring further workup) and the mild fatigue pain (noted above) reported

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by Ramirez et al. and others (82,85). During adolescence, activity-related musculoskeletal low back pain occurs at a frequency greater than in childhood, but less than in adults (86,87).

Age at onset, rate of curve progression, and the presence of neurologic symptoms and signs are the most useful findings in identifying nonidiopathic scoliosis. In younger patients (less than 10 years) with a neurologic cause, actual neurologic findings on physical examination are often absent, and often the spinal curvature itself must be considered the initial sign of a neural axis abnormality (79,88,89 and 90). The most common intraspinal abnormality found in this age group is syringomyelia (dilation of the central spinal canal) with an associated Chiari malformation (brain stem below the level of the foramen magnum) (Fig. 18-6).

FIGURE 18-6. A: This 14-year-6-month-old male who



Rapid development of a severe curve suggests a nonidiopathic type of scoliosis. Neurologic symptoms such as weakness, sensory changes, and balance/gait disturbance suggest intraspinal pathology (syringomyelia, tethered cord, tumor, etc.) as the cause of spinal curvature (83,89,90). The neurologic history should therefore focus on difficulties with walking, running, and stair-climbing. A history of radiating pain, numbness, and tingling in the limbs, and difficulties with bowel or bladder control, should also be sought.

Physical Examination

Physical examination of a scoliosis patient includes evaluation of trunk shape, trunk balance, the neurologic system, limb length, skin markings, and associated skeletal abnormalities. Assessment of pubertal development includes assessment of the stages of breast development and the presence of axillary/pubic hair (Tanner stages). This can be done discretely without fully undressing the patient. Examination of girls while dressed in a two-piece swimsuit (patient instructed at time of telephone appointment to wear a swimsuit for the examination) reduces anxiety and apprehension, yet allows assessment of breast development and axillary hair.

With the patient standing, the back and trunk are inspected for asymmetry of shoulder height, scapular position, and shape of the waist (Fig. 18-7) viewed from both behind and in front. Potential pelvic tilt, (an indicator of limb-length difference) is determined by palpating the iliac crests and posterior inferior iliac spines bilaterally in the standing patient with both hips and knees fully extended. Lateral translation of the head can be measured in centimeters of deviation from the gluteal cleft by dropping a plumb line from C7 (Fig. 18-8). Deviation of the chest cage (trunk

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shift) should also be assessed, since patients can have full head compensation (return of the head and neck back to midline), yet have marked lateralization of the trunk.

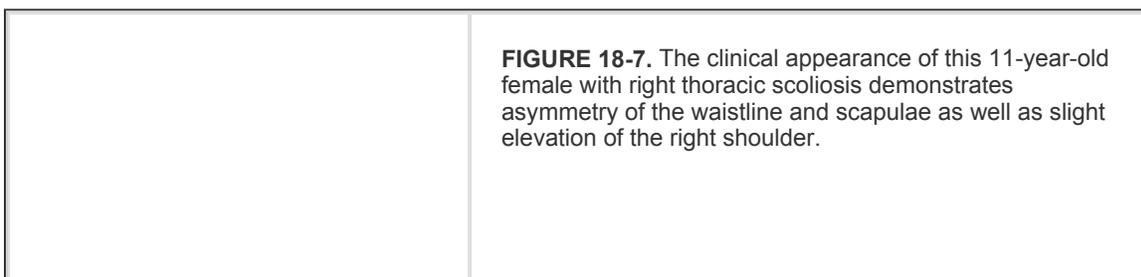
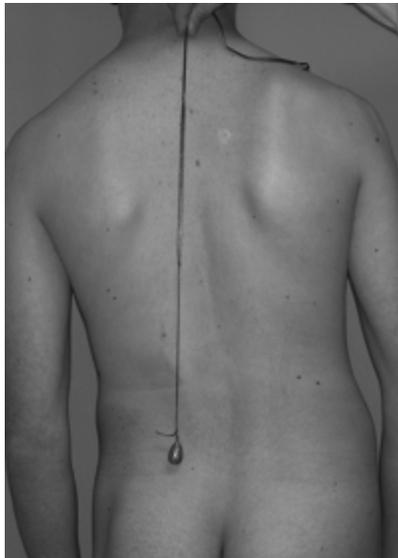




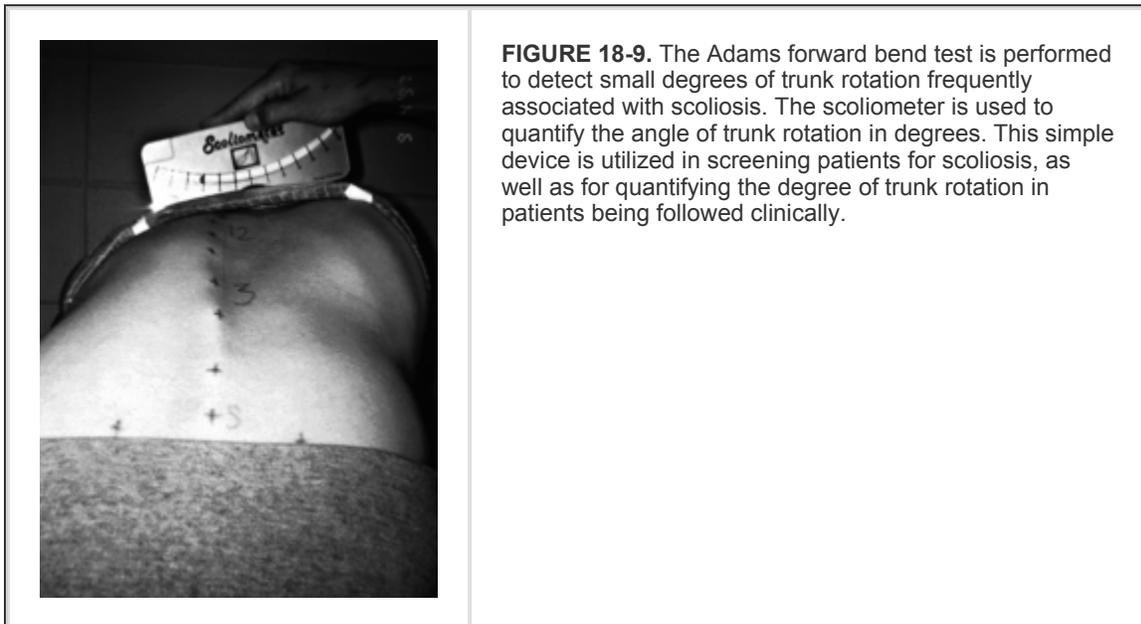
FIGURE 18-8. A small weight hanging from a string (“plumb bob”) serves as a simple tool for quantifying trunk deviation. In this case, the plumb line is measured from C7 and quantified as a deviation in centimeters from the gluteal cleft below (5 cm).



Forward-bend Test.

The forward-bend test, first described by Adams in Britain (91), has the patient bend forward at the waist, with their knees straight and palms together. This examination should be performed from behind (to assess lower trunk rotation), from in front (to assess upper trunk rotation), as well as from the side (to assess kyphosis). Any asymmetry of the upper thoracic, midthoracic, thoracolumbar, and lumbar regions should be quantitated with a scoliometer (92) (angle of trunk rotation—ATR), or by measuring the height of the prominence in centimeters (Fig. 18-9). This prominence reflects the rotational deformity of the spine associated with scoliosis (93,94). Although not always exactly correlated, in

general an angle of trunk rotation of 5 to 7 degrees is associated with a radiographic Cobb angle measurement of 15 to 20 degrees. (This is a guideline—occasionally patients have little trunk rotation yet have significant radiographic scoliosis, and vice versa (95)).



An inability to bend directly forward at the waist, or decreased range with forward/side bending, may be due to pain, lumbar muscle spasm, and/or hamstring tightness; any of which should suggest underlying pathology. These findings, plus abnormalities in straightleg-raise testing suggests irritation of the lumbar roots due to spondylolysis, disc herniation, infection, neoplasm, or other causes.

Skin, Limb Length.

Additional components of a comprehensive scoliosis examination include inspection of the skin (both on the back and elsewhere) for cutaneous evidence of an associated disease. Café au lait spots and/or axillary freckles suggest possible neurofibromatosis, while dimpling or a hairy patch in the lumbosacral area may suggest an underlying spinal dysraphism. Excessive skin or joint laxity may be related to a connective tissue disorder, such as Marfan or Ehlers-Danlos syndrome.

Limb length should also be measured in the supine position if pelvic tilt is noted on the standing examination. A spinal curvature which results from a limb-length difference is usually compensatory and serves to rebalance the trunk over the pelvis. A short right leg results in a compensatory right lumbar curve. There is no rotational deformity of the spine with these curves, and in the lumbar region the rotational prominence noted on the forward-bend test is on the

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concave side of the curve (the long leg makes the iliac crest and lumbar spine more prominent on that side). This is the opposite of what is seen in true lumbar scoliosis, in which the rotational prominence noted on the bending test is found on the side of the curve convexity. Presence of the bending-test rotational prominence, on the “wrong” side in a

lumbar curve, is almost always diagnostic of limb-length discrepancy spinal asymmetry, rather than true scoliosis. The prominence disappears if the pelvis is leveled with an appropriately sized block underneath the short leg.

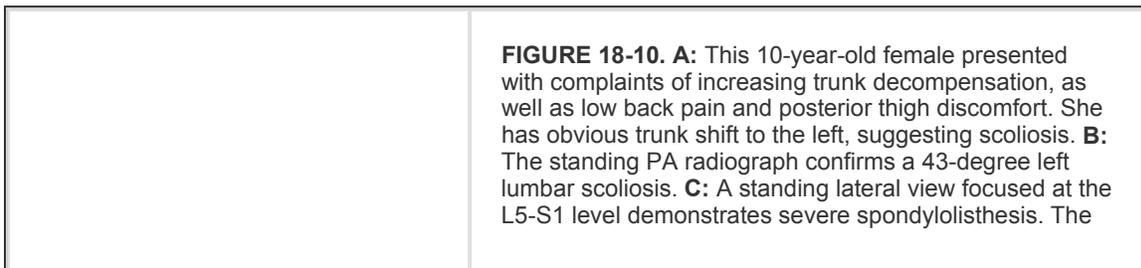
Neurologic Examination

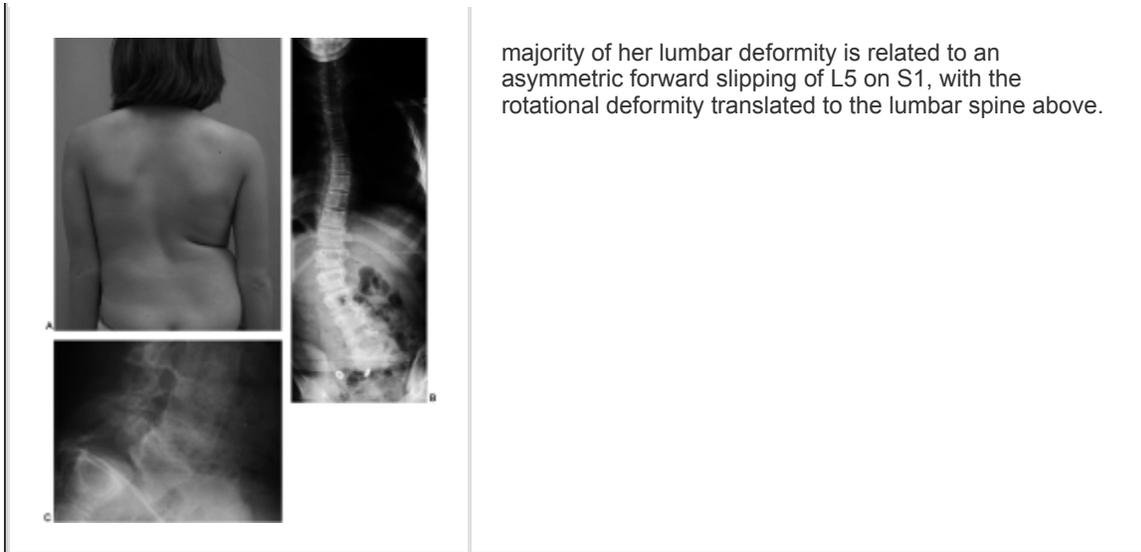
The neurologic examination should evaluate balance, motor strength in the major muscle groups of all four extremities, as well as sensation. Watching the patient walk, toe and heel walk, tandem walk, squat deeply, and single-leg hop allows rapid assessment of balance and motor strength. Reflex testing includes upper- and lower-extremity deep-tendon reflexes, as well as abdominal reflexes that are obtained by lightly stroking the abdominal wall with a blunt instrument (key, end of reflex hammer) adjacent to the umbilicus, with the patient supine and relaxed. The expected brisk and symmetric unilateral contraction of the abdominal musculature, pulling the umbilicus toward the side being stroked, indicates normalcy. When persistently abnormal (reflex absent on one side and present on the other), intraspinal disorders, particularly syringomyelia, should be considered and an MRI study ordered (65,96).

Radiographic Assessment

The ideal screening radiograph for scoliosis is an upright (standing) posteroanterior (PA) projection of the entire spine exposed on a single cassette. In an adolescent, due to body size, this requires a three-foot length film to visualize the entire spine, as well as the head and pelvis on a single radiograph. Many radiology units do not have long cassettes and a chest-film-size cassette can be substituted, with the film centered on the area of maximal deformity (usually the thorax). If a lumbar curve is present, a separate film must be performed. Clearly, the child is better served if they can be referred to a center that uses long cassettes, allowing a single film.

The patient must be standing, since diagnostic and treatment standards developed over the years are based on upright films. In young patients, or those with severe neuromuscular involvement, sitting or even supine radiographs may be the only position possible. Curve magnitude is greater when the patient is upright (compared to supine), and is of particular importance in infantile and congenital curves with films taken before and after walking age. "Curve progression" may be noted with the first upright radiograph, compared to prior supine views, when in fact one has simply documented that gravity causes a curve to be more severe. A lateral film is not required as part of the initial x-ray screening of a thoracic curve, unless back pain or sagittal deformity are noted. A lateral view of the lumbosacral junction is often performed in lumbar scoliosis to assess for spondylolysis/spondylolisthesis as a possible cause (Fig. 18-10).

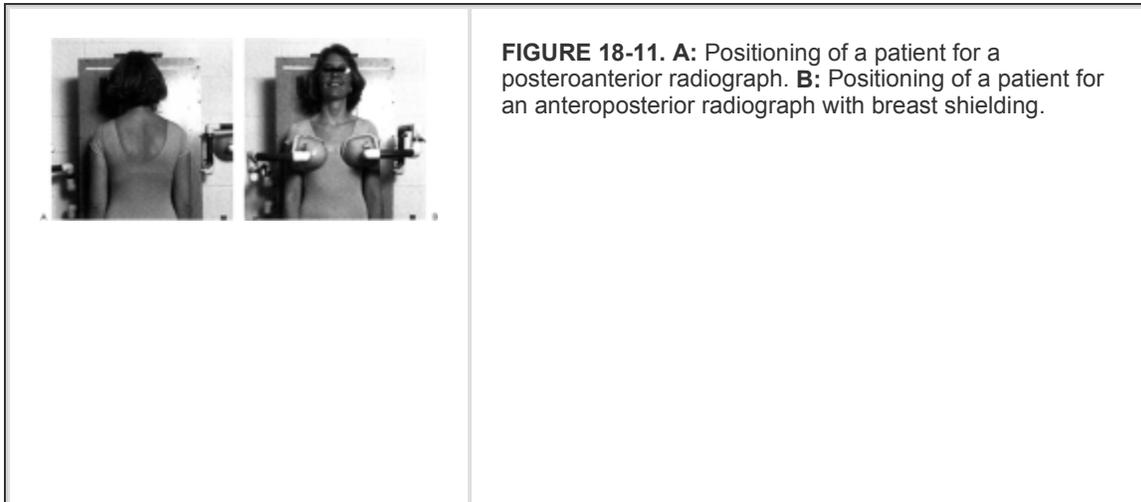




Radiographic techniques used to minimize radiation of sensitive organs (breast, thyroid, ovaries, bone marrow) include taking only the required number of x-rays, utilizing rare earth radiographic enhancing screens with fast film, and a posterior to anterior exposure (97,98 and 99). The lifetime risk for developing cancer of the breast and thyroid has been suggested to increase by 1 to 2% for patients exposed to multiple x-rays associated with scoliosis treatment; however, this rate was generated in the 1960s and 1970s, before new radiation reducing techniques were available. The greatest reduction to breast and thyroid exposure is associated with the posteroanterior exposure (compared to the anteroposterior), which reduces breast/thyroid exposure 3- to 7-fold (99). Shielding of the breasts with anteroposterior (AP) projection is possible, but not recommended, because of the increased thyroid exposure (shielding the thyroid obstructs the view of the upper spine) (Fig. 18-11). Wise doctors

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counsel their patients by telling them that only the minimum number of x-rays required to treat the disorder correctly will be performed, and that the benefit of having the x-rays outweighs the risk of not knowing the type and severity of the scoliosis.

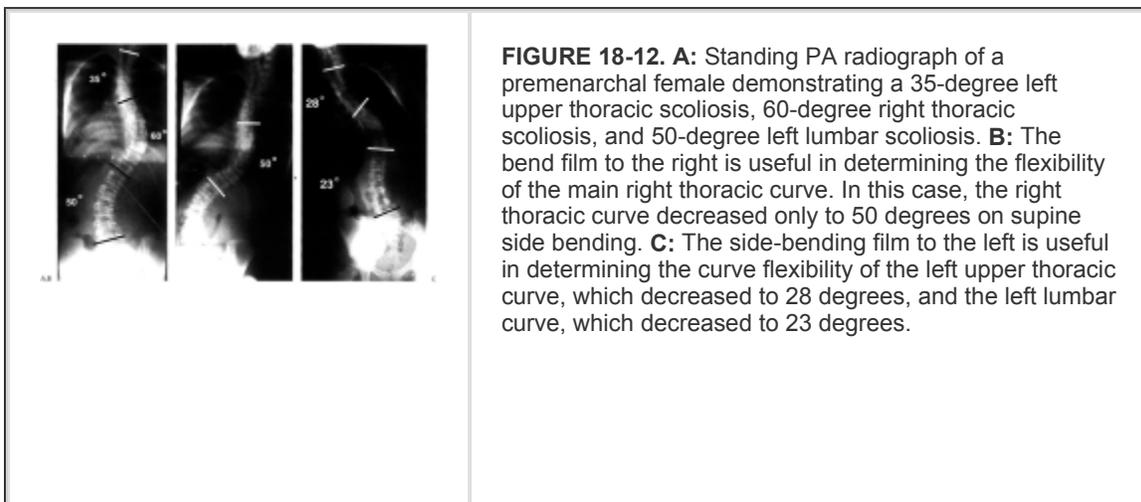


When surgical treatment is being considered, lateral-bend radiographs to assess curve flexibility as well as a standing lateral view are required. Side-bending radiographs allow one to determine curve flexibility, and to decide what levels to include in the instrumented and fused segment. Controversy remains regarding the best method for obtaining bending films, with supine AP views (patient maximally bent to the right and left) being standard at many institutions (Fig. 18-12), whereas others believe that a standing bend film is a better indicator, particularly in the lumbar spine. Lateral bending over a bolster provides somewhat greater correction, and has been proposed as a more accurate predictor of the correction obtained with the more powerful modern surgical

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instrumentation methods (100,101). In curves greater than 60 to 70 degrees, longitudinal traction films may also be helpful in evaluating curve flexibility (102,103).

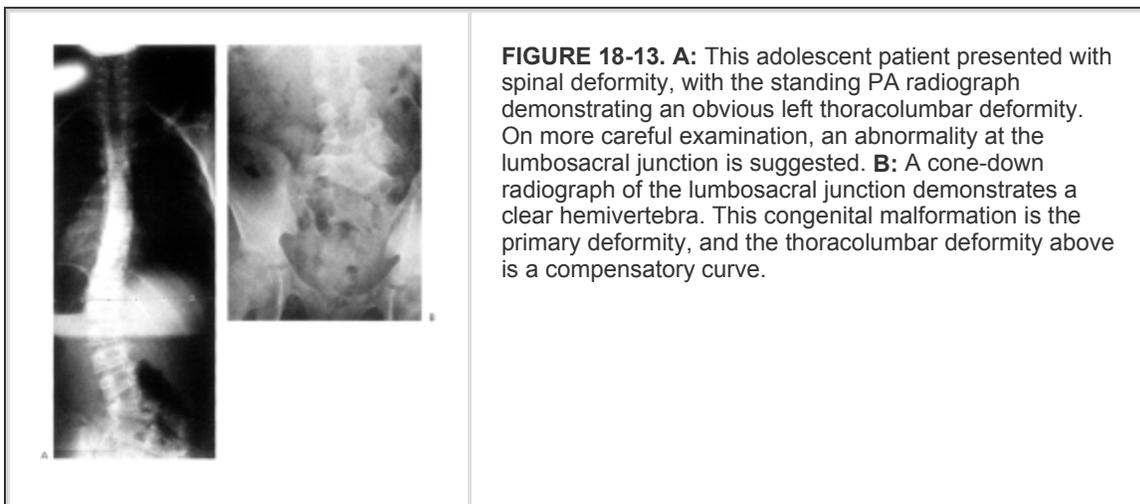


The Stagnara oblique view, taken perpendicular to the rib prominence rather than in the PA direction, provides a more accurate picture of large curves with a large rotational component. Taken in this manner the true magnitude of the scoliosis can be measured

(104).

Reading Scoliosis Films.

Assessment of the standing PA film begins by looking for soft tissue abnormalities, congenital bony abnormalities (wedged vertebra, etc.), then by assessing curvature (coronal plane deviation). Bone assessment includes looking for wedged or hemivertebrae (Fig. 18-13), bar formation bridging a disc space, as well as midline irregularities, such as spina bifida or a bony spike suggesting diastematomyelia. The pedicles should be inspected to be certain that they are present bilaterally and that the interpedicular distance is not abnormally increased, suggesting an intraspinal mass (105,106). Absent pedicles or vertebral body lucency are associated with lytic processes, such as tumor or infection. If a curve is noted, the symmetry and levelness of the pelvis are analyzed. A limb length discrepancy can be estimated by determining iliac wing and hip joint height differences, assuming the patient had both hips and knees fully extended when the film was exposed.



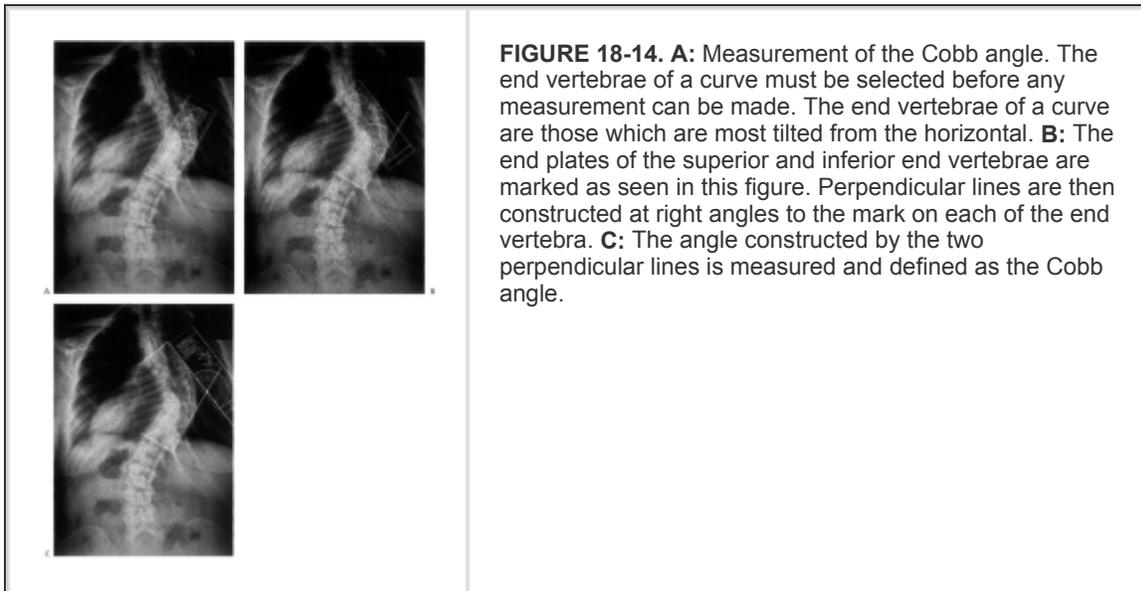
Curve measurement by the Cobb method (107) allows quantification of the curve. A protractor with single-degree demarcations that is not bent or warped allows more accurate measurements. The caudal and cranial end vertebrae to be measured are the vertebrae that are the most tilted, with the degree of tilt between these two vertebrae defining the Cobb angle (in a normal spine this angle is 0 degrees). One outlines the superior end plate of the cranial end vertebra and the inferior end plate of the caudal end vertebra, constructs a perpendicular to these lines, then measures the angle where the perpendicular lines cross. When more than one curve exists, a Cobb angle measurement is made for each curve (Fig. 18-14). When comparing serial radiographs of the same patient, the end vertebra chosen should generally

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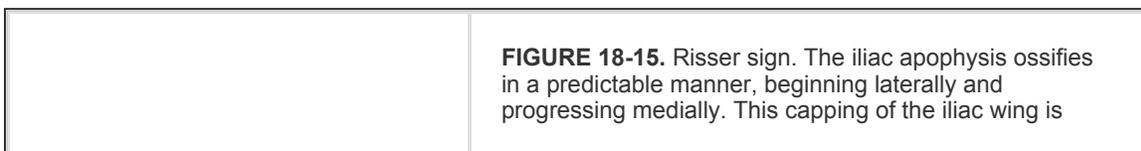
remain constant; however, adjustments may be required over time, due to brace-influenced change or other curve pattern changes. The wide variation of inter- and intraobserver error (about 5 degrees for any curve measurement) should be understood by the surgeon and the anxious parents (and patient) (108,109 and 110). Carman et al. state that to be 95% certain

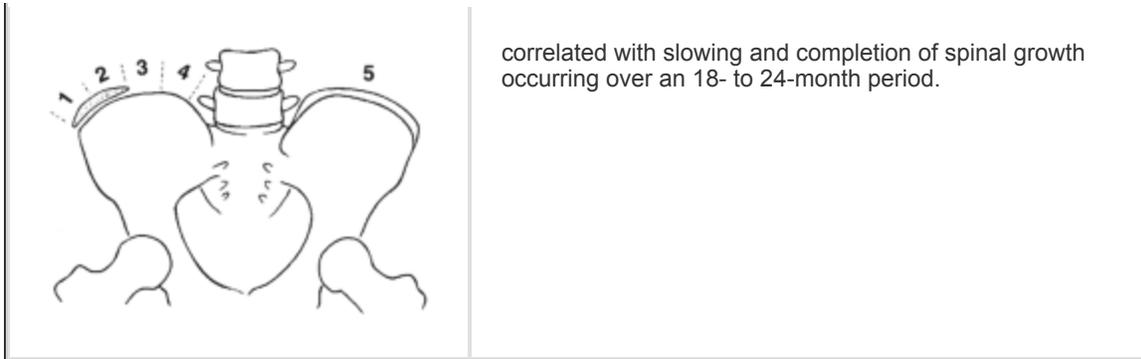
that two measurements are truly different, a 10-degree change must be measured (111). A useful maneuver for both the neophyte and expert surgeon includes viewing the current film, the prior-visit film, and the original film side by side. (A good scoliosis clinic needs at least three long view boxes mounted side-by-side). Then, before making a Cobb measurement, one should use the “eyeball method” to see whether the radiographic curve appears to be getting worse. Patients and their parents often want to make this assessment with you. This type of exercise puts the Cobb measurement in perspective (and sometimes humbles you as to your accuracy and reproducibility in measurement).



Vertebral rotation, maximal at the apex of a curve, is demonstrated radiographically by asymmetry of the pedicles and a shift of the spinous processes toward the concavity. Two methods are available for quantifying it: Nash and Moe (112), and Perdriolle (113). Vertebral rotation is not routinely measured clinically, and both methods have substantial inaccuracies, which limit their usefulness (114).

Skeletal maturity should be assessed radiographically to estimate remaining spinal growth, an important predictor of risk for curve progression. The most widely used method in scoliosis patients is that of Risser (115), who noted that the iliac crest apophysis ossifies in a predictable fashion, from lateral to medial, and that its fusion to the body of the ilium mirrors the fusion of the vertebral ring apophysis, signifying completion of spinal growth. The lateral to medial ossification of the iliac crest apophysis occurs over a period of 18–24 months, finally capping the entire iliac wing. Risser classified the extent of apophyseal ossification in stages, with Risser 0 indicating absence of ossification in the apophysis and Risser 5 indicating fusion of the fully ossified apophysis to the ilium (spinal growth complete) (116). Risser 1 through 4 are assigned to the intermediate levels of maturity as seen in Fig. 18-15.





correlated with slowing and completion of spinal growth occurring over an 18- to 24-month period.

The status of the triradiate cartilage of the acetabulum also provides a landmark for assessing growth potential. The triradiate growth cartilage usually closes before the iliac apophysis appears (Risser 0) at about the time of maximal spinal growth (117,118). Skeletal age can also be measured using the Greulich and Pyle atlas to compare hand radiographs against illustrated standards, although these readings become less accurate (large standard deviations) in the adolescent age group (119).

Specialized Imaging Studies

Most idiopathic scoliosis cases do not require imaging beyond plain radiography. Specialized imaging methods that can be used to evaluate cases with unusual features include magnetic resonance imaging (MRI), computed tomography (CT), and bone scintigraphy, each with specific indications and advantages.

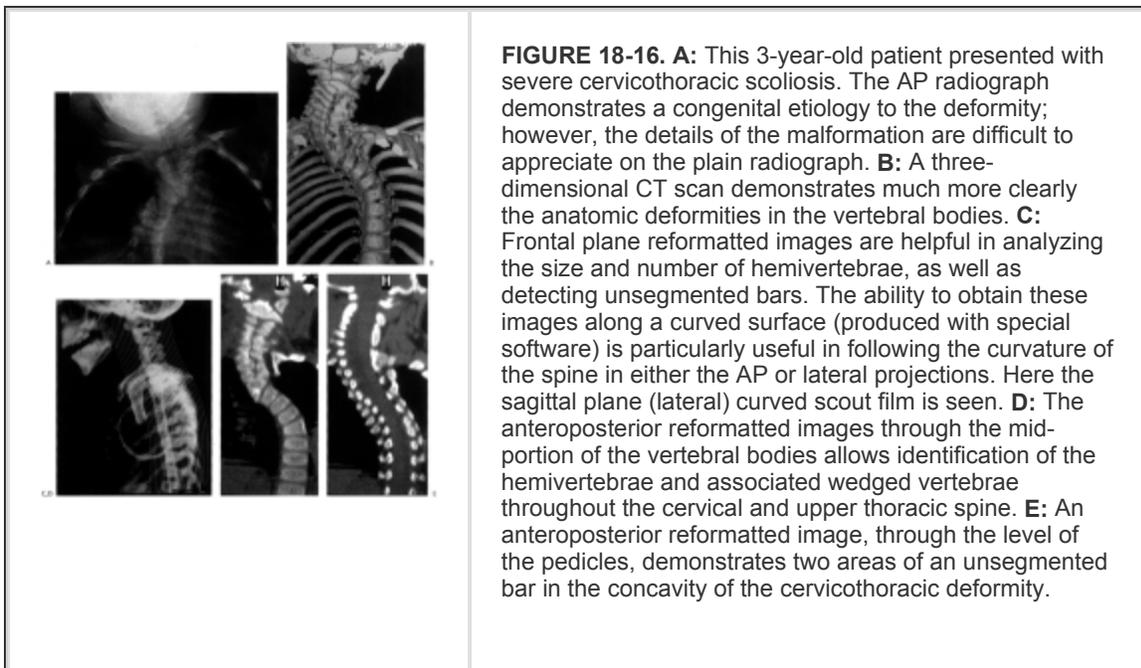
In the developed world, MRI has almost completely replaced myelography for the study of the neural elements in spine disorders. An exception is the patient who has had prior placement of stainless steel hardware (making MRI visualization nearly impossible) who has continued or new symptoms that require study.

MRI study of the spine is indicated for all infantile and juvenile idiopathic patients (79,120,121), as well as those with congenital bony anomalies, if surgical correction is planned (122,123). Left thoracic curves and scoliosis in boys have been shown to have an increased association with spinal cord anomalies and may be an indication for MRI study (120,124). Indications for routine MRI study in patients with typical idiopathic scoliosis prior to corrective surgery (and who have a normal clinical neurologic examination), remain unclear (125). At present there is no prospective study that confirms the efficacy of MRI screening for preoperative assessment (spine and brain) of all patients with idiopathic scoliosis, although a few centers have made this the routine for all operative cases. Clearly, patients with an abnormality in the neurologic examination (120), or with cutaneous findings (suggesting dysraphism or neurofibromatosis), should have an MRI study of the spine and/or brain. Severe angular and rotational deformities may be difficult to analyze with an MRI, because the spinal canal deviates into and out of the planar cuts of the sagittal and coronal images. CT myelography that produces a dye column may be better for revealing stenosis or an intraspinal filling defect in extremely severe cases of scoliosis.

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The workup of patients with substantial back pain with no obvious cause may require a bone scan to evaluate for possible tumor, infection, or spondylolysis. The bone scan is an excellent screening test for studying the painful scoliotic patient, allowing one to screen for conditions ranging from osteoid osteoma to hydronephrosis. A single proton emission computed tomography (SPECT) type bone scan (computerized tomographic enhancement) is very useful in identifying spondylolysis and its varying presentations (unilateral, bilateral, cold scan, hot scan, etc.). If an area of increased activity is noted on the bone scan, additional imaging (either MR or CT) may be required. CT studies can be performed with increasing sophistication, and provide the best method for imaging the bony anatomy in complex deformities and congenital anomalies. Standard two-dimensional transverse images are less helpful in scoliosis, compared to coronal, sagittal, and three-dimensional reformatted images. Additional multiplanar (curved along the deformity) reformatted coronal and sagittal images are particularly helpful in imaging the scoliotic spine when congenital anomalies are suspected (Fig. 18-16).



Imaging the kidneys and urologic collecting system is important in patients with congenital scoliosis (126,127), because identification of a congenital spinal deformity may be the first clue of an abnormality of the genitourinary (GU) system (which, if unrecognized, could lead to permanent kidney damage). An ultrasound study is the most practical screening test for detecting GU system abnormalities and should be obtained once a congenital spinal abnormality has been identified (126).