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PERSPECTIVE

Patient evaluation in idiopathic scoliosis: Radiographic assessment, trunk deformity and back asymmetry

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ABSTRACT

Progressive adolescent idiopathic scoliosis (AIS) produces specific signs and symptoms, including trunk and spinal deformity and imbalance, impairment of breathing function, pain, progression during adult life, and psychological problems, as a whole resulting in an alteration of the health-related quality of life. A scoliosis-specific rehabilitation program attempts to prevent, improve, or minimize these signs and symptoms by using exercises and braces as the main tools in the rehabilitation treatment. Patient evaluation is an essential point in the decision-making process and determines the selection of the specific exercises and the specifications of the brace design. However, this article is not addressed to scoliosis management. In this present article, a complete definition and discussion of radiological aspects, such as the Cobb angle, axial rotation, curve pattern classifications, and sagittal configuration, follow a short description of the three-dimensional nature of AIS. The relationship between AIS and growth is also discussed. There is also a section dedicated to the assessment of trunk deformity and back asymmetry. Other important clinical aspects, such as pain and disability, changes in other regions of the body, muscular balance, breathing function, and health-related quality of life, are not discussed in this present article.

INTRODUCTION

Idiopathic scoliosis is a multifactorial, three-dimensional deformity of the spine and trunk that can appear and sometimes progress during any rapid growth period in apparently healthy children. Adolescent idiopathic scoliosis (AIS) is the most common form and affects children at 10 years of age or older. Although its ultimate cause is unknown, there is evidence to support that there are two types of pathogenic factors called initiating factors and progression factors for AIS (Burwell, 2003). There is consensus that curve progression involves a mechanical process called torsion with eccentric loading of the spine and vertebral growth modulation (vicious cycle model) (Stokes, Burwell, and Dangerfield, 2006). The "vicious cycle" model has been used to support the conservative management of scoliosis and other spinal deformities. Scoliosis rehabilitation including physiotherapy methods and bracing can alter the natural evolution of this condition (Weiss, 2007). The importance of multidisciplinary team work in scoliosis rehabilitation has been recently pointed out and physiotherapists are an essential part of such a team (Negrini et al, 2009). As part of the rehabilitation team, the role of the physiotherapist is to teach the patient to correctly perform specific exercises and also inform and educate the patient and patient's family about activities of daily living.

Curve progression is related to both changes in the morphology of the spine and the trunk, as well as changes in the geometry of the spine. Physiotherapists should be highly familiar with these changes, which can be sufficiently understood by completing a thorough radiological assessment as well as a full assessment of the back shape. Therefore, patient evaluation in relation with spinal and trunk deformity is an issue of necessary interest for physiotherapists considering the multidisciplinary approach. The aim of this article is to define, describe, and discuss several radiological parameters as well as clinical aspects related to the spinal and trunk deformities in AIS.

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Any physiotherapist with interest in this field can use the information and references presented in this article to better understand such a complex issue. Obviously, it is not the intention of this author to substitute, but to highlight a number of very useful publications in reference to AIS, such as the manual on radiographic measurement edited by the Spinal Deformity Study Group in 2004. The description of scoliosis—a three-dimensional deformity of the spine and the trunk—plane by plane, represents a fragmentation of a whole and will always be imperfect and incomplete. The radiological and nonradiological parameters discussed in this article are all necessary to make a clinical evaluation, but each parameter would be insufficient by itself, considering the three-dimensional nature of the condition. The three-dimensional nature of idiopathic scoliosis will also be shortly described in this present article, but a more in-depth understanding is recommended and cannot be provided by this article. The best references are offered by the comprehensive collection published by the International Research Society on Spinal Deformities-IRSSD (D'Amico, Merolli, and Santambrogio, 1994; Dansereau, 1992; Dangerfield, 2008; Grivas, 2002; Sawatzky, 2004; Sevastik and Diab, 1997; Stokes, 1999; Tanguy and Peuchot, 2000; Uyttendaele and Dangerfield, 2006). Other clinical signs, such as pain and disability, muscle imbalance, breathing impairment, and health-related quality of life are essential in scoliosis patient evaluation but are not discussed in this present article. Para-spinal/trunk signs, such as leg length discrepancy or even pelvis obliquity, would deserve a full article as well. Patient evaluation is a crucial point in the doctor's decision-making process, but this article is not addressed to spinal surgeons or other medical specialists involved in such a process; therefore, specific recommendations on when and how to treat shall not be addressed.

The three-dimensional nature of AIS

At an elementary level of understanding, AIS is considered a lateral deviation of the spine. In reality, any comprehensive definition of AIS must address the three-dimensional nature: the basic components of the scoliotic deformity are intervertebral lordosis, axial rotation, and lateral inclination. Lateral inclination—maximum at both limits of any curve—is the consequence of lateral deviation or translation. The most translated or deviated vertebra is called the apical vertebra and presents at the same time as the maximum axial rotation. Intervertebral lordosis seems to be related to relative anterior spinal overgrowth; hence, from a morphological point of view, AIS must be considered a structural lordotic deformity. Rather than a succession of lateral deviations, Dubousset (1992) considered that "idiopathic scoliosis represents the combination of torsional regions joined by junctional zones, each torsional region including a variable number of vertebrae in extension, rotated and translated to the same side." The term torsion has two meanings: (1) mechanical torsion of the spine and (2) geometrical or helicoidal torsion of the spine. Mechanical torsion relates to the morphology and geometrical torsion relates to the geometry (Stokes, 1994). Perdriolle and Vidal (1985) described mechanical torsion as: (1) intervertebral torsion, affecting the discs; and (2) intravertebral torsion, affecting the vertebra itself. Perdriolle and Vidal (1985) considered that the proper term for axial rotation of the vertebrae in the apical region is "torsion angle." In addition, the term "specific rotation" represents the sum of the angles of axial rotation in the vertebrae from the junctional or transitional region (i.e., contralateral rotations). The "torsion angle" as well as the "specific rotation" in the upper junctional region of a thoracic scoliosis are both good predictors for progression during the prepubertal period of growth (Perdriolle and Vidal, 1985). Specific rotation in the upper and lower junctional regions of a lumbar or a thoracolumbar scoliosis is the prelesion of holistesis (n.b. rotatory listesis or 3D listesis are synonyms), which has been associated with back pain in adult life (Kostuik and Bentivoglio, 1981). For practical reasons, this author will use the term "angle of axial rotation" instead of that recommend by Perdriolle and Vidal (1985) "torsion angle" when referring to the apical vertebra of any curve. Further considerations of the three-dimensional changes of spinal geometry are presented in forthcoming sections.

The scoliotic deformity in the frontal plane

This section addresses the frontal plane projection of the deformed spine in a full spine radiograph. In such a plane, the scoliotic curve is defined by: (1) the inclination of both end vertebrae, superior and inferior; and (2) the lateral translation of the apical vertebra, which presents, at the same time, the maximum axial rotation. According to the Scoliosis Research Society's nomenclature, a primary curve can appear at the thoracic region (apical vertebra between Th2 and Th11), at the thoracolumbar region (apical vertebra between Th12 and L1), and at the lumbar region (apical vertebra between L2 and L4). AIS can be primary single or combined. A single curve is usually compensated by two functional curves. Lumbosacral, cervicothoracic, and cervical curves are considered secondary in AIS.

The inclination of the end vertebrae, and indirectly the magnitude of the curve, can be assessed by measuring the

Cobb angle (Cobb, 1948). The Cobb angle is formed by the inclination of the upper end plate of the upper end vertebra and the inclination of the lower end plate of the lower end vertebra (Figure 1). The Cobb angle was adopted to supercede the old Ferguson angle, which more properly defined the lateral deviation because it used three points marked on the curve (upper and lower end vertebrae and apical vertebra) instead of the two references points used by Cobb (upper and lower end vertebrae). Both angles are reliable (Stokes et al, 1993), but the Ferguson angle was ostensibly better suited to automated measurement. Lateral deviation has also been assessed by using a Ferguson's modified angle with an increased accuracy and acceptable reliability (Diab, Sevastik, Hedlund, and Suliman, 1995).

Interobserver reliability measuring the Cobb angle has been shown to be variable in different studies, from 4.2 to 7.2° (Beekman and Hall, 1979; Morissy et al, 1990). Pruijs et al (1994) found a good reproducibility of the Cobb angle measurement between different investigators, but they concluded that the variation in production of a spinal radiograph can be an important source of error, and this should be taken into account when making decisions in scoliosis management. De Smet, Goin, Asher, and Scheuch (1982) showed that the angles on the posteroanterior radiographs were larger than those on the anteroposterior radiographs by a mean of 2.4° for the thoracic curves and 1.7° for the lumbar curves with a high correlation (r=0.96) between the angles measured in both projections. Conventional and digital radiographic methods seem to be comparable (Gstoettner et al, 2007; Mok et al, 2008; Zmurko et al, 2003). Kuklo, Potter, Schroeder, and O'Brien (2006) have concluded that the importance of digital vs. manual measurement reliability will increase as digital radiograph viewing becomes more prevalent. Some attempts have been made to estimate the Cobb angle by using active shape models in patients with AIS (Allen et al, 2008; Hill et al, 2006). In both studies, the automated method to assess the Cobb angle was reliable just for moderate size curves but did not properly detect vertebrae among the largest curves unless a modified training set of large curves was used. On the other hand, intraday variability of what the Cobb angle attempts to measure (i.e., the scoliotic curve) must also be considered as a possible source of error (Beauchamp et al, 1993; Gram and Hasan, 1999; Harrison et al, 2006). Beauchamp et al (1993) measured the Cobb angle in 19 girls with moderate to severe scoliosis in two different X-rays, one at 8:00 AM and a second one repeated at 8:00 PM under the same conditions. The average Cobb angle was 60° in the morning radiographs and 65° and in the afternoon's ($p < 0.001$). They concluded that there is a statistically and clinically significant daily increase of curve severity in moderate to severe scoliosis.

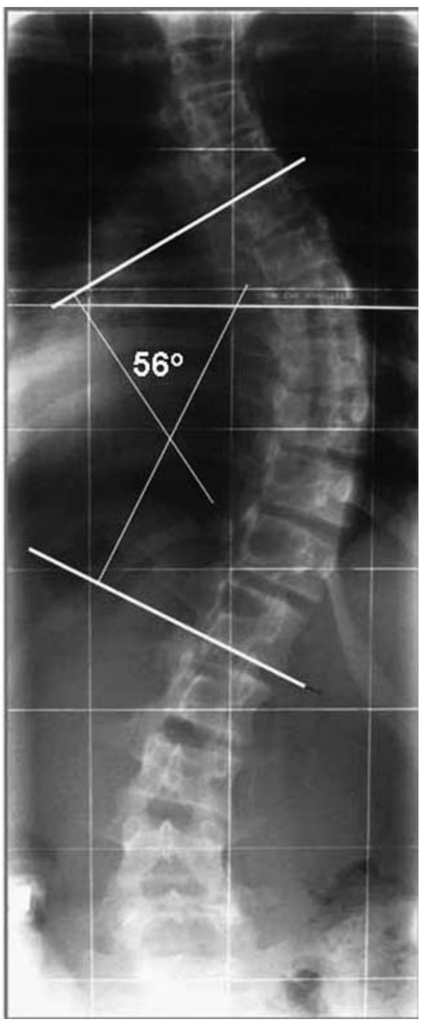


FIGURE 1 The Cobb angle is formed by the inclination of both "end vertebrae," the upper and the lower "end vertebra." The Cobb angle does not describe the deformity but it correlates with curve progression.

Although indications for treatment are related to angular value of the Cobb angle in scoliosis over 30° in immature patients with mild scoliosis (Cobb angle < 30°), the Cobb angle has to be combined with other parameters to establish the risk of further progression. To recognize a scoliotic curve as a progressive one in a retrospective way is relatively easy. A patient with a 45° scoliotic curve in the thoracic region who presented with a 25° curve 1 year before can be documented as a progressive case. In this case, the Cobb angle changed significantly in 1 year, and such a change can be also considered clinically significant. However, definition of progression in a prospective way is not an easy issue. Prospectively, definition of progression is related to an increase of the Cobb angle during a limited period of time (5° or more in an observational time of 6 months referred to curves of 20° or more, and 10° or more in curves initially under 20°). However, all the above mentioned source of errors and variability should be taken into consideration when making decisions (to treat or not to treat) and when changing strategies (to treat conservatively or surgically) or even when reporting the effectiveness of any treatment modality. A significant change in the Cobb angle after an observational time of 6 months only has clinical value if it is able to predict that during the next 6 months the angle will further increase after a longer observational time (i.e., a mild scoliosis will become moderate to severe). On the other hand, a Cobb angle change defined as “not significant” could also be a sign of further progression. Thus, decisions should be made by an experienced clinician with the lowest individual error when measuring the Cobb angle. On the other hand, such a clinician should consider other sources of error and variability to achieve best practice. In any case, the Cobb angle should not be used as an isolated parameter to define a rigid protocol of threshold values of deformity when therapy is indicated, but used in combination with other parameters and variables, sometimes objective and sometimes subjective.

The relationship between progression and growth has been well established in a way that the younger the patient is and the higher the initial Cobb angle, the greater the risk for progression (Lonstein and Carlson, 1984). Lonstein and Carlson (1984) defined a progression factor by combining the initial Cobb angle, the chronological age, and the bone age (Risser sign). This methodology has been adopted by the guidelines committee of the International Society for Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) to recommend indications for conservative management of scoliosis (Weiss et al, 2006). Although Lonstein and Carlson’s progression factor cannot predict the individual risk for progression like 0=non progressive and 1=progressive, it can express in a percentage from 0 to 100 the incidence of progression for a segment of the population with a particular age, Risser sign, and Cobb angle, allowing the establishment of useful guidelines (Figure 2).

Axial rotation

Viewing idiopathic scoliosis as a three-dimensional deformity and its component in the transversal plane—axial rotation—has received increasing interest during the last two decades. Regardless whether vertebral rotation in the transverse plane is a primary factor in the pathogenesis of AIS or not, it is an important component of the three-dimensional deformity and has been correlated with (1) the Cobb angle (Krawczinski, Kotwicki, Szulc, and Samborski, 2006; Kuklo, Potter, and Lenke, 2005); (2) the angle of trunk rotation (Krawczinski, Kotwicki, Szulc, and Samborski, 2006); and (3) the progression of the deformity (Villemure et al, 2002).

According to anatomical terminology, axial rotation of a vertebra is to the right when the anterior component—vertebral body—rotates to the right or the posterior component of the vertebra (i.e., the vertebral arch) rotates to the left (Figure 3). Axial rotation in AIS is typically to the same side of the lateral deviation—axial rotation to the right when lateral deviation is to right and axial rotation to the left

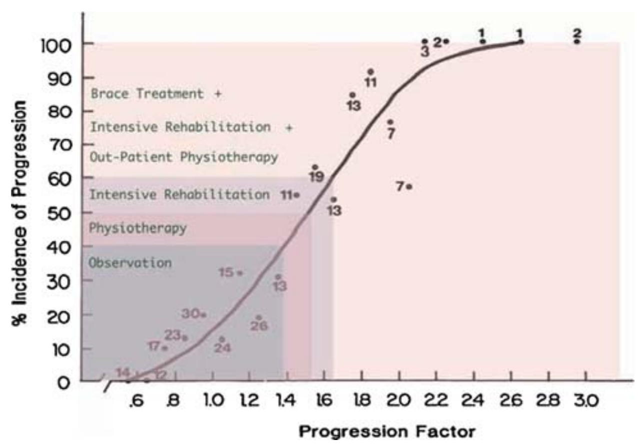


FIGURE 2 The progression factor from Lonstein and Carlson is calculated by using the formula: progression factor=Cobb angle – 3 × Risser sign/Chronological age. Some guidelines can be established according to the risk for progression.

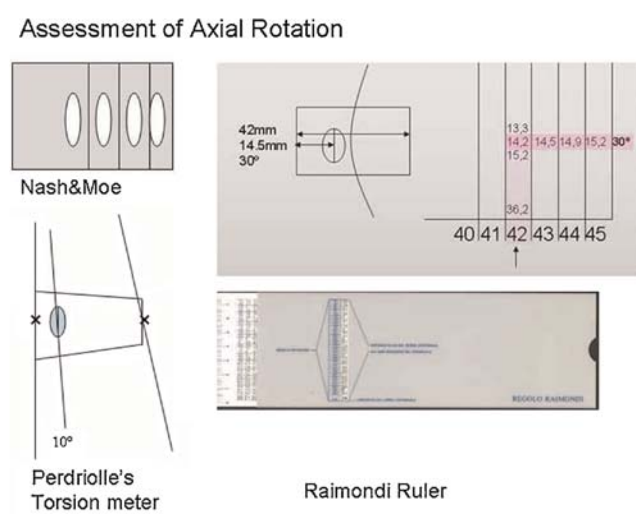


FIGURE 3 Different methods to assess axial rotation. Raimondi method is easier and a little more reliable than the Perdriolle’s torsion meter, which has been the one most frequently used by clinicians.

when lateral deviation is to the left—although in some cases (7%) it can be observed in opposition to the major curve (n.b. this is nonstandard or atypical scoliosis) (Armstrong, Livermore, Suzuki, and Armstrong, 1982). According to personal observations as well as reports in the literature (Deacon, Berkin, and Dickson, 1985), it is not uncommon that patients diagnosed with thoracic juvenile kyphosis—or Scheuermann disease—present a mild scoliotic curve in the lumbar or thoracolumbar region with standard rotation. However, in these patients, sometimes rotation extends cranially into the thoracic region, which is at the same time minimally counter-deviated. This is a clinical observation of nonstandard rotation that appears in a kyphotic region minimally deviated to the side.

Causality of the scoliotic axial rotation is undetermined. Coupled rotation would be the putative mechanism during scoliosis progression to explain axial rotation (Haderspeck and Schultz, 1981). Dickson, Lawton, Archer, and Butt (1984) stated that axial rotation to the same side of the lateral deviation is related to a dorsalization of the instantaneous axis of axial rotation. According to Dickson et al, when the main thoracic region is normally kyphotic, the instantaneous axis of axial rotation, located ventrally in the vertebral body, and throughout a mechanism of physiological coupling, would allow axial rotation in a way that the dorsal arch moves to the same side of the lateral deviation. Axial rotation in AIS would represent a sort of abnormal coupling where the vertebral body rotates to the same side of the lateral deviation around an axial axis located dorsally in the vertebral arch as a result of a polysegmental rectification of the thoracic kyphosis.

As a second putative mechanism, axial rotation could be related to primary torsional forces affecting the spine (Perdriolle and Vidal, 1987). Torsional forces will cause rotational translation of the spine changing the geometry of the spine in 3D (geometrical torsion) and also producing a mechanical torsion of the spine. In accordance with this finding, some elements of the intravertebral deformity have been clearly associated with rotational translation, both in opposite direction (Kotwicki and Napiontek, 2008). Both primary torsion and coupled vertebral rotation are two different mechanisms related to axial rotation of the vertebrae in IS.

Vertebral rotation can be measured by using different technologies and methods. Computer tomography (CT) has been considered the most accurate method, but its clinical utility is limited for several reasons (i.e., cost, radiation exposure, or posture of the patient). A new method that uses specific landmarks on the vertebral body in an X-ray film, in combination with appropriate geometrical relationships and a computer iteration method to obtain rapidly the rotation angle of the vertebra in the transversal plane, provides more accurate results than CT (Chi et al, 2006). Notwithstanding, the Nash-Moe and Perdriolle methods remain the standard measurements in daily clinical practice because of their simplicity and sufficient reliability (Figure 4). Measurement of vertebral rotation from frontal X-ray projections of the pedicles in relation with the frontal projection of the vertebral body was introduced by Nash and Moe (1969). Drerup (1984, 1985) proposed a modified method from Nash and Moe to increase accuracy and reliability. The torsion meter from Perdriolle became the most widely used tool to measure vertebral rotation on frontal X-ray projections in its classical format. General findings report accurate measurements to within ±5 degrees (Barsanti, deBari, and Covino, 1990; Omeroglu, Ozekin, and Biçimoglu, 1996; Weiss, 1995), despite some negative findings (Richards, 1992). A recent article by Lam et al (2008) about vertebral rotation methods summarizes and compares the most used radiographic methods as well as two CT methods. The authors provide a very useful comparative table that offers a simple but complete overview of the advantages and disadvantages between the different methods. The Raimondi method is less known than the above

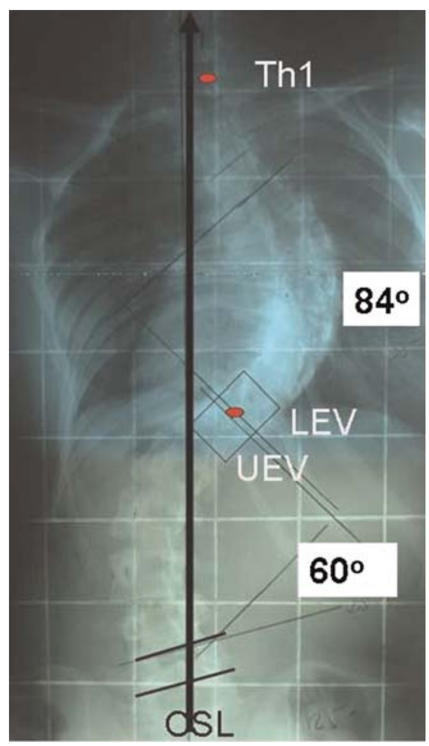
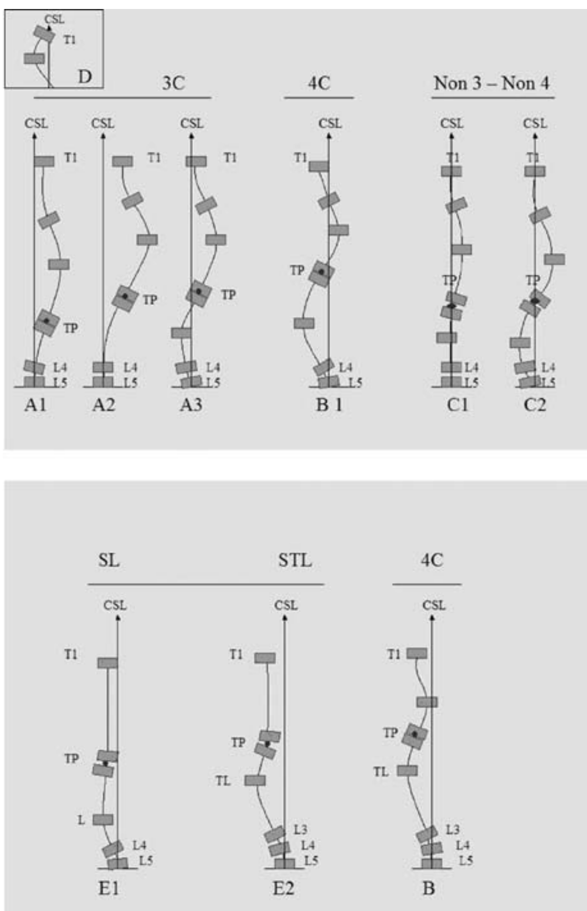


FIGURE 4 Spinal imbalance in the frontal plane can be assessed by the T1/CSL offset as well as from the TP/CSL offset. T1=the first thoracic vertebra; CSL=Central Sacral Line; and TP=Transitional Point.

mentioned methods, and it is missed in the Lam et al (2008) article. The Raimondi ruler is a modification of the Nash and Moe method providing a specific value of vertebral rotation, in a bigradual scale, according to the percentage displacement of the convex pedicle with respect to the vertebral body width (Figure 5). Weiss (1995) found the Raimondi ruler easier to use and slightly more reliable than the Perdriolle torsion meter. On the other hand, the common size printed digital X-ray is too small to use either of the two last methods. We have currently diminished the proportion of the



(A)

(B)

FIGURE 5 (a) Rigo classification includes thoracic scoliosis, also called 3-curve scoliosis pattern (A) and true double major scoliosis, also called four curve scoliosis pattern (B). A balanced thoracic scoliosis with no lumbar curve or with a structural lumbar curve is called non 3 – non 4 curve scoliosis pattern (C). Three curve scoliosis pattern (A) can be seen without lumbar curve (A1), with a minor functional curve (A2) or with a minor structural curve (A3). The main criteria for diagnosis is the TP/CSL offset: to the convex thoracic side in three curves, to the concave thoracic side in four curves and no offset in non 3–non 4. (b) The Rigo classification also includes single lumbar (E1) and thoracolumbar (E2) scoliosis pattern. Thoracolumbar scoliosis is, in some cases, combined with a minor functional thoracic curve. In this last case the curve pattern is four curve scoliosis pattern like (B).

original Perdriolle torsionmeter to be used in such small formats, but its reliability has not been established. An additional advantage of the Raimondi ruler would be the possibility to measure vertebral rotation directly from the screen of any PC with no marks and just increasing the size of the measurable vertebra to reach a minimum transversal diameter of 20 mm (the minimum value for such a diameter provided by the Raimondi ruler). According to our personal experience this is an affordable, simple, and very rapid procedure to be used in daily clinical practice. Again, reliability of this method has not been established yet.

Vertebral rotation has also been measured by using ultrasound (Burwell et al, 2002; Suzuki et al, 1989), magnetic resonance imaging (MRI), and three-dimensional MRI (Birchall et al, 1997). Burwell et al (2002) have used a portable real-time ultrasound machine to measure spinal and rib rotation in preoperative patients with AIS. Reliability measuring the mean average of spinal rotation and rib rotation was acceptable, although repositioning the patient altered significantly the findings.

Axial rotation is seldomly reported in articles about treatment indications and results in AIS despite the general perception that it constitutes an essential point in patient evaluation besides the Cobb angle. Considering the different methods and personal preferences, authors should report their own intra-observer reliability of the elected method when publishing articles about treatment results.

Spinal balance/imbalance

The SRS Working Group on 3D terminology of spinal deformity (Stokes, 1994) defined four axis systems for the whole body, the spine, curve regions, and individual vertebrae called, respectively, (1) global, (2) spinal, (3) regional, and (4) local coordinate systems. Spinal balance/imbalance is defined by using the comparison of two axial oriented axes from the less restrictive systems, the spinal and the global coordinate systems. Both systems have their center in the middle of the upper end plate of S1. The global axial axis goes from the center of the coordinate system perpendicularly to the floor with a cranial direction. Most clinicians call this axis “central sacral line” (CSL), and it can be drawn easily on the X-ray film. The spinal axial axis goes from the center of the coordinate system to the center of T1. In a balanced spine both axes are superimposed. Frontal plane imbalance of the spine can be considered as the angle formed by the two axes when they are not coincident. In daily practice, frontal plane imbalance is usually assessed by measuring the offset of T1 from the CSL (Figure 6). Notwithstanding,

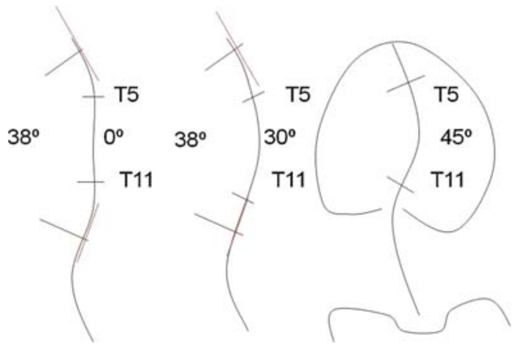


FIGURE 6 The restricted thoracic kyphotic angle takes as end vertebrae the end vertebrae of the scoliotic curve. Two patients with the same regional thoracic kyphotic angle can present a different restricted kyphotic angle.

this radiological parameter did not correlate with the patient's own clinical observation of imbalance compared with the head/pelvis alignment in the Walter Reed Visual Assessment Scale (WRVAS) (Bago, Climent, Pineda, and Gilperez, 2007). The authors had the impression that patients related this question regarding trunk imbalance in the frontal plane with waist asymmetry, an aspect that was not specifically covered by any of the pictures provided by the WRVAS. A radiological parameter called "frontal plane balance/imbalance of the transitional point" described by Rigo could be more closely related with trunk imbalance observed clinically (Rigo, Villagrasa, and Gallo, 2010). This parameter has been used by Rigo et al (2010) as radiological criteria for a classification correlating with brace design and physiotherapy (Figure 6). Interobserver reliability and correlation with clinical assessment of trunk balance/imbalance need further investigations.

The simplest parameter to assess sagittal spinal balance/imbalance is the C7-sacral promontory line on lateral film (McCance, Denis, Lonstein, and Winter, 1998). The sagittal geometry of the normal and scoliotic spine is described later in a different section.

Curve patterns in the frontal plane

Frontal plane projection is just a one-dimensional view of a complex scoliotic 3D geometry. However, for decades a constant effort has been made to classify the curve patterns in this frontal projection to describe the deformity, to predict its spontaneous evolution, to establish a proper treatment, to design a correct surgical strategy, to define brace biomechanical principles, and to describe specific exercises. Ponseti and Friedman (1950) published a study on 394 untreated patients with idiopathic scoliosis with different curve patterns. They concluded that these anatomic-radiological forms showed differentiated types of evolutions, pathological consequences, and therapy approaches. Ponseti and Friedman's (1950) classification was later revised by Moe and Kettleson (1970). Moe and Kettleson's (1970) classification recognized three single types: (1) thoracic, (2) thoracolumbar, and (3) lumbar; and four combined types: (1) main thoracic/minor lumbar, (2) double major thoracic/lumbar, (3) double major thoracic/ thoracolumbar, and (4) thoracic double major. Lee, Denis, Winter, and Lonstein (1993) after introducing later a single upper thoracic type, analyzed the behavior of the upper structural curve creating a new concept of the double thoracic curve pattern. Moe and Kettleson's classification was the most used by orthopedic surgeons and rehabilitation doctors until the introduction of the King classification (King, Moe, Winter, and Bradford, 1983). King et al (1983) presented a specific classification to determine the selection of fusion level in thoracic idiopathic scoliosis. The King classification differentiates five types, numbered I to V. Type III and IV correspond to single thoracic and long single thoracic curves. Type V is defined as a main thoracic curve combined with an upper structural curve; in other words, the thoracic double major curve pattern. In type III, IV, and V thoracic curves the lower level of fusion should be centered over the sacrum to achieve a balanced and stable spine. Type I is defined as true double and type II as false double. According to King et al (1983), in type II of less than 80° selective thoracic fusion can be performed while care is taken to use the vertebra that is neutral and stable so the lower level of the fusion is centered over the sacrum. Cummings et al (1998) showed that the King classification had poor reliability. After analyzing the interobserver reliability and the intraobserver reproducibility, they concluded that according to the definition of Landis and Koch, the classification of King et al (1983) is substantially reproducible but only moderately reliable. However, according to the stricter criteria reproducibility was defined as fair and reliability poor (Cummings et al, 1998). Lenke et al (2001a) also concluded that the King classification does not appear to have sufficient interobserver and intraobserver reliability among scoliosis surgeons to portray curve patterns accurately. However, the sources of unreliability are not well understood. Stokes and Aronsson (2002) carried out an investigation to determine sources of variability in radiographic classification. They used the King classification to determine whether unambiguous rules encoded in a computer program would ensure reliable classification. The conclusion was that objective measurements and rule-based algorithms were able to eliminate some sources of interobserver and intraobserver errors in classification of spinal deformity. However, when classification parameters fall close to the boundaries for classification, reliability problems will persist (Stokes and Aronsson, 2002). A different classification was developed by Coonrad et al (1998). They performed a logical classification of 2,000 consecutive IS cases based on the Scoliosis Research Society-defined apical vertebra. Later, in 2001, Lenke et al (2001b) presented a new classification system to determine the extent of spinal arthrodesis. Lenke classification has been widely used since then, and reliability has been shown to be better than the old King classification in some studies (Lenke et al, 2001b; Ogon et al, 2002). Professional training appears as a putative factor influencing results in reliability studies. Niemeyer et al (2006) showed that Lenke and King classifications demonstrated poor to fair interobserver and good intraobserver agreement on non-measured radiographs, whereas both classifications demonstrated a good to excellent interobserver agreement on premeasured radiographs. These authors concluded that on non-measured radiographs, the degree of professional training and the measurement process influenced the outcome, whereas on premeasured radiographs, the interobserver agreement does not seem to be influenced by the level of professional training. Thus, professional training should be taken into consideration when discussing the variability of scoliosis classification. Lenke classification correlates with treatment plan when surgery is the treatment (Lenke, Edwards, and Bridwell, 2003; Lenke et al, 2001a; Puno et al, 2003). Looking at the current evidence, Lenke classification should be used by orthopedic surgeons when planning surgery in AIS; however, its description and use surpass the objective of this present article.

In conservative management King (Liao et al, 2007) and Lenke (de Mauroy et al, 2008) classifications have been used to specify brace design. The Lenke classification seems to be less appropriate for brace design and exercises due to its unnecessary complexity. Historically, brace design has been based on a single classification differentiating between single and double curve patterns. In 2001 D'Amato, Griggs, and McCoy published an article presenting the results of nighttime bracing with the Providence brace in adolescent girls with IS, where brace design was based on a simple classification. The Providence brace system proposes three basic models: (1) lumbar, (2) thoracolumbar, and (3) double curve brace designs, with an extension available for high thoracic curves. This simplified approach had been used previously by Lehnert-Schroth (2000) to differentiate two functional types of curves in physical therapy, for which she created the terms "three curves" and "four curves" scoliosis pattern. The terms and diagnosis criteria defined by Lehnert-Schroth (2000) appeared simple, but were, in fact, more sophisticated than a mere classification of single and double. Lehnert-Schroth (2000) differentiated between single thoracic with no lumbar or with a minor lumbar curve (i.e., "three curves") from a true double curve associated with a compensatory-fractioned lumbosacral curve (i.e., "four curve"). In addition, Lehnert-Schroth (2000) had categories for single lumbar and thoracolumbar scoliosis. The Lehnert-Schroth classification has been used by many physiotherapists in Europe to teach postural autocorrection in scoliosis patients. Later, Chêneau (1994) incorporated Lehnert-Schroth's terminology but not her criteria. Chêneau (1994) initially defined "three curve scoliosis" as any single curve and "four curve scoliosis" as any double curve; correspondingly, he proposed two basic brace designs also called "three curve scoliosis brace" and "four curve scoliosis brace." Since 1968 the Barcelona Scoliosis Rehabilitation School ("BSRS") has been using specific three-dimensional physical therapy methods and bracing as a nonsurgical therapy option. In 1988 the BSRS began utilizing the Chêneau brace in place of the Milwaukee and Boston braces because, at least theoretically, the Chêneau brace was closer to the necessary detorsional forces, with no deleterious effect on the sagittal configuration of the spine. The main impetus for such a change was the intention to prevent the flat back syndrome so often associated with the Milwaukee and Boston braces. A secondary justification was to find a better correlation between the principles of correction applied in physical therapy and bracing. The Chêneau brace was the closest to this correlation, despite the fact that initially we observed failures in the Chêneau original classification with cases where the basic three curves or four curves brace design produced undesired changes in the original curve pattern or resulted in inadequate in-brace corrections. Coming back to simplicity, Rigo, Villagrasa, and Gallo (2010) have combined clinical and radiological criteria to present a new classification to make brace design more logical. Clinical criteria are, in part, those described previously by Lehnert-Schroth (2000), while radiological criteria are new. The new classification correlates with physical therapy and brace design when the Chêneau brace is indicated (Rigo and Weiss, 2008). A full description of this new classification is available in a recent article (Rigo, Gallo, and Villagrasa, 2010).

The scoliotic deformity in the sagittal plane

Morphologically, idiopathic scoliosis is a fixed or structural lordotic deformity; let us call it "structural flat back." However, from the geometrical point of view the spinal midline adopts a complex and highly variable torsional geometry in the three dimensions of the space, from a geometrical lordoscoliosis to a paradoxical kyphoscoliosis. Evolution of a classical thoracic scoliosis has been described as a torsion with the apex vertebra translating away from the upper end vertebra and at the same time following a clockwise angular pathway to the upper end vertebra of right thoracic curves and a counterclockwise angular pathway for left upper curves (De Smet et al, 1984; Asher and Cook, 1995). According to Asher and Cook (1995), the apical vertebra in a right thoracic scoliosis moves away from the upper end vertebrae first in a ventrolateral direction and later in a laterodorsal direction. Thus, while the structural lordosis increases during the whole course of progression, the geometry of the spine in a particular case can be sequentially described as hypokyphotic, flat, lordotic, then flat again, hypokyphotic, normokyphotic, and finally paradoxically hyperkyphotic. Paradoxical hyperkyphosis represents a hyperrotated spine where lateral translation occurs in an oblique plane closer to the patient's sagittal plane. The plane where lateral deviation progresses is called "plane of maximum deformity." The Cobb angle is the highest in such a plane. Recently, Sangole et al (2009), proposing a new clinically relevant means (the daVinci representation) to report 3D spinal deformities, have studied several thoracic segment indices derived from 3D reconstructions of coronal and lateral standing radiographs of 172 patients with right thoracic AIS. The indices were the: Cobb angle in the frontal plane; axial rotation of the apical vertebrae; and orientation of the plane of maximum curvature (PMC) of the main thoracic curve and the angle of kyphosis between T 4 and T 12 (Sangole et al, 2009). The authors were able to distinguish two subgroups within the surgical cases (major curves) of Lenke type 1 curves, suggesting that thoracic curves are not always hypokyphotic in their geometry. These results supported previous data and have provided a nuance to the dogma according to which thoracic scoliosis is always a hypokyphotic deformity. Once again, such a dogma works when describing the morphology of the scoliotic spine (and even this could be debatable) but not its geometry. Notwithstanding, there is still no clarity in describing idiopathic scoliosis as normokyphotic, hypokyphotic, hyperkyphotic, or even lordotic. The regional angles of thoracic kyphosis and lumbar lordosis are insufficient to assess the sagittal plane of the scoliotic spine due to its 3D nature. The "restrictive kyphotic angle" seems to be more accurate for this purpose (Stokes, 1994). The restrictive kyphotic angle takes as upper and lower end vertebrae those that act as upper end and lower end vertebra of the scoliotic region in the frontal projection (Figure 6). An additional complication for the understanding of the 3D nature of idiopathic scoliosis is the configuration of the normal and the scoliotic spine in the lateral projection. The spine is normally rectilinear in the frontal plane projection. However, in the lateral projection, its particular sagittal morphology and geometry can be observed. Several authors have described the morphology and geometry of the spine in the sagittal plane, but the most relevant is the study from Bernhardt and Bridwell (1989) because they found a normal regional thoracic kyphosis of $36° \pm 10°$ (9–53) and a normal lumbar regional lordosis of $-44° \pm 12°$ (14–69). Typically, the anatomical thoracolumbar junction acts also as a normal geometric junction or transition. The upper anatomical thoracolumbar region (T10–T12) is mildly kyphotic (mean 5.5°), whereas the lower thoracolumbar region is mildly lordotic (mean $-3°$). Thus, a totally lordotic or totally kyphotic thoracolumbar region is abnormal and would represent an extension to cranial of the lumbar lordosis or an extension to caudal of the thoracic kyphosis, respectively. The scoliosis spine has been described as highly variable in its sagittal configuration. Sangole et al (2009) measured the angle of kyphosis in a large thoracic region (T4–T12), whereas Kotwicki (2002) concluded that the global thoracic kyphosis angle is a misleading parameter because it covers hypokyphotic and hyperkyphotic zones. Kotwicki (2002) measured different parameters in the X-ray on a lateral projection of 46 patients admitted for surgery with the same frontal plane curve pattern (Lenke type I, King type III). He assessed the following parameters: sagittal thoracic Cobb angle (T4–T12); upper thoracic kyphosis angle (T5–T8); lower thoracic Cobb angle (T9–T12); superior and inferior hemicurve sagittal angles; and others. Results showed a great variability. Kotwicki (2002) found a disharmonic distribution of kyphosis in the thoracic region. The lower thoracic region (T9–T12) was hypokyphotic while the main thoracic region (T5–T8) was hyperkyphotic in most of the cases for this particular pattern. According to Kotwicki (2002), the so-called normokyphotic curves were composed of one hyperkyphotic and one hypokyphotic zone in this specific frontal plane pattern of Lenke type 1. Duval-Beaupère et al (1992) were the first using the terms harmonic and disharmonic when describing the sagittal configuration of the scoliosis spine. Rigo and collaborators also found a significant variability of sagittal geometries in scoliotic as well as in nonscoliotic patients concluding that anatomical regional angles—T3–T12 and L1–L5—are inaccurate to describe the spinal shape in the lateral projection (Rigo, Quera-Salvá, and Villagrasa, 2006).

Other authors have intended to classify idiopathic scoliosis using 3D parameters. Poncet, Dansereau, and

Labelle (1999) proposed a new classification based on a first 3D analysis and using different patterns of geometric torsion in idiopathic scoliosis. Torsion behavior was different for curves presenting similar patterns in the frontal plane projection (Poncet, Dansereau, and Labelle, 1999). Also Negrini and Negrini (2006, 2007) and Negrini, Negrini, Atanasio, Santambrogio (2006) have published an easy three-dimensional morphological (3-DEMO) classification that has an acceptable repeatability and correlates with other clinical classifications.

This complex issue deserves more research because too many treatment approaches are based on too simple general assumptions and do not take into consideration the suspected high variability and individuality when considering 3D aspects in AIS.

AIS and growth: Skeletal age

The initiation and further progression of idiopathic scoliosis may occur during any rapid growth period. The Cambridge Encyclopedia of Human Growth and Development differentiate four stages of postnatal growth until reaching maturity: (1) infancy, (2) childhood, (3) juvenile, and (4) adolescent (Bogin, 1998). According to this author, infancy finishes at 36 months of age. Childhood goes from the end of infancy until completion of growth of the brain in weight, around 7 years of age. Juvenile period ends at the beginning of puberty, so it can also be called prepubertal period. Human adolescent period begins with puberty, marked by some visible sign of sexual maturation (secondary sexual development, pubic hair, breast development, voice and body habitus changes), well-established by Tanner stage 2 (Tanner, 1962). There have been two recognized growth spurts (growth acceleration): (1) at the end of childhood, before juvenile period; and (2) much more intense is the pubertal spurt (growth peak height velocity) and is followed by a deceleration phase until maturity is reached. Both spurts occur earlier, on average, in girls (10–11 years of chronological age) than in boys (12–13 years of chronological age).

The highest risk for progression in AIS coincides with the acceleration phase of growth observed during puberty. Duval-Beaupère (1971) established a clear relationship between scoliosis progression and growth peak height velocity. Potential for progression depends on growth velocity and residual growth. Assessment of skeletal age is an essential point to establish these two factors for progression.

Classically, skeletal age can be determined by using an atlas of skeletal maturity or by bone-specific scoring techniques (Cameron, 1998). The first one is based on the atlas created by Greulich and Pyle (1950). The second edition of the Greulich and Pyle atlas improved the quality of the original standard photographic plates and the drawings of the maturity indicators and added a method to predict adult height developed by Bailey in 1952 (Greulich and Pyle, 1959). The second one, bone-specific scoring techniques, was developed, according to Cameron (1998), to overcome the two main disadvantages of the atlas techniques: (1) the concept of the "evenly maturing skeleton"; and (2) the difficulty of using "age" in a system measuring maturity. The main technique was first developed in 1962 by Tanner and Whitehouse (TW1) and further updated in 1975 (TW2). By using the TW2 technique, skeletal maturity may be based on either the carpus (CARPAL) or the radius, ulna, and short bones (RUS) or a combination of the 13 RUS bones and the 7 CARPAL bones called TW2. The system is not simple and needs to be used with the help of a manual that contains written criteria, drawings, and photographs of the maturity indicators (Tanner et al, 1983).

From a practical point of view, in a clinical daily basis, the three most important features to be noted are (1) the beginning of the pubertal spurt, (2) the end of the pubertal spurt, and (3) cessation of growth. AIS progressing over 30° Cobb during the pubertal spurt will reach a final Cobb angle between 40° and 90° at cessation of growth, while AIS staying under 30° Cobb at the end of the pubertal spurt is a sign that the final Cobb angle will remain under 40° at cessation of growth (Perdriolle and Vidal, 1985). As written above in this same section, pubertal spurt coincides with the beginning of adolescence, which is marked by some signs of sexual maturation described by Tanner (e.g., Tanner stage 1 represents the prepubertal period and Tanner 2 marks the initiation of the pubertal spurt). Tanner stage 2 is characterized by the appearance of pubic hear and thelarche (breast development) in girls. On the other hand, menarche, or the onset of menstruation, is the clearest indicator of sexual maturation in girls, and it occurs after the spurt in height growth in 99–100% of girls, when height growth is slowing down (Eveleth and Tanner, 1990). In any case, to ensure that the growth peak height velocity has finished, the best is to combine menarchal status together with some indicator of bone maturation. The most popular and reliable method to establish bone maturity among scoliosis specialists has been and still is the Risser sign (Risser, 1958). The Risser sign can be established in a frontal scoliogram classically used for diagnoses and follow-up in AIS. Joseph C. Risser divided into six stages the process of ossification of the iliac epiphysis until its total fusion with the iliac crest by forming the iliac apophysis. At Risser sign 0 the excursion of the iliac apophysis is not yet visible. Risser sign 1 represents the start of the excursion of the iliac apophysis on the lateral aspect of the iliac crest. If the visible part of the iliac crest in the frontal scoliogram is divided in four parts or quarters, Risser sign 1 finishes when the excursion of the iliac apophysis completes the first part or quarter; at Risser sign 2 the excursion reaches the end of the second part or quarter; Risser 3 represents the excursion on the third part or quarter; Risser 4 the excursion is completed; and Risser 5 represents the total fusion of the iliac apophysis with the iliac crest. Risser sign 1 is recognizable a few months after menarche. Thus, the combination of menarche and Risser sign 1 is a good marker to establish the end of the pubertal spurt. There is not as simplistic a marker in boys unless the change in voice (an equivalent of menarche) can be clearly fixed in time. Maturity or end of growth is determined by Risser sign 5. No proliferative condrocyte zone of the iliac iliac apophysis can be found in AIS patients when either 16 years of skeletal age or Risser sign 5 as well as 2 years after menarche or over 15 years of age in patients with DSA stage III (from Digital Short bones Age scoring system) and Risser sign 4 (Wang et al, 2009). In a recent study, Wang et al (2008) found that the residual growth potential of spinal growth plates of the patients with the Risser grades of 2–5 was significantly lower than of the patients with Risser grades of 0–1. All these recent data stress the importance of the Lonstein and Carlson study on natural history of AIS, where the risk of progression was related to the chronological age, the Risser sign, and the Cobb angle, which has been already discussed above (Lonstein and Carlson, 1984). It must be noted here that the Risser sign is not assessed the same way in the whole world. There is one original and classical grading system used in the United States and also the French or European scale. In a well-designed study it has been concluded that the French-European grading system uniformly undervalued the ossification excursion of the iliac crest apophysis compared with the American Risser grading system (Bitan, Veliskakis, and Campbell, 2005). These authors also concluded that the observed discordance is a source of miscommunication and descriptive confusion in the literature and in patient treatment. For example, for most of the patients graded Risser 4 by using the original American Risser scale, the French-European scale would be grading Risser 3. Because databases cannot be corrected retrospectively and many European authors historically recorded their data according to the French-European scale, this point should be always clarified when submitting an article where the Risser sign is reported for a particular population or group of patients.

It has been stated above that in daily clinical practice it would be enough to establish the beginning of the pubertal growth spurt (Tanner 2), the end of the growth spurt (menarche and Risser sign 1), and maturity (Risser 4–5). However, in some individual cases, when indication for bracing is borderline in accordance with the Cobb angle, chronological age, menarchal status, and Risser sign, to know about residual growth potential is an essential point for best practice. The two above-mentioned systems to determine skeletal age (Greulich and Pyle atlas and the Tanner-Whitehouse RUS scoring systems) would then be recommended. In a quite recent study Sanders et al (2007) found that the TW-III RUS scoring system is the most reliable and accurate method to mark the initiation of the acceleration phase of growth. In this last study Sanders et al (2007) noted that the skeletal maturation score derived with the use of the TW-III RUS method was not only the best to mark the period of the curve acceleration phase but also separated patterns into low, moderate, and rapid curve acceleration. They concluded that the curve acceleration phase separates curves into various types of curve progression and strongly recommend the TW-III RUS method as the primary maturity measurement to determine skeletal maturity accurately in girls with idiopathic scoliosis. In a further study, Sanders et al (2008) found the use of the TW-III RUS scoring method as well as other methods to be impractical in a busy clinical setting, and they recommend a simplified scoring system involving the TW-III descriptors. These authors concluded that the simplified skeletal maturity scoring system is reliable and correlates stronger with the behavior of IS than the Risser sign or the Greulich and Pyle skeletal ages.

In conclusion, although Risser sign, in combination with other variables, such as chronological age and pubertal age, has been historically considered enough for the surgical and nonsurgical management of adolescent idiopathic scoliosis, the most accurate and reliable method to assess skeletal maturity, proposed by Sanders et al (2008), would be recommended for best practice.

Trunk deformity and back asymmetry

Idiopathic scoliosis is a 3D deformity of the spine and the trunk. Some authors have suggested that back asymmetry could play a primary role in the pathogenesis of IS (Grivas, Vasiliadis, Mihas, and Savvidou, 2007; Grivas et al, 2006).

Physical appearance, which is closely related to trunk deformity and back asymmetry, is claimed to be an important element in surgical as well as nonsurgical decision making. Donaldson et al (2007) have shown that "severity of deformity" can be consistently ranked as the most important surgical consideration. In their study, five surgeons had to rank the relative importance of 13 surgical considerations. While viewing clinical photographs of 40 patients, surgeons rated shoulder blades, shoulders, waist asymmetry, and the "overall appearance" of the back. Surgeons varied widely in their reliability of their ratings of physical appearance. The authors concluded that "because a patient's physical appearance is an important element of surgical decision-making, differences among surgeons could be contributing to inconsistent recommendations" (Donaldson et al, 2007). Experts in the conservative treatment of scoliosis from the International Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) tried to establish a consensus about what they wanted to obtain and to avoid for their patients. In other words, the question was "Why do we treat adolescent idiopathic scoliosis?" (Negrini et al, 2006). In this above-mentioned article the most important treatment outcomes were considered aesthetics (100%) and quality of life and disability (more than 90%). The question is how to objectively assess trunk deformity, back asymmetry, or physical appearance. Different instruments and technology have been used with more or less acceptation: specific instruments or scales to measure trunk deformity or aesthetic appearance; inclinometric systems designed to measure the angle of trunk inclination or rotation (ATI or ATR) in several postures; and systems based on surface topography measure are the most accepted in daily practice.

The Walter Reed Visual Assessment Scale (WRVAS) is a valid instrument used by health care professionals, patients, and their parents to assess trunk deformity from idiopathic scoliosis in adolescent as well as in adults (Bago, Climent, Pineda, and Gilperez, 2007; Pineda, Bago, Gilperez, and Climent, 2006; Sanders et al, 2003; Tones and Moss, 2007). Sanders et al (2003) found that WRVAS scores correlated significantly with curve magnitude and treatment. Parents and patients showed similar scores, but parents perceived more deformity of the ribs and shoulders than patients. Also Pineda, Bago, Gilperez, and Climent (2006) reported a highly significant correlation between the results of the test and the magnitude of the deformity. The WRVAS showed excellent internal consistency and absence of collinearity. Another interesting finding in this last study is the correlation between WRVAS and the SRS-22 image scale. However, in a further evaluation it was found that the profile of the individual WRVAS scores does not differentiate among specific curve patterns (thoracic, double major, and thoracolumbar or lumbar), and some of the drawings (WR3 flank prominence, WR5 trunk imbalance, and WR6 shoulder asymmetry) did not correlate with the radiological deformity they were designed to measure (Bago, Climent, Pineda, and Gilperez, 2007). The WRVAS is similarly reliable when administered to adults (Tones and Moss, 2007). A new WRVAS derivative instrument has been developed: the Trunk Appearance Perception Scale (TAPS), which shows excellent distribution of scores, internal consistency and test retest reliability. The TAPS has good capacity to differentiate the severity of the deformity. This new tool is simple and easy to complete and score, the figures are more natural than in the WRVAS, and includes a new ventral view (Bago, Sanchez-Raya, Sanchez Perez-Grueso, and Climent, 2010).

Other tools have been presented called Aesthetic Index (AI) and Trunk Aesthetic Clinical Evaluation (TRACE). Aesthetic Index uses a three-point scale for the asymmetry of shoulders, scapulae, and waist. TRACE uses a 12-point scale based on four subscales, shoulders, scapulae, hemithorax, and waist. There is fair repeatability for AI. TRACE shows fair intrarater but poor interrater repeatability, although increased clinical sensitivity to changes of the aesthetic scale (Zaina, Negrini, and Atanasio, 2009).

Two important signs from trunk deformity are (1) the dorsal rib hump (single thoracic curves and double major) and (2) the lumbar or thoracolumbar prominence (single lumbar or thoracolumbar curves and double major). Both prominences cause rotation or inclination measurable on the back with a Bunnell scoliometer (Figure 7). Although well visible when looking at the patient from the back in relaxed upright posture for moderate to severe curves, in mild curves the prominences are usually more recognizable in forward bending posture (Adams test). However, objective measurements showed that in the thoracic region the angle of trunk inclination (ATI) decreased from standing erect posture (measured with ISIS; see below) to sitting forward bending posture (measured with a Bunnell scoliometer) (Upadhyay, Burwell, and Webb, 1988).

Even though this article does not address patient management, a first question is "How useful is the scoliometer in the management of idiopathic scoliosis?" Several studies have shown that the scoliometer can be a reliable noninvasive method for repetitively assessing trunk rotation when used by a single trained observer (Amendt et al, 1990; Côté et al, 1998; Murrell, Coonrad, Moorman, and Fitch, 1993). Murrell et al (1993) found an interrater agreement using the scoliometer to measure the angle of trunk rotation of 0.81 and 0.82 for the thoracic and lumbar regions, respectively. In the study from Amendt et al (1990) intrarater and interrater reliability coefficients were also high, 0.97 and 0.86, respectively. In this last study the frequency of the analysis revealed good specificity, sensitivity, and predictive value of the scoliometer. However, correlation coefficients with

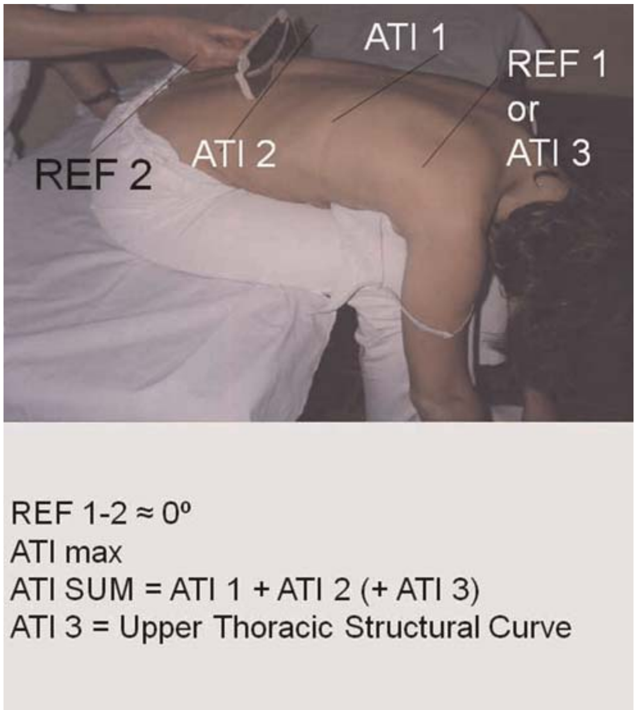


FIGURE 7 The angle of trunk inclination (ATI) can be measured with the scoliometer in forward bending in different positions. One of the recommended postures is forward bending in the sitting position. The pelvis should be nonrotated as well the upper thoracic region, unless there is a structural upper thoracic curve. The ATIs are measured at thoracic level (ATI 1) and at lumbar/thoracolumbar level (ATI 2).

pedicle rotation (0.32–0.46) and with the Cobb angle (0.46–0.54) were estimated less than optimal by the authors, suggesting that the validity of the scoliometer measurements is not sufficient to use this method alone for determining patient diagnosis and management. The tool would be appropriate just for screening according to these authors (Amendt et al, 1990). In addition, it has been shown that the use of a single ATI measurement has limitations in scoliosis detection and a multiple ATI system has advantages in early detection (Burwell, Patterson, Webb, and Wojcik, 1988). In addition, Côté et al (1998) concluded that the high level of interobserver measurement error limits its use as an outcome instrument. On the contrary, a study from Korovessis and Stamatakis (1996) showed a statistically significant correlation between the scoliometer value and the Cobb angle. They created two mathematical formulas to predict the Cobb angle of the thoracic and lumbar scoliosis with similar sensitivity and accuracy. However, no further studies have been carried out to estimate the clinical utility of these two formulas. It is still controversial whether the scoliometer should be used to measure the ATI in forward bending from a standing or a sitting posture. Burwell et al (1988) found that forward bending from standing gave the best reproducibility, whereas Grivas et al (2006) recommended forward bending from sitting posture because it correlated better with spinal deformity. The effect of leg length inequality on back shape asymmetry can be a reason for variability, but this effect can be estimated by placing the scoliometer transversely over the sacrum in the standing forward bending position. In standing forward bending, pelvis inclination caused by leg length inequality will be converted into pelvis rotation, which affects ATI. To eliminate this effect, the observer can use a shoe lift to measure the ATI with a sacrum horizontal to the floor.

The measurement of the ATI in combination with the spinous processes line has also been used to predict the Cobb angle with an error under 5° in mild to moderate curves by exploring the patient with a radiation-free system (Ovadia et al, 2007). The measurements from four independent sites and six independent examiners were not significantly different. This radiation-free system that quantitatively assesses scoliosis (Orthelius 800) was further validated by Parisini et al (2006). The author of this article has had a positive experience with the Orthelius 800. However, its use is limited due to the necessity of training, time consumption, and cost. On the other hand, the Cobb angle can also be predicted by using simpler and less expensive tools.

Notwithstanding, it should be considered that the scoliometer reliably measures the ATI, which is an important sign of the trunk deformity by itself, independent of its major or minor correlation with the spinal deformity. Grivas, Vasiliadis, Mihas, and Savvidou (2007) have demonstrated that growth has a significant effect in the correlation between the thoracic and the spinal deformity in girls with idiopathic scoliosis. They measured the posteroanterior and lateral radiographs of 83 referred girls to determine the effect of age on the correlation between thoracic deformity and spinal deformity. All the girls had a considerable trunk asymmetry with their ATI measuring at least 7° in any of the regions of the trunk (thoracic, thoracolumbar, or lumbar). An important finding of this study is that 25% of the patients with an ATI more than or equal to 7° had a spinal curve under 10° or had a straight spine, concluding that the Cobb angle alone cannot explain the whole deformity of the surface. A second important finding in the Grivas Vasiliadis, Mihas, and Savvidou (2007) article is that in younger children the concordance of the surface and the spinal deformity is weak and becomes stronger as the children mature. The results of this study also support the hypothesis that the rib cage deformity precedes the spinal deformity in the pathogenesis of IS.

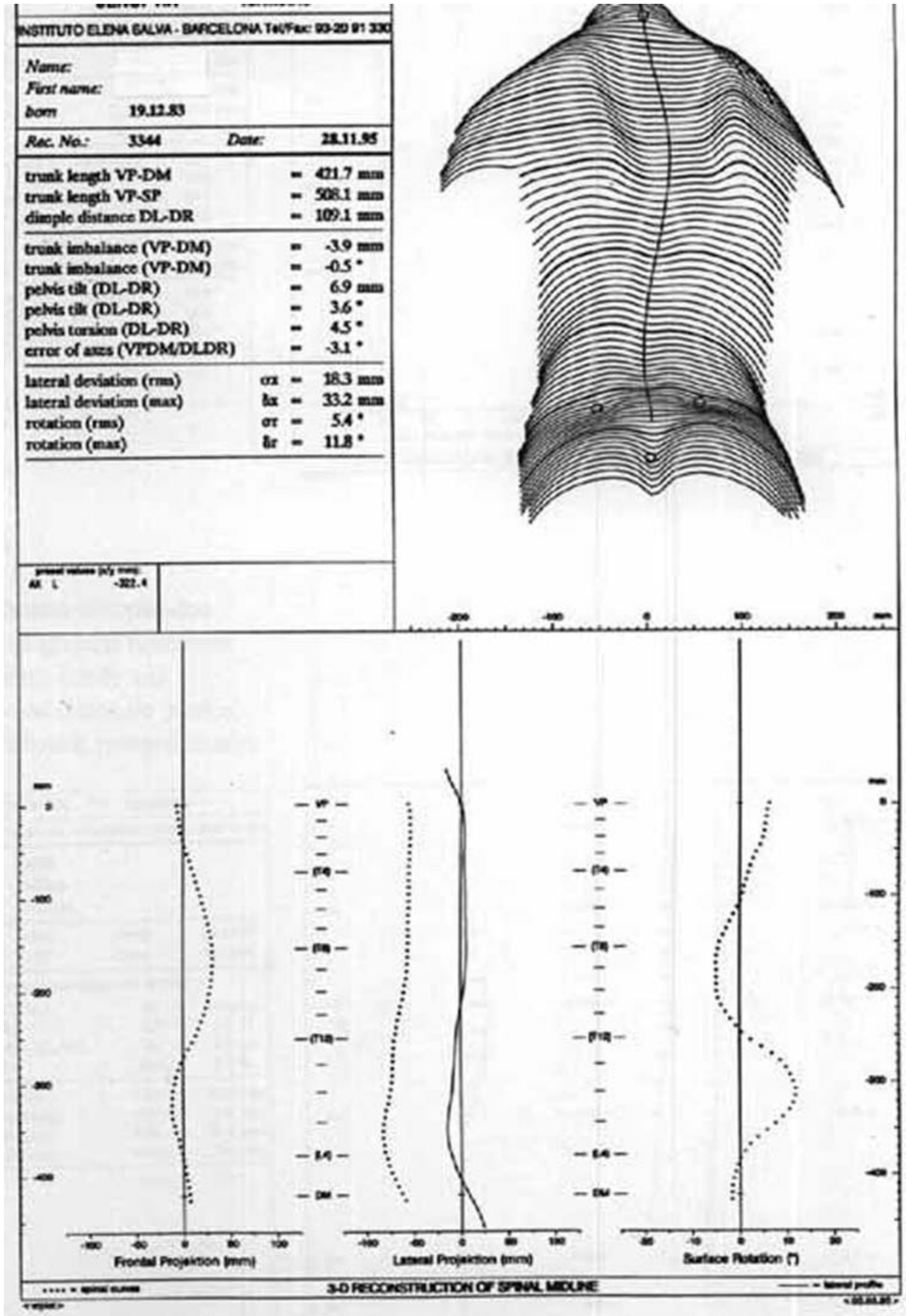


FIGURE 8 The formetric system is based on video rasterstereography. The spinal midline is virtually reconstructed from back shape.

Factors other than growth can influence the correlation between spinal deformity and trunk deformity. Kotwicki, Kinel, Stryla, and Szulc (2007) also found discrepancy in clinical versus radiological parameters describing deformity due to brace treatment for moderate idiopathic scoliosis. A case report showed a significant progression of the spinal deformity while back asymmetry had been improving during the follow-up of a girl with early onset IS treated with a brace (Weiss, 2006).

Optoelectronic devices are a different technology used to objectively assess back asymmetry. The surface topography of the back can be explored, and in some cases the spinal midline can be virtually reconstructed and presented in its frontal, lateral, and transversal view. The history of surface topography measurements is short but quite rich. Jean Dansereau organized the First International Symposium on 3-D Scoliotic Deformities joined to the VIIth International Symposium on Spinal deformity and Surface Topography in 1992. The meeting took place in Montréal, Canada. This group met again 2 years later in Pescara, Italy, to start a new society, the International Research Society of Spinal Deformities. Since then, a series of biannual meetings have been organized, and most of the research produced by this group has been published by IOS Press in a series of books under the name *Research into Spinal Deformities* as a part of the collection *Studies in Health Technology and Informatics* (Vol. 15, 37, 59, 88, 91, and 140). The amount of research on this specific issue, spinal deformities and surface topography, is vast and its full discussion is not feasible by the author of this current article, considering space limitations and the extension of the already discussed topics. A recent article has been published, which remarks on the essential contributions to science made by the IRSSD (Bagnall et al, 2009). Summarizing, different systems have been presented such as Quantec, Auscan, ISIS, SIPS, Formetric, and Moiré. Moiré has been used, for example, to define an aesthetic index called Posterior Trunk Symmetry Index (POTSI), which was proposed for the clinical assessment of scoliosis and to evaluate objectively the effect of surgery on trunk deformity (Inami et al, 1999; Suzuki et al, 1999). The Integrated Shape Imaging System (ISISI) has also been used by several groups to produce outcomes from surgery (Bettany, Partridge, and Edgar, 1995; Jefferson et al, 1988; Hullin, McMaster, Draper, and Duff, 1991; Wemyss-Holden, et al, 1992; Theologis et al, 1993). Theologis et al (1993) developed an equation based on ISIS parameters, which was able to show cosmetic changes in a reliable way. Although ISIS scanning has been able to identify curve evolution correctly in 84% of a patient group (Weisz et al, 1988), the system failed in the comparison between back shape changes and spinal deformity evolution in a group of braced patients (Tredwell and Bannon, 1988). The Formetric system uses video rasterstereography to measure the back shape and virtually reconstruct the spinal midline in 3D (Figure 8). The system provides useful clinical parameters for follow-up like trunk imbalance, pelvic tilt, pelvis torsion, lateral deviation, surface rotation, and a complete set of values from the analysis of the sagittal profile of the spine (Drerup and Hierholzer, 1994; Drerup and Hierholzer, 1996; Drerup, Hierholzer, and Ellger, 1997). On the one side, several studies have concluded that using the parameters of lateral deviation and vertebral rotation, rasterstereography accurately reflects the radiographically measured progression of idiopathic scoliosis during the long-term follow-up (Liljenqvist et al, 1998; Schulte et al, 2008). On the other side, Schumann, Püschel, Maier-Hennes, and Weiss (2008) concluded that surface measurements can be influenced by artificial postures and therefore cannot be attributed as objective. In this study, a group of patients following an intensive scoliosis rehabilitation treatment was able to influence the results of the rasterstereographic exploration by actively changing their posture. Schumann et al (2008) recommend that surface measurements should be made by someone independent from the treatment process to exclude bias. The system may be used for postural monitoring in the rehabilitation process of patients with scoliosis. On the other hand, Weiss (2009), in a critical review of the literature where the effect of conservative treatment was evaluated by using the outcome parameters from rasterstereography, found just two articles where the average of improvement was greater than the error of measurement. The technical error of the system had been shown by Weiss, Lohschmidt, and El Obeidi (1997) in a previous article. Thus, although rasterstereography has been used with accuracy to compare back shape before and after surgical treatment (Hackenberg, Hierholzer, and Liljenqvist, 2002; Hackenberg et al, 2003), even accepting that accuracy (compared to radiographs) was less after the treatment than before, it should be used with caution when interpreting outcomes from conservative management.

CONCLUSIONS

The evaluation of idiopathic scoliosis cannot only be related to the measurement of the Cobb angle and a particular frontal plane curve pattern classification. The Cobb angle is a valid parameter to identify the deformity but is insufficient, considering the complexity of this condition. A better understanding of the three-dimensional nature and the natural history of IS will help the specialist in the decision-making process and in the definition of different principles of correction to be applied in conservative as well as surgical treatment. Specific knowledge regarding the relationship between spinal deformity and trunk deformity is essential in monitoring changes produced by different treatments.

This article has defined and discussed critical aspects related to 3D nature of the deformity and back shape; lateral deviation; axial vertebral rotation; spinal balance and imbalance; curve pattern classifications; growth; and trunk deformity and surface topography. Radiological measurements have to be interpreted by considering measurement errors, reliability, variability produced by the acquisition of the images, and positioning of the patient, as well as postural and diurnal variations. On the other hand, information from radiographs is limited to one or two planes and if used alone in diagnosis could lead to incorrect interpretations that lead to wrong treatment principles. Assessment of skeletal age is also an essential point in surgical and nonsurgical management of AIS. Regarding AIS and growth, the Risser sign in combination with signs indicating the beginning of adolescence as well as menarchal status is enough for daily clinical practice. However, best practices require the use of an accurate system to calculate the residual growth potential and the different curve acceleration growth patterns. In measuring trunk deformity and back shape, inclinometric systems like the scoliometer can provide useful information, which is important by itself independent of its agreement with the spinal deformity. However, to improve repeatability, a rigid protocol should be established for a measurement procedure that should finally define whether to use forward flexion posture from a standing or from a sitting position. Surface topography systems properly describe back asymmetry, and some of them reconstruct the spinal shape with accuracy. These systems can be used for follow-up of nontreated patients to monitor the evolution of the deformity. Interpretation of the surface topography values during and after surgery and especially after conservative management to describe outcomes should be made with caution.

Other issues, such as pain, breathing function, psychological aspects, and health-related quality of life, which are also highly important in the scoliosis population, deserve a deeper discussion, which is beyond the scope of this article.

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REFERENCES

Allen S, Parent E, Khorasani M, Hill DL, Lou E, Raso JV 2008 Validity and reliability of active shape models for the estimation of Cobb angle in patients with adolescent idiopathic scoliosis. Journal of Digital Imaging 21: 208–218

Amendt LE, Ause-Ellias KL, Eybers JL, Wadsworth CT, Nielsen DH, Weinstein SL 1990 Validity and reliability testing of the scoliometer. Physical Therapy 70: 456–458

Armstrong GW, Livermore NB 3rd, Suzuki N, Armstrong JG 1982 Nonstandard vertebral rotation in scoliosis screening patients. Its prevalence and relation to the clinical deformity. Spine 7: 50–54

Asher MA, Cook LT 1995 The transverse plane evolution of the most common adolescent idiopathic scoliosis deformities. A cross-sectional study of 181 patients. Spine 20: 1386–1391

Bagnall KM, Grivas TB, Alos N, Asher M, Aubin CE, Burwell GR, Dangerfield PH, Edouard T, Hill D, Lou E, Moreau A, O'Brien J, Stokes I, Weiss HR, Raso J 2009 The International Research Society of Spinal Deformities (IRSSD) and its contribution to science. Scoliosis 4: 28

Bago J, Climent JM, Pineda S, Gilperez C 2007 Further evaluation of the Walter Reed Visual Assessment Scale: Correlation with curve pattern and radiological deformity. Scoliosis 2: 12

Bago J, Sanchez-Raya J, Sánchez Pérez-Grueso FJ, Climent JM 2010 The Trunk Appearance Perception Scale (TAPS): A new tool to evaluate subjective impression of trunk deformity in patients with idiopathic scoliosis. Scoliosis 5: 6

Barsanti CM, de Bari A, Covino BM 1990 The torsion meter: A critical review. Journal of Pediatric Orthopedics 10: 527–531

Beauchamp M, Labelle H, Grimard G, Stanciu C, Poitras B, Dansereau J 1993 Diurnal variation of Cobb angle measurement in adolescent idiopathic scoliosis. Spine 18: 1581–1583

Beekman CE, Hall V 1979 Variability of scoliosis measurement from spinal roentgenograms. Physical Therapy 59: 764–765

Bernhardt M, Bridwell KH 1989 Segmental analysis of the sagittal plane alignment of the normal thoracic and lumbar spines and thoracolumbar junction. Spine 14: 717–721

Bettany J, Partridge C, Edgar M 1995 Topographical, kinesiological and psychological factors in the surgical management of adolescent idiopathic scoliosis. Studies in Health Technology and Informatics 15: 321–326

Birchall D, Hughes DG, Hindle J, Robinson L, Williamson JB 1997 Measurement of vertebral rotation in adolescent idiopathic scoliosis using three-dimensional magnetic resonance imaging. Spine 22: 2403–2407

Bitan FD, Veliskakis KP and Campbell BC 2005 Differences in the Risser grading system in the United States and France. Clinical Orthopaedics and Related Research 436: 190–195

Bogin B 1998 Patterns of human growth. In: Ulijaszek SJ, Johnston FE, Preece MA (eds), The Cambridge Enciclopedia of Human Growth and Development, pp 91–95. Cambridge, Cambridge University Press

Burwell RG 2003 Aetiology of idiopathic scoliosis: Current concepts. Pediatric Rehabilitation 6: 137–170

Burwell RG, Aujla RK, Cole AA, Kirby AS, Pratt RK, Webb JK, Moulton A 2002 Preliminary study of a new real-time ultrasound method for measuring spinal and rib rotation in preoperative patients with adolescent idiopathic scoliosis. Studies in Health Technology and Informatics 91: 262–266

Burwell RG, Patterson JF, Webb JK, Wojcik AS 1988 School screening for scoliosis—The multiple ATI system of back shape appraisal using the Scoliometer with observations on the sagittal declive angle. Surface Topography and Body Deformity Proceedings of the 5th International Symposium, pp 17–23

Cameron N 1998 Radiographic assessment. In: Ulijaszek SJ, Johnston FE, Preece MA (eds), The Cambridge Enciclopedia of Human Growth and Development, pp 42–44. Cambridge, Cambridge University Press

Chêneau J 1994 Corset-Chêneau. Manuel d'orthopédie des scolioses suivant la technique originale. Paris, Éditions Frison-Roche

Chi WM, Cheng CW, Yeh WC, Chuang SC, Chang TS, Chen JH 2006 Vertebral axial rotation measurement method. Computer Methods and Programs. Biomedicine 81: 8–17

Cobb JR 1948 Outline for the study of scoliosis. Instructional Course Lectures, American Academy of Orthopaedic Surgeons, vol V: 261–275. Ann Arbor, MI, J.W. Edwards Co

Coonrad RW, Murrell GA, Motley G, Lytle E, Hey LA 1998 A logical coronal plane classification of 2,000 consecutive IS cases based on the Scoliosis Research Society-defined apical vertebra. Spine 23: 1380–1391

Côté P, Kreitz BG, Cassidy JD, Dzus AK, Martel J 1998 A study of the diagnostic accuracy and reliability of the scoliometer and Adam's forward bend test. Spine 23: 796–802

Cummings RJ, Loveless EA, Campbell J, Samelson S, Mazur JM 1998 Interobserver reliability and intraobserver reproducibility of the system of King et al. for the classification of adolescent idiopathic scoliosis. Journal of Bone and Joint Surgery Am 80: 1107–1111

D'Amato CR, Griggs S, McCoy B 2001 Nighttime bracing with the providence brace in adolescents with idiopathic scoliosis. Spine 26: 2006–2012

D'Amico M, Merolli A, Santambrogio GC 1995 Three-dimensional Analysis of Spinal Deformities. Studies in Health Technology and Informatics 15 IOS Press

Dangerfield PH 2008 Research into Spinal Deformities 6. Studies in Health Technology and Informatics 140 IOS Press

Dansereau J 1992 International Symposium on 3-D Scoliotic Deformities. Éditions de l'École Polytechnique de Montréal

Deacon P, Berkin CR, Dickson RA 1985 Combined idiopathic kyphosis and scoliosis. An analysis of the lateral spinal curvatures associated with Scheuermann's disease. Journal of Bone and Joint Surgery Br 67: 189–192

de Mauroy JC, Fender P, Tato B, Lusenti P, Ferracane G 2008 Lyon Brace. Studies in Health Technology and Informatics 135: 327–340

De Smet AA, Asher MA, Cook LT, Goin JE, Scheuch HG, Orrick JM 1984 Three-dimensional analysis of right thoracic idiopathic scoliosis. Spine 9: 377–381

De Smet AA, Goin JE Asher MA, Scheuch HG 1982 A clinical study of the differences between the scoliotic angles measured on posteroanterior and anteroposterior radiographs. Journal of Bone and Joint Surgery Am 64: 489–493

Diab KM, Sevastik JA, Hedlund R, Suliman IA 1995 Accuracy and applicability of measurement of the scoliotic angle at the frontal plane by Cobb's method, by Ferguson's and by a new method. European Spine Journal 4: 291–295

Dickson RA, Lawton JO, Archer IA, Butt WP 1984 The pathogenesis of idiopathic scoliosis. Biplanar spinal asymmetry. Journal of Bone and Joint Surgery Br 66: 8–15

Donaldson S, Hedden D, Stephens D, Alman B, Howard A, Naravanan U, Wright JC 2007 Surgeon reliability in rating physical deformity in adolescent idiopathic scoliosis. Spine 32: 363–367

Drerup B 1984 Principles of measurement of vertebral rotation from frontal projections of the pedicles. Journal of Biomechanics 17: 923–935

Drerup B 1985 Improvement in measuring vertebral rotation from frontal projections of the pedicles. Journal of Biomechanics 18: 369–378

Drerup B, Hierholzer E 1994 Back shape measurement using raster stereography and three-dimensional reconstruction of the spinal shape. Clinical Biomechanics 9: 28–36

Drerup B, Hierholzer E 1996 Assessment of scoliotic deformity from back shape asymmetry using an improved mathematical model. Clinical Biomechanics 11: 376–383

Drerup B, Hierholzer E, Ellger B 1997 Shape analysis of the lateral and frontal projection of the spine curves assessed from rasterstereographs. Studies in Health Technology and Informatics 37: 271–276

Dubousset J 1992 Importance of the three-dimensional concept in the treatment of scoliotic deformities. In: Jean Dansereau (ed), International Symposium on 3-D Scoliotic Deformities, pp 302–311. Montréal, Éditions de l'École Polytechnique de Montréal

Duval-Beaupère G 1971 Pathogenic relationship between scoliosis and growth. In: Zorab PA (ed), Proceeding of 3rd Symposium held at the Institute of Diseases of the Chest. London, Scoliosis and Growth

Duval-Beaupère G, Taussig G, Mouilleseaux B, Pries P, Mounier C 1992 Prognostic factors for idiopathic scoliosis. In: Jean Dansereau (ed), International Symposium on 3-D Scoliotic Deformities, pp 211–216. Montréal, Éditions de l'École Polytechnique de Montréal

Eveleth PB, Tanner JM 1990 Worldwide Variation in Human Growth, 2nd edn. Cambridge, Cambridge University Press

Gram MC, Hasan Z 1999 The spinal curve in standing and sitting postures in children with idiopathic scoliosis. Spine 24: 169–177

Greulich WW, Pyle SI 1950 Radiographic Atlas of the Skeletal Development of the Hand and Wrist. Stanford, Stanford University Press

Greulich WW, Pyle SI 1959 Radiographic Atlas of the Skeletal Development of the Hand and Wrist, 2nd edn. Stanford, Stanford University Press

Grivas TB 2002 Research into Spinal Deformities 4. Studies in Health Technology and Informatics 91 IOS Press

Grivas TB, Vasiliadis ES, Koufopoulos G, Segos D, Triantafyllopoulos G, Mouzakis V 2006 Study of trunk asymmetry in normal children and adolescents. Scoliosis 1: 19

Grivas TB, Vasiliadis ES, Mihas C, Savvidou O 2007 The effect of growth on the correlation between the spinal and rib cage deformity: Implications on idiopathic scoliosis pathogenesis. Scoliosis 2: 11

Gstoettner M, Sekyra K, Walochnik N, Winter P, Wachter R, Bach CM 2007 Inter- and intraobserver reliability assessment of the Cobb angle: Manual versus digital measurement tools. European Spine Journal 16: 1587–1592

Hackenberg L, Hierholzer E, Liljenqvist U 2002 Accuracy of rasterstereography versus radiography in idiopathic scoliosis after anterior correction and fusion. Studies in Health Technology and Informatics 91: 241–245

Hackenberg L, Hierholzer E, Pötzl W, Götze C, Liljenqvist U 2003 Rasterstereographic back shape analysis in idiopathic scoliosis after posterior correction and fusion. Clinical Biomechanics 18: 883–889

Haderspeck K, Schultz A 1981 Progression of idiopathic scoliosis: An analysis of muscle actions and body weight influences. Spine 6: 447–455

Harrison DE, Betz JW, Cailliet R, Colloca CJ, Harrison DD, Haas JW, Janik TJ 2006 Radiographic pseudoscoliosis in healthy male subjects following voluntary lateral translation (side glide) of the thoracic spine. Archives of Physical Medicine and Rehabilitation 87: 117–122

Hill D, Allen S, Parent E, Khorasani M, Lou E, Raso J 2006 Validity and reliability of active shape models for estimation of Cobb angles in adolescent idiopathic scoliosis. Studies in Health Technology and Informatics 123: 207–212

Hullin MG, McMaster MJ, Draper ER, Duff ES 1991 The effect of Luque segmental sublaminar instrumentation on the rib hump in idiopathic scoliosis. Spine 16: 402–408

Inami K, Suzuki T, Ono T, Yamashita Y, Kohno K, Morisue H 1999 Analysis of Posterior Trunk Symmetry Index (POTSI) in Scoliosis. Part 2. Studies in Health Technology and Informatics 59: 85–88

Jefferson RJ, Weisz I, Turner-Smith AR, Harris JD, Houghton GR 1988 Scoliosis surgery and its effects on back shape. Journal of Bone and Joint Surgery Br 70: 261–266

King HA, Moe JH, Winter DS, Bradford RB 1983 The selection of fusion levels in thoracic idiopathic scoliosis. Journal of Bone and Joint Surgery Am 65: 1302–1313

Korovessis PR, Stamatakis MV 1996 Prediction of scoliotic Cobb angle with the use of the scoliometer. Spine 21: 1661–1666

Kostuik JP, Bentivoglio J 1981 The incidence of low-back pain in adult scoliosis. Spine 6: 268–273

Kotwicki T 2002 Sagittal and transversal plane deformity in thoracic scoliosis. Studies in Health Technology and Informatics 91: 251–256

Kotwicki T, Kinel E, Stryla W, Szulc A 2007 Discrepancy in clinical versus radiological parameters describing deformity due to brace treatment for moderate idiopathic scoliosis. Scoliosis 2: 18

Kotwicki T, Napiontek M 2008 Intravertebral deformation in idiopathic scoliosis: A transverse plane computer tomographic study. Journal of Pediatric Orthopedics 28: 225–229

Krawczynski A, Kotwicki T, Szulc A, Samborski W 2006 Clinical and radiological assessment of vertebral rotation in idiopathic scoliosis. Ortopedia, Traumatologia, Rehabilitaja 8: 602–607

Kuklo TR, Potter BK, Lenke LG 2005 Vertebral rotation and thoracic torsion in adolescent idiopathic scoliosis: What is the best radiographic correlate? Journal of Spinal Disorders and Techniques 18: 139–147

Kuklo TR, Potter BK, Schroeder TM, O'Brien MF 2006 Comparison of manual and digital measurements in adolescent idiopathic scoliosis. Spine 31: 1240–1246

Lam GC, Hill DL, Le LH, Raso JV, Lou EH 2008 Vertebral rotation measurement: A summary and comparison of common radiographic and CT methods. Scoliosis 3: 16

Lee CK, Denis F, Winter RB, Lonstein JE 1993 Analysis of the upper thoracic curve in surgically treated idiopathic scoliosis. A new concept of the double thoracic curve pattern. Spine 18: 1599–1608

Lehnert-Schroth C 2000 Dreidimensionale Skoliosebehandlung, 6th edn. Stuttgart, Urban and Schwarze

Lenke LG, Betz RR, Haher TR, Lapp MA, Merola AA, Harms J, Sufflebarger HL 2001a Multisurgeon assessment of surgical decision-making in adolescent idiopathic scoliosis: Curve classification, operative approach, and fusion levels. Spine 26: 2347–2353

Lenke LG, Betz RR, Harms J, Bridwell KH, Clements DH, Lowe TG, Blanke K 2001b Adolescent idiopathic scoliosis: A new classification to determine extent of spinal arthrodesis. Journal of Bone and Joint Surgery Am 83: 1169–1181

Lenke LG, Edwards CC 2nd, Bridwell KH 2003 The Lenke classification of adolescent idiopathic scoliosis: How it organizes curve patterns as a template to perform selective fusions of the spine. Spine 28: S199–S207

Liao YC, Feng CK, Tsai MW, Chen CS, Cheng CK, Ou YC 2007 Shape modification of the Boston braces using finite-element method with topology optimization. Spine 32: 3014–3019

Liljenqvist U, Halm H, Hierholzer E, Drerup B, Weiland M 1998 3-Dimensional surface measurement of spinal deformities with video rasterstereography. Zeithschrift für Orthopädie und Ihre Grenzgebiete 136: 57–64

Lonstein E, Carlson JM 1984 The prediction of curve progression in untreated scoliosis during growth. Journal of Bone and Joint Surgery Am 66: 1061–1071

McCance SE, Denis F, Lonstein JE, Winter RB 1998 Coronal and sagittal balance in surgically treated adolescent idiopathic scoliosis with the King II pattern. A review of 67 consecutive cases having selective thoracic arthrodesis. Spine 23: 2063–2073

Moe JH, Kettleson DN 1970 Idiopathic scoliosis. Analysis of curve patterns and the preliminary results of Milwaukee-brace treatment in one hundred sixty-nine patients. Journal of Bone and Joint Surgery Am 52: 1509–1533

Mok JM, Berven SH, Diab M, Hackbarth M, Hu SS, Deviren V 2008 Comparison of observer variation in conventional and three digital radiographic methods used in the evaluation of patients with adolescent idiopathic scoliosis. Spine 33: 681–696

Morissy RT, Goldsmith GS, Hall EC, Kehl D, Cowie HC 1990 Measurement of the Cobb angle on radiographs of patients who have scoliosis. Evaluation of intrinsic error. Journal of Bone and Joint Surgery Am 72: 320–327

Murrel GA, Coonrad RW, Moorman 3rd CT, Fitch RD 1993 An assessment of the reliability of the scoliometer. Spine 18: 709–712

Nash C, Moe JH 1969 A study of vertebral rotation. Journal of Bone and Joint Surgery Am 51: 223–229

Negrini A, Negrini S 2006 Three-dimensional easy morphological (3-DEMO) classification of scoliosis. Part II. Repeatability. Scoliosis 1: 23

Negrini S, Negrini A 2007 Three-dimensional easy morphological (3-DEMO) classification of scoliosis. Part III. Correlation with clinical classification and parameters. Scoliosis 2: 5

Negrini S, Grivas TB, Kotwicki T, Maruyama T, Rigo M, Weiss HR, the members of the Scientific society On Scoliosis Orthopaedic and rehabilitation Treatment (SOSORT) 2006 Why do we treat adolescent idiopathic scoliosis? What we want to obtain and to avoid for our patients. Scoliosis 1: 4

Negrini S, Grivas TB, Kotwicki T, Rigo M, Zaina F, The International Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) 2009 Guidelines on standards of management of idiopathic scoliosis with corrective braces in everyday clinics and in clinical research: SOSORT Consensus 2008. Scoliosis 4: 2

Negrini S, Negrini A, Atanasio S, Santambrogio GC 2006 Three-dimensional easy morphological (3-DEMO) classification of scoliosis. Part I. Scoliosis 1: 20

Niemeyer T, Wolf A, Kluba S, Halm HF, Dietz K, Kluba T 2006 Interobserver and intraobserver agreement of Lenke and King classifications for idiopathic scoliosis and the influence of level of professional training. Spine 31: 2103–2107

Ogon M, Giesinger K, Behensky H, Wimmer C, Nogler M, Bach CM, Krismer M 2002 Interobserver and intraobserver reliability of Lenke's new scoliosis classification system. Spine 27: 858–862

Omeroglu H, Ozekin O, Biçimoglu A 1996 Measurement of vertebral rotation in idiopathic scoliosis using the Perdriolle torsionmeter: A clinical study on intraobserver and interobserver error. European Spine Journal 5: 167–171

Ovadia D, Bar-on E, Fragnière B, Rigo M, Dickman D, Leitner J, Wientroub S, Dubousset J 2007 Radiation-free quantitative assessment of scoliosis: A multi center prospective study. European Spine Journal 16: 97–105

Parisini P, Lolli F, Greggi T, Di Silvestre M, Cioni A, Giacomini S, Bakaloudis G 2006 An innovative diagnostic procedure of vertebral deformities without exposure to X-rays. Studies in Health Technology and Informatics 123: 527–532

Perdriolle R, Vidal J 1985 Thoracic idiopathic scoliosis curve evolution and prognosis. Spine 10: 785–791

Perdriolle R, Vidal J 1987 Morphology of scoliosis: Three-dimensional evolution. Orthopedics 10: 909–915

Pineda S, Bago J, Gilperez C, Climent JM 2006 Validity of the Walter Reed Visual Assessment Scale to measure subjective perception of spine deformity in patients with idiopathic scoliosis. Scoliosis 1: 18

Poncet PH, Dansereau J, Labelle H 1999 Geometric torsion in idiopathic scoliosis: A first 3D analysis and a proposal to a new classification. Studies in Health Technology and Informatics 59: 122–125

Ponseti IV, Friedman B 1950 Prognosis in idiopathic scoliosis. Journal of Bone and Joint Surgery Am 32: 381–395

Pruijis JE, Hageman MA, Keessen W, van der Meer R, van Wieringen JC 1994 Variation in Cobb angle measurements in scoliosis. Skeletal Radiology 23: 517–520

Puno RM, An KC, Puno RL, Jacob A, Chung SS 2003 Treatment recommendations for idiopathic scoliosis: An assessment of the Lenke classification. Spine 28: 2102–2115

Richards BS 1992 Measurement error in assessment of vertebral rotation using the Perdriolle torsionmeter. Spine 17: 513–517

Rigo M, Quera-Salvá G, Villagrasa M 2006 Sagittal configuration of the spine in girls with idiopathic scoliosis: Progressing rather than initiating factor. Studies in Health Technology and Informatics 123: 90–94

Rigo M, Villagrasa M, Gallo D 2010 A specific classification correlating with brace treatment: Description and reliability. Scoliosis 5: 1

Rigo M, Weiss HR 2008 The Chêneau concept of bracing—Biomechanical aspects. Studies in Health Technology and Informatics 135: 303–319

Risser JC 1958 The iliac apophysis: An invaluable sign in the management of scoliosis. Clinical Orthopaedics and Related Research 11: 111–119

Sanders JO, Browne RH, MaConnell SJ, Margraf SA, Cooney TE, Finegold DN 2007 Maturity assessment and curve progression in girls with idiopathic scoliosis. Journal of Bone and Joint Surgery Am 89: 64–73

Sanders JO, Khoury JG, Kishan S, Browne RH, Mooney 3rd JF, Arnold KD, MaConnell SJ, Bauman JA, Finegold DN 2008 Predicting scoliosis progression from skeletal maturity: A simplified classification during adolescence. Journal of Bone and Joint Surgery Am 90: 540–553

Sanders JO, Polly Jr DW, Cats-Baril W, Jones J, Lenke LG, O'Brien MF, Stephens Richards B, Sucato DJ: AIS section of the Spinal Deformity Study Group 2003 Analysis of patient and parent assessment of deformity in idiopathic scoliosis using the Walter Reed Visual Assessment Scale. Spine 28: 2158–2163

Sangole AP, Aubin CE, Labelle H, Stokes IA, Lenke LG, Jackson R, Newton P 2009 Three-dimensional classification of thoracic curves. Spine 34: 91–99

Sawatzky BJ 2004 International Research Society on Spinal deformities Symposium 2004

Sevastik JA, Diab KM 1997 Research into Spinal Deformities 1. Studies in Health Technology and Informatics 37

Schulte TL, Hierholzer E, Boerke A, Lerner T, Liljenqvist U, Bullmann V, Hackenberg L 2008 Raster stereography versus radiography in long-term follow-up of idiopathic scoliosis. Journal of Spinal Disorders and Techniques 21: 23–28

Schumann K, Püschel I, Maier-Hennes A, Weiss HR 2008 Postural changes in patients with scoliosis in different position revealed by surface topography. Studies in Health Technology and Informatics 140: 140–143

Stokes IA 1994 Three-dimensional terminology of spinal deformity. A report presented to the Scoliosis Research Society by the Scoliosis Research Society Working Group on 3-D terminology of spinal deformity. Spine 19: 236–248

Stokes IA 1999 Research into Spinal Deformities 2. Studies in Health Technology and Informatics 59

Stokes IA, Aronson DD 2002 Identifying sources of variability in scoliosis classification using a rule-based automated algorithm. Spine 27: 2801–2805

Stokes IA, Aronson DD, Ronchetti PJ, Labelle H, Dansereau J 1993 Reexamination of the Cobb and Ferguson angles: Bigger is not always better. Journal of Spinal Disorders 6: 333–338

Stokes IAF, Burwell RG, Dangerfield PH 2006 Biomechanical spinal growth modulation and progressive adolescent scoliosis—A test of the "vicious cycle" pathogenetic hypothesis: Summary of an electronic focus group debate of the IBSD. Scoliosis 1: 16

Suzuki N, Inami K, Ono T, Kohno K, Asher MA 1999 Analysis of Posterior Trunk Symmetry Index. Part 1. Studies in Health Technology and Informatics 59: 81–84

Tanguy A, Peuchot B 2002 Research into Spinal Deformities 3. Studies in Health Technology and Informatics 88

Tanner JM 1962 Growth at Adolescence, 2nd edn. London, Blackwell

Tanner JM, Whitehouse RH, Cameron N, Marshal WA, Healy MJR, Goldstein H 1983 Assessment of Skeletal Maturity and Prediction of Adult Height, 2nd edn. London, Academic Press

Theologis TN, Jefferson RJ, Simpson AH, Turner-Smith AR, Fairbank JC 1993 Quantifying the cosmetic defect of adolescent idiopathic scoliosis. Spine 18: 909–912

Tones MJ, Moss ND 2007 The impact of patient self assessment of deformity on HRQL in adult with scoliosis. Scoliosis 2: 14

Tredwell SJ, Bannon M 1988 The use of the ISIS optical scanner in the management of the braced adolescent idiopathic scoliosis patients. Spine 13: 1104–1105

Upadhyay SS, Burwell RG, Webb JK 1988 Hump changes on forward flexion of the lumbar spine in patients with idiopathic scoliosis. A study using ISIS and the Scoliometer in two standard positions. Spine 13: 146–151

Uyttendaele D, Dangerfield PH 2006 Research into Spinal Deformities 5. Studies in Health Technology and Informatics 123

Villemure I, Aubin CE, Grimard G, Dansereau J, Labelle H 2002 Evolution of 3D deformities in adolescents with progressive idiopathic scoliosis. Studies in Health Technology and Informatics 91: 54–58

Wang SF, Qui Y, Zhu ZZ, Zhu F, Ma ZL, Xia CW 2008 Assessment of the residual spine growth potential in idiopathic scoliosis by risser sign and histological grading. Zhonghua Yi Xue Za Zhi 88: 461–464

Wang WW, Xia CW, Zhu F, Zhu ZZ, Wang B, Wang SF, Yeung BH, Lee SK, Cheng JC, Qui Y 2009 Correlation of Risser sign, radiographs of the hand and wrist with the histological grade of iliac crest apophysis in girls with adolescent idiopathic scoliosis. Spine 34: 1849–1854

Weiss HR 1995 Measurement of vertebral rotation: Perdriolle versus Raimondi. European Spine Journal 4: 34–38

Weiss HR 2006 Clinical improvement and radiological progression in a girl with early onset scoliosis (EOS) treated conservatively—A case report. Scoliosis 1: 13

Weiss HR 2007 Is there a body of evidence for the treatment of patients with adolescent idiopathic scoliosis (AIS)? Scoliosis 2: 19

Weiss HR 2009 Conservative treatment effects on spinal deformities revealed by surface topography—A critical review of the literature. Scoliosis 4 (suppl 1): O17

Weiss HR, Lohschmidt K, El Obeidi N 1997 The automated surface measurement of the trunk. Technical error. Studies in Health Technology and Informatics 37: 305–308

Weiss HR, Negrini S, Rigo M, Kotwicki T, Hawes MC, Grivas TB, Maruyama T, Landauer F, SOSORT guidelines committee 2006 Indications for conservative management of scoliosis (guidelines). Scoliosis 1: 5

Weisz I, Jefferson RJ, Turner-Smith AR, Houghton GR, Harris JD 1988 ISIS scanning: A useful assessment technique in the management of scoliosis. Spine 13: 405–408

Wemyss-Holden SA, Burwell RG, Polak FJ, Jacobs KJ, McNeill AS, Webb JK, Moulton A, Wojcik AS 1992 Segmental evaluation of the surface and radiological deformity after Cotrel-Dubousset (CD) instrumentation for King type II and III adolescent idiopathic scoliosis (AIS): Surgical and etiological implications. Acta Orthopaedica Belgica 58 (suppl 1): 135–138

Zaina F, Negrini S, Atanasio S 2009 TRACE (Trunk Aesthetic Clinical Evaluation), a routine clinical tool to evaluate aesthetics in scoliotic patients: Development from the Aesthetic Index (AI) and repeatability. Scoliosis 4: 3

Zmurko MG, Mooney 3rd JF, Podeszwa DA, Minster GJ, Mendelow MJ, Guirgues A 2003 Inter- and intraobserver variance of Cobb angle measurements with digital radiographs. Journal of Surgical Orthopaedic Advances 12: 208–213