Spinal Deformity Study Group

Radiographic Measurement Manual

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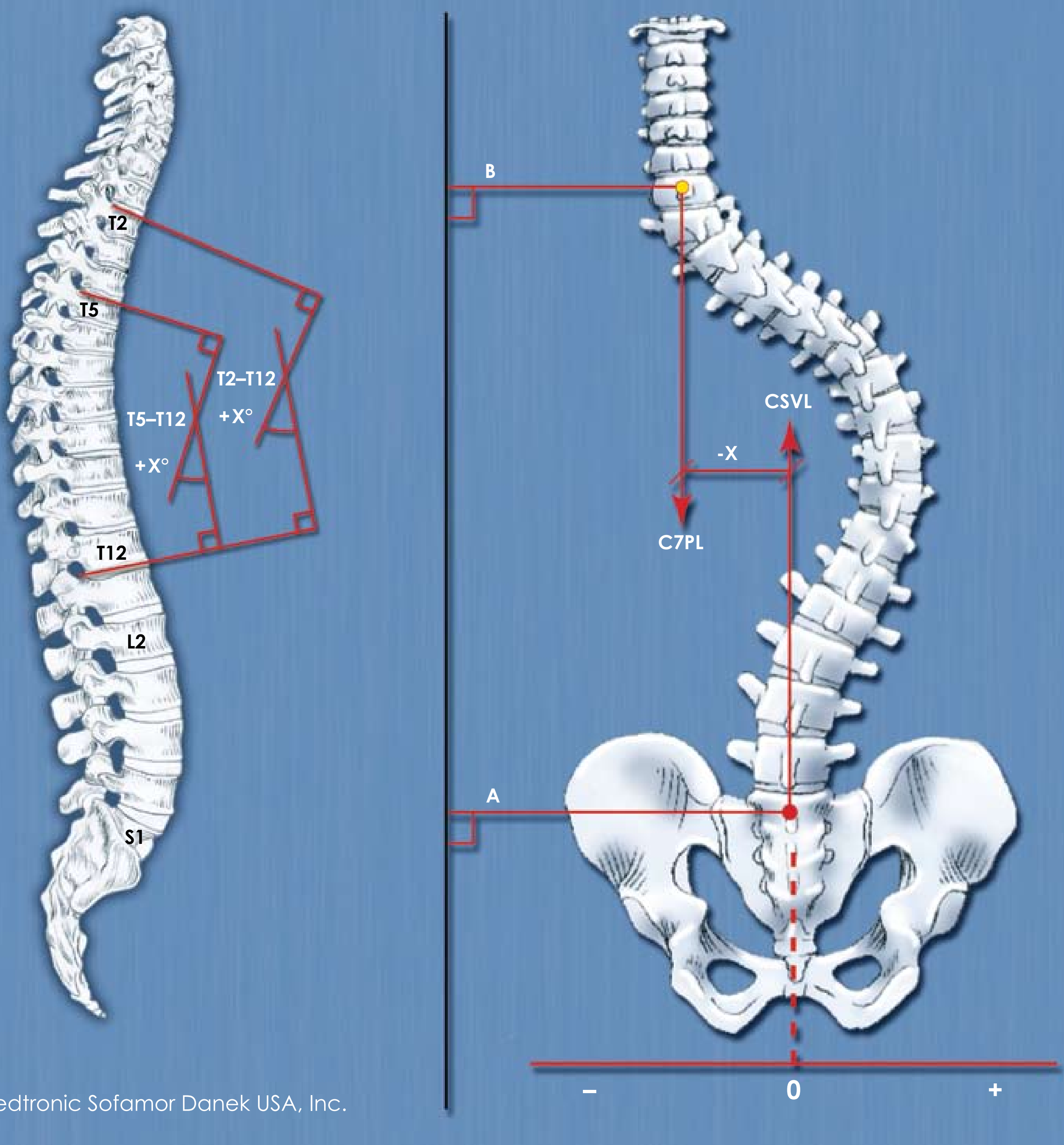

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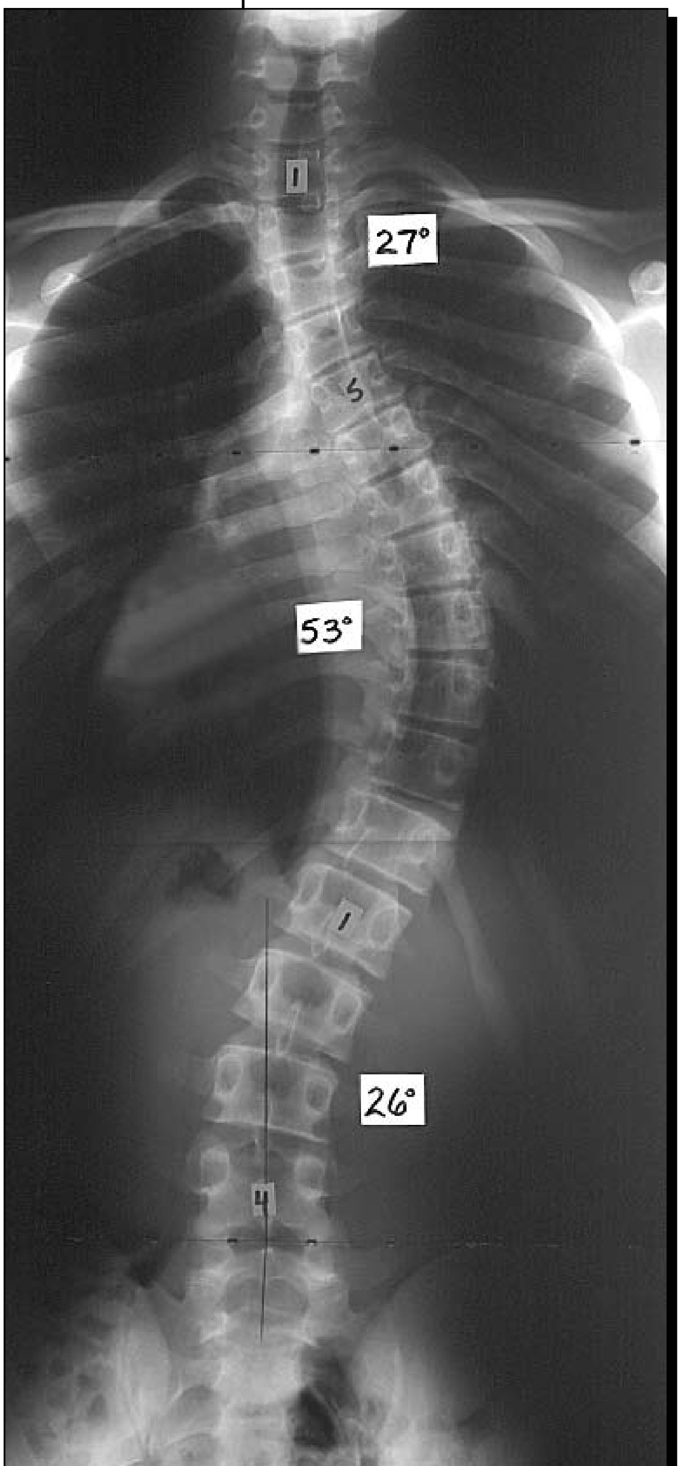

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Radiographic Measurement Manual

The radiographic measurement manual has been developed to present standardized techniques for radiographic measurement. In addition, this manual will serve as a complimentary guide for the Spinal Deformity Study Group's radiographic measurement software.

Special thanks to the following members of the Spinal Deformity Study Group in the development of this manual.

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Preface

Keith H. Bridwell, MD

Over the last several decades, the Cobb measurement performed on radiographs has been the most universally used method to characterize a spinal deformity. However, the Cobb measurement does not describe all of the important characteristics of a spinal deformity. The Radiographic Measurement Manual (RMM) describes many of the intricacies of spinal deformity, such as vertebral numbering, segmental sagittal alignment, lumbosacral transitional vertebra, the correct standing posture for long cassette coronal and sagittal radiographs, the tidemark for an acceptable versus unacceptable long cassette radiograph, parameters for assessment of spinal flexibility in the coronal and sagittal planes, how to obtain useful clinical photographs, and a classification strategy for adolescent idiopathic scoliosis (AIS). In addition, it details measurement techniques for coronal and sagittal balance, apical deviation, vertebral rotation, and how to define the end, neutral, and stable vertebrae, which are critical in the assessment of spinal deformities. In spite of this detail we must acknowledge that certain regions of the spine remain difficult to reproducibly assess, especially in the sagittal plane. This is particularly true of the proximal thoracic spine where it is overlapped by the shoulder girdle from T1 to T8. This region remains challenging to radiographically visualize and assess, even in thin patients.

Also included in this manual are measurement parameters that are specific for adult deformity. In particular, rotatory subluxations are quite difficult to measure in a reproducible fashion. The Spinal Deformity Study Group has spent many hours and numerous conferences reaching a consensus on how to measure these deformities. Achieving one hundred percent agreement on these parameters has not been possible, but consensus has been achieved and I personally feel that this manual addresses how to measure adult rotatory olisthesis far better than any current textbook.

The parameters of spondylolisthesis are comprehensively depicted. Meyerding's classification is most commonly used to describe spondylolisthesis. However, we know that two individuals with a grade 4 spondylolisthesis may look and clinically behave quite differently because of differences in the slip angle, pelvic tilt, sacral slope, and the pelvic incidence. All of these alternative techniques to describe spondylolisthesis are clearly depicted in the spondylolisthesis section.

The benefits of a standardized measurement manual are countless. This manual provides clear text and outstanding radiographic and illustrative detail to define the important parameters that describe spinal deformity. As you will see, the quality of the illustrations and radiographs are unsurpassed by any textbook or peer-review journal. It is common even in peer-review journals to see long cassette radiographs published that are so shrunken in size that important radiographic details and spinal balance cannot be appreciated by the reader. I can only hope that major publishers will look at this manual and adopt these standards for clarity and size of reproduction for long cassette films. This Radiographic Measurement Manual will finally provide researchers and clinicians a common language to discuss spinal deformity.

All physician members of the Spinal Deformity Study Group are members of the Scoliosis Research Society (SRS). I would encourage all members of the SRS to adopt this manual as a reference. It is a tremendous resource, not only for clinical research, but also for day-to-day practice. I am hopeful that when medical students and orthopaedic and neurosurgery residents see this manual that they will be inspired to devote their careers to the study of spinal deformity and related clinical research.

I would be remiss if I did not mention the names of several mentors who have inspired all of us. These spinal surgeons have been responsible for the rapid growth and advancement of spinal deformity research and treatment over the last 40 years. Notable in this group are Marc Asher, MD; David Bradford, MD; Yves Cotrel, MD; Ronald DeWald, MD; Jean Dubousset, MD; Jürgen Harms, MD; Kenton Leatherman, MD; Dean MacEwen, MD; John Moe, MD; Thomas Whitesides Jr, MD; and Robert Winter, MD. I am saddened that Edgar Dawson, MD, who was very active in the Spinal Deformity Study Group, could not see this final product. He would have been proud.

I wish to recognize and thank David Poley and Michael Ferguson at Medtronic for their continuous support of the Spinal Deformity Study Group and for making this landmark project possible. Also, Randal Betz, MD, Co-Chairman of the study group, deserves special recognition for the instrumental role he has played in the group's foundation and in its tremendous accomplishments.

In conclusion, my hat goes off to the chief editors, Michael O'Brien, MD; Timothy Kuklo, MD; Lawrence Lenke, MD; and Kathy Blanke, RN, who have spent endless hours working on precise definitions and illustrations to achieve consensus on these measurements. Significant time and effort has been put forth over three years to finalize this manual. Recognition is also given to the section editors and members of the Spinal Deformity Study Group who have participated in this project. And finally special thanks and appreciation must be given to JoAnn Jones with Medtronic for her tireless support and assistance in bringing this book to publication.

Congratulations!

Keith H. Bridwell, MD
St. Louis, Missouri USA

Preface (continued)

Harry Shufflebarger, MD

The collection and production of this standardized set of radiographs, illustrations, and photographs represent an enormous effort. The result is an excellent and highly user-friendly textbook.

The written explanations accompanying the figures throughout the text are clear and concise. The section on clinical photography provides a standardized methodology to produce clinical photographs of patients acceptable for any need. The same may be said for the instructions on obtaining and capturing radiographic images.

The section on adolescent idiopathic scoliosis provides one-stop shopping for all clinically relevant measurements. This in itself is an excellent contribution to the spinal community. The adult deformity section repeats many of the measurements described in the adolescent chapter, with additional measurements specific for adult onset degenerative scoliosis. The spondylolisthesis section will familiarize the reader with all measurements pertinent to this condition, and to accurately utilize them clinically.

Drs. O'Brien, Kuklo, Lenke, and Kathy Blanke, RN, are to be congratulated on producing such a simple but immensely useful reference textbook. There should be little question in the future as to how a particular measurement is correctly made.

Harry Shufflebarger, MD
Miami, Florida USA

From the Editors In Chief:

We wish to extend special acknowledgment to JoAnn Jones for her patience, drive, and dedication to the development of the Radiographic Measurement Manual. Her unyielding and cheerful support through many changes is greatly appreciated. Her superb assistance has made the entire process easier. Thanks JoAnn, we couldn't have done it without you!

Mike, Tim, Kathy, and Larry

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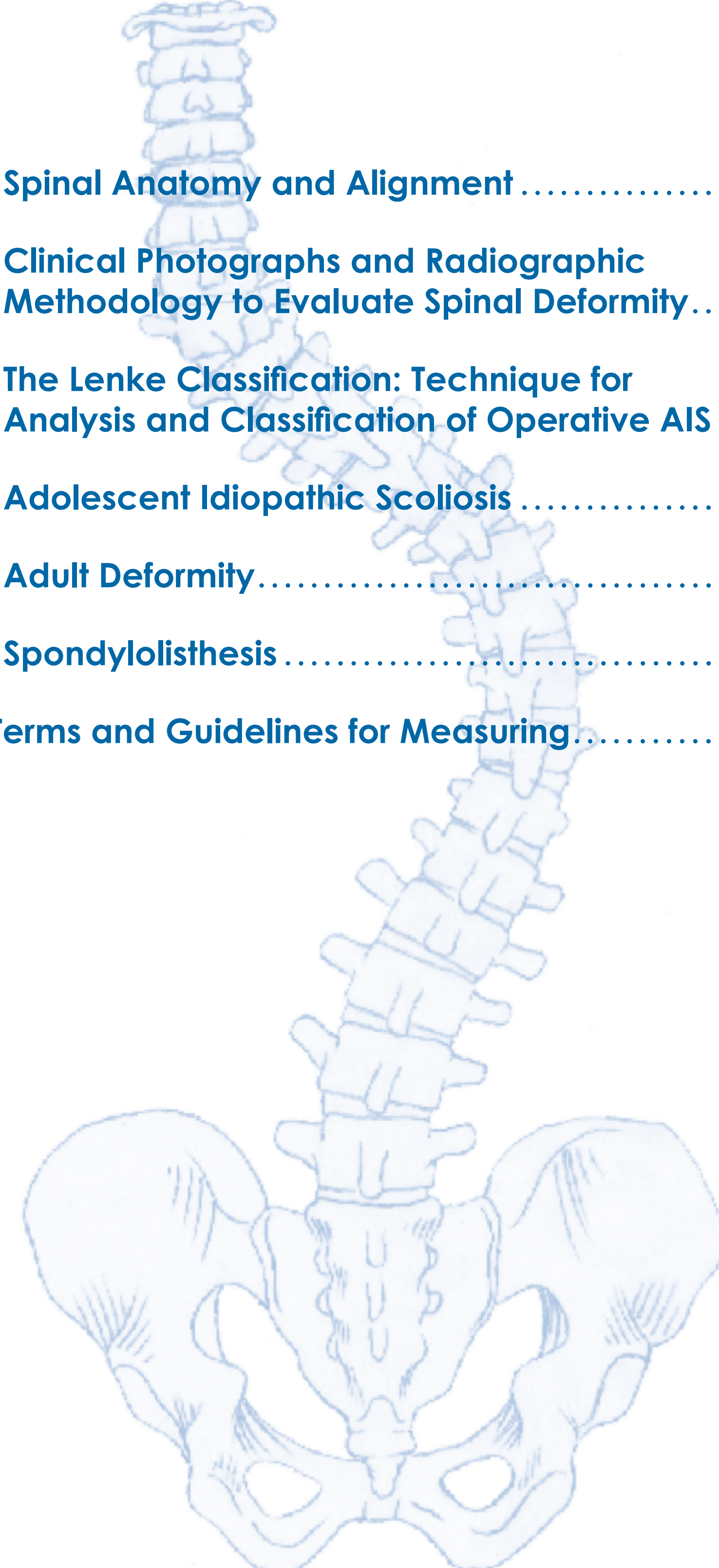
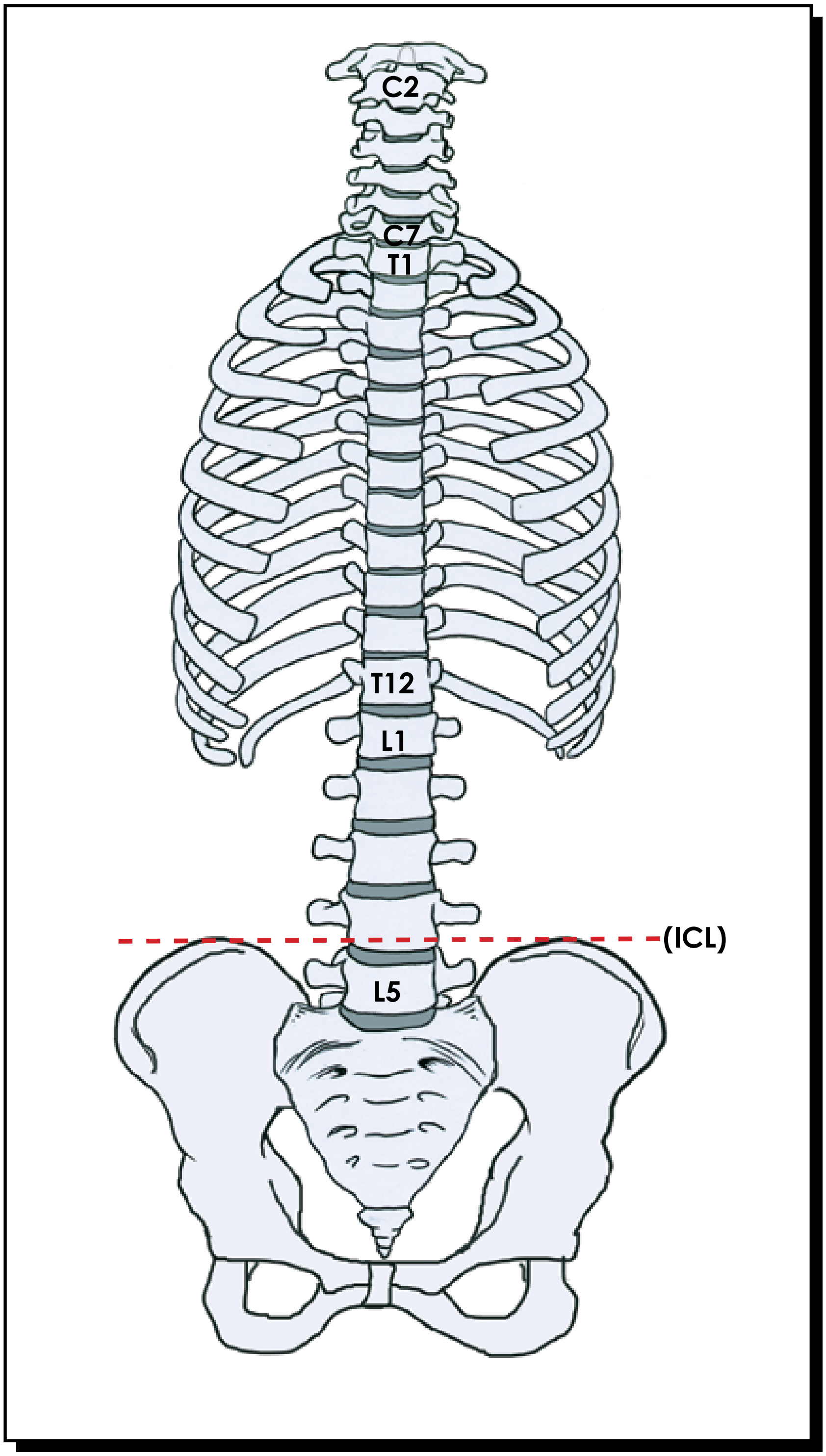


Spinal Anatomy and Alignment



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Spinal Anatomy and Alignment

Introduction

Understanding normal spinal anatomy is a prerequisite to identifying, describing, and treating spinal deformity. Without a clear understanding of normal anatomy, one cannot understand the importance or implications of the sometimes subtle anatomic variations identified in spinal deformity. Only with a clear understanding of both normal and altered anatomy will the surgeon be able to effectively interpret the radiographic images and formulate a plan to correct spinal deformities.

In addition to visualizing and understanding the anatomic variations present in spinal deformity, it is essential that the deformity can be reliably described in a quantitative fashion. Quantifying the deformity facilitates developing a clear understanding of the important structural features of the altered spinal anatomy necessary to develop an effective treatment plan. Equally important, it facilitates accurate communication between healthcare providers regarding the important features of the deformity so that comparative analysis of alternative treatment regimens can be undertaken for similar deformities.

Although a detailed description of spinal anatomy is beyond the scope of this current work, it is germane to briefly touch on normal spinal anatomy. There are four distinct regions of the spine: cervical, thoracic, lumbar, and sacropelvic. Each region is separated by transition zones: craniocervical, cervicothoracic, thoracolumbar, and lumbosacropelvic. These transition zones represent areas of anatomic metamorphoses between spinal regions. It is important to understand the unique anatomy, biomechanics, and alignment of each of these regions of the normal spine. Only then can an appreciation be developed for the consequences of spinal deformity so that an effective surgical plan can be created.

Abnormalities in embryologic, osseous, and neurologic development may precipitate the development of spinal deformities. Segmentation defects caused by abnormalities in embryologic development may result in osseous pathology, such as hemivertebra, block vertebra, and bars. Alterations in neurologic development may result in abnormalities of the central nervous system, including syringomyelia, Chiari malformations, split cords, and tethered cords. Other more subtle abnormalities, such as alteration in CNS pathways for balance and spinal reflexes, and disturbances in melatonin production, have been implicated in what has been described as "idiopathic" spinal deformity. It is, therefore, clear that a detailed understanding of normal spinal anatomy and the possible pathologic entities that can disturb it are important in developing an understanding of spinal deformity.

Anatomy

One of the simplest descriptors of spinal anatomy is often overlooked: vertebral numbering. Having a consistent method of vertebral labeling is important in developing a detailed description of both normal and altered spinal anatomy. In the normal spine the cervical region consists of the skull base (C0) and seven mobile segments: C1-C7. The thoracic spine has 12 mobile segments: T1-T12. Each thoracic segment has a pair of ribs that articulate with the named vertebral body. The ribs from T1-T10 are usually joined anteriorly at the costochondral junction or sternum. T11 and T12 usually have "floating ribs," which are not connected anteriorly to the rib cage. The normal lumbar spine has five mobile segments: L1-L5. The sacropelvic unit consists of the sacrum/coccyx and the bilateral ilium. The sacrum is comprised of five fused segments that articulate with the ilium through the SI joints bilaterally (see Figures 1A and 1B).

Spinal Anatomy and Alignment

Vertebral Numbering

When the patient's spinal anatomy is normal, numbering the spinal segments is relatively easy. This may not be the case when evaluating a spine with atypical segments or when a spinal deformity is present. It is essential when describing a spinal deformity that a consistent method for vertebral numbering be employed. Failure in this regard will result in miscommunication about the deformity or worse, surgical interventions which are performed at the wrong levels due to mislabeling.

The cervical vertebrae are seldom involved in spinal deformity. Therefore, numeric labeling of these segments is usually not an issue for the deformity surgeon. More importantly, there is seldom any variation in the number of cervical segments, remaining fairly consistent at seven. In congenital and Klippel-Feil abnormalities, the number of mobile segments may be fewer because of congenital fusions, but seven cervical segments can usually be identified. Numbering commences from the atlas (C1).

T1 is defined as the first vertebra with a pair of associated ribs. All vertebrae distal to T1 with associated ribs are defined as thoracic. Usually there are 12 thoracic vertebrae. The most common variations are 11 or 13 thoracic segments (see Figures 2A and 2B, 3A and 3B). Identifying the terminal thoracic vertebra is not always a simple matter, since distinguishing between a very small rib or a thin elongated transverse process may be difficult. Occasionally this distinction can only be made intraoperatively by direct inspection and manual palpation of the transverse process/rib anatomy. The determination of the terminal thoracic vertebra should not affect surgical planning. It may, however, affect the final labeling of the spinal segments.

L1 will always be the vertebra immediately below the last thoracic vertebra, that is the last vertebra with an associated pair of ribs. The lumbar spine typically has five vertebrae, but may occasionally have four or six segments. It is not mandatory that the overall number of spinal segments be conserved at 24 (i.e., 7 cervical + 12 thoracic + 5 lumbar = 24). It is possible that a patient may have 13 thoracic vertebrae and six lumbar vertebrae. It is more common, however, that the number of spinal segments are conserved. For example, a patient with 11 thoracic vertebrae will usually have 6 lumbar vertebrae and a patient with 13 thoracic vertebrae will have 4 lumbar vertebrae.

Another area where errors in vertebral labeling may occur is at the lumbosacral junction. The last lumbar vertebra may be partially or fully "sacralized" or the first sacral vertebra may be "lumbarized". Castelvi *et al.* have nicely detailed the possible osseous variations at the lumbosacral junction (see Figure 4). These may involve unilateral or bilateral articulation of the transverse process of L5 with the ilium and/or the sacrum. This may create the appearance of a segmented S1–S2 or an asymmetric or abnormally formed sacral ala on one or both sides. As with variations at the thoracolumbar junction, vertebral labeling inconsistencies at the lumbosacral junction should not interfere with the development or implementation of an appropriate surgical plan. Failure to take these variations into account may result in wrong level surgery if a consistent labeling scheme is not agreed upon by all involved in the care of the patient.

Accurate labeling of the vertebral segments is important in our ability to communicate a detailed description of the spinal anatomy, whether normal or pathologic. It is also important for clearly identifying vertebral levels intra-operatively. With the advent of CT scans and MRIs, a clear understanding of the anatomy can be achieved in most cases. Once the anatomy is clearly visualized, the pathology can be described and effective surgical plans can be formulated.

Steps for labeling and measuring normal and atypical vertebrae:

1. Start at the first vertebra with ribs and call that T1.
2. Continue labeling vertebrae until the last one with ribs is identified (it could be T11, 12, or 13).
3. If there are 11 definite ribs with 6 vertebrae below and it is not clear if the 12th vertebra has a rib, call it T12 to maintain the 12 Thoracic and 5 Lumbar numbering.
4. In all other cases, the first vertebra below the last thoracic vertebra (last vertebra with ribs) is considered L1.
5. The L5 junction is reviewed for lumbarization or sacralization of the transitional vertebra. If L5 is sacralized it is still necessary to measure coronal and sagittal Cobbs to S1 (versus L5) and also measure the sagittal balance from C7 to S1 (versus L5).

Spinal Anatomy and Alignment

Sagittal Alignment

The spine has characteristic alignment in the coronal and sagittal planes. In the coronal (frontal) plane the spine is straight. In the sagittal (lateral) plane, the spine is lordotic in the cervical and lumbar regions and kyphotic in the thoracic region. There is a wide range of normal sagittal profiles for each region. Initially, these regional alignments were discussed in terms of fixed absolute values. However, with an improved understanding of the importance of the sacropelvic foundation, which is discussed and diagrammatically detailed in the spondylolisthesis section, a wide range of normals are now considered likely.

It is possible that each individual has specific requirements for cervical/lumbar lordosis and thoracic kyphosis because of unique fixed pelvic relations. The lordotic and kyphotic segments of the spine must ultimately balance the occiput over the sacropelvic axis in an energy efficient position. The C7 plumbline (C7PL) should pass within a few millimeters of the posterior superior corner of S1. The thoracic spine should have approximately 10 to 40° of kyphosis and the lumbar spine should have approximately 40 to 60° of lordosis. The lumbar spine should arithmetically have 30° more lordosis than thoracic kyphosis (i.e., 60° of lumbar lordosis should be accompanied by 30° of thoracic kyphosis).

It is clear from this brief discussion that understanding normal and abnormal spinal anatomy and our ability to clearly describe it is important. This knowledge is at the heart of our ability to develop and implement treatment options for spinal deformity. It is also necessary so that we can evaluate the effect of our interventions and compare alternative treatments for similar deformities.

If there are an atypical number of vertebrae, the sagittal measures will be performed as shown in Table 1 below. The thoracolumbar region (T10-L2) will remain constant regardless of the number of vertebral bodies in that region. For example, it is possible to have one extra vertebra if there are thirteen thoracic segments or one less vertebra if there are eleven thoracic segments.

Table 1

Normal	12 Thoracic/5 Lumbar	T5-T12	T10-L2	T12-S1
Atypical	11 Thoracic/6 Lumbar	T5-"T12"*	T10-L2	"T12"-S1*
	11 Thoracic/5 Lumbar	T5-T11	T10-L2	T11-S1
	11 Thoracic/4 Lumbar	T5-T11	T10-L2	T11-S1
	13 Thoracic/4 Lumbar	T5-T12	T10-L2	T12-S1
	13 thoracic/5 Lumbar	T5-T12	T10-L2	T12-S1

*** See step 3 of labeling and measuring under atypical vertebra and Figure 2a and 2b on page 7.**

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Spinal Anatomy and Alignment

Normal Anatomy
12 Thoracic and 5 Lumbar Vertebrae

Figure 1a

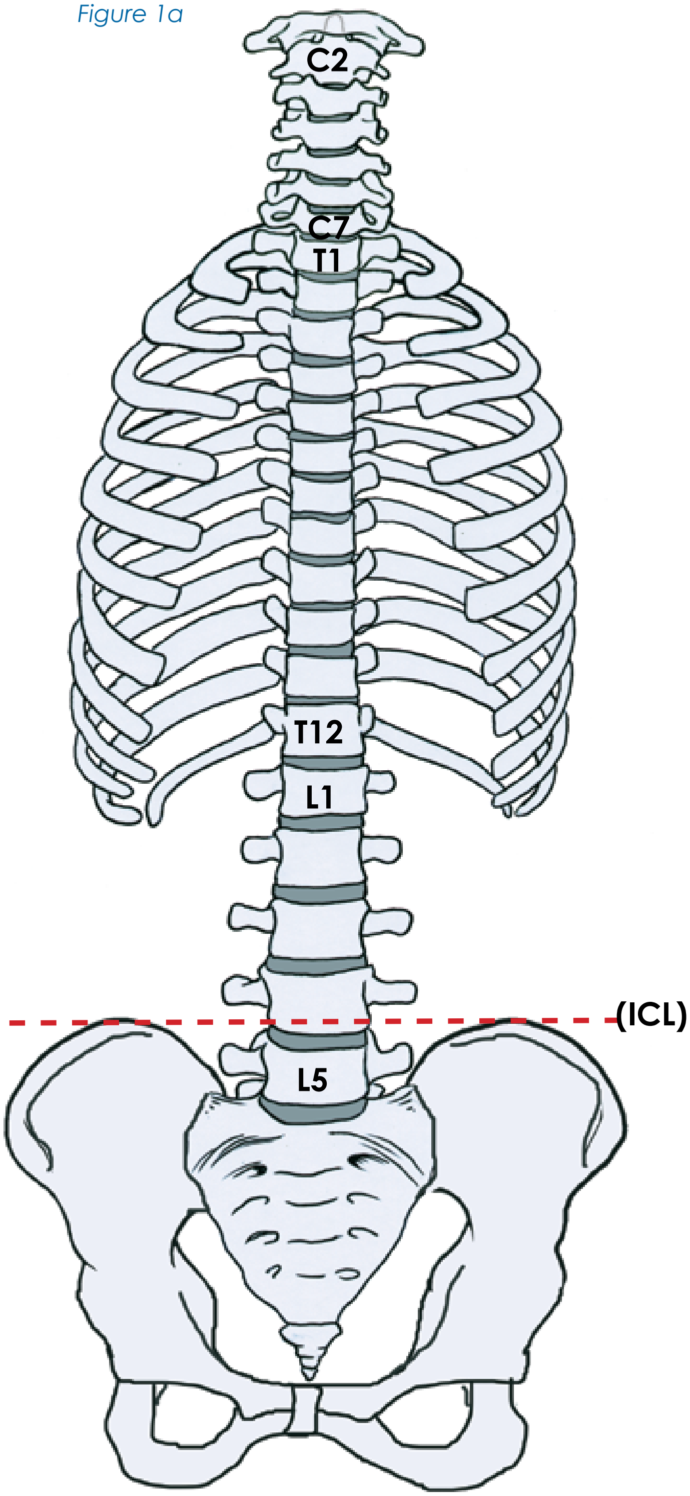
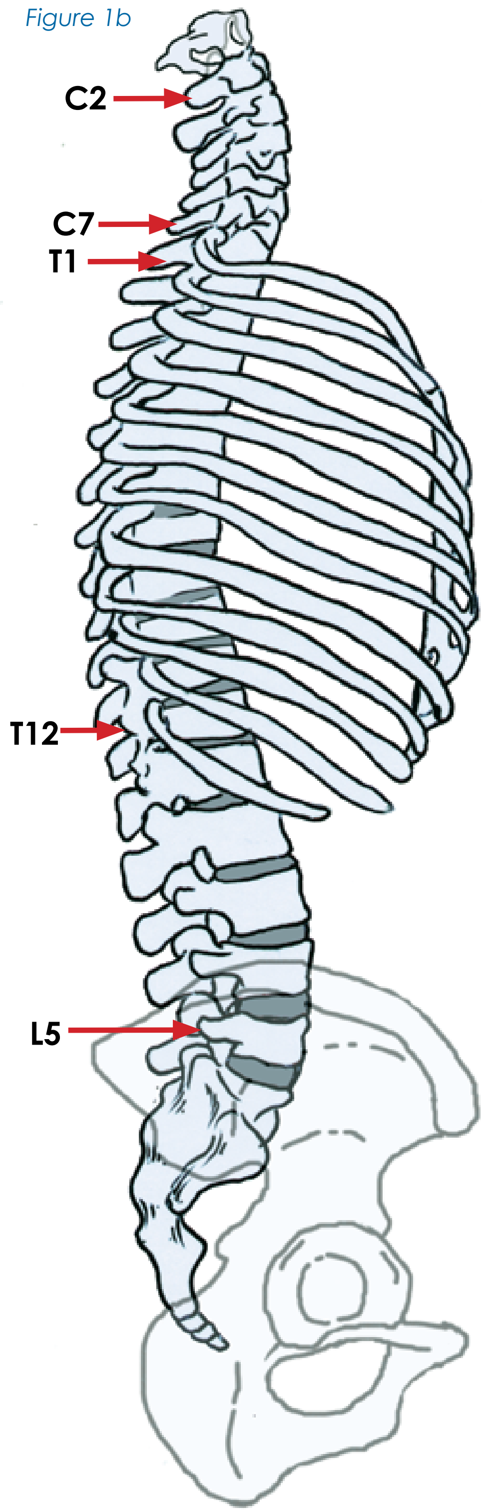


Figure 1b



Note that the position of the intercrestal line (ICL) confirms the location of L5 on AP and lateral x-rays.

Atypical Anatomy
11 Thoracic and 6 Lumbar Vertebrae*

Figure 2a

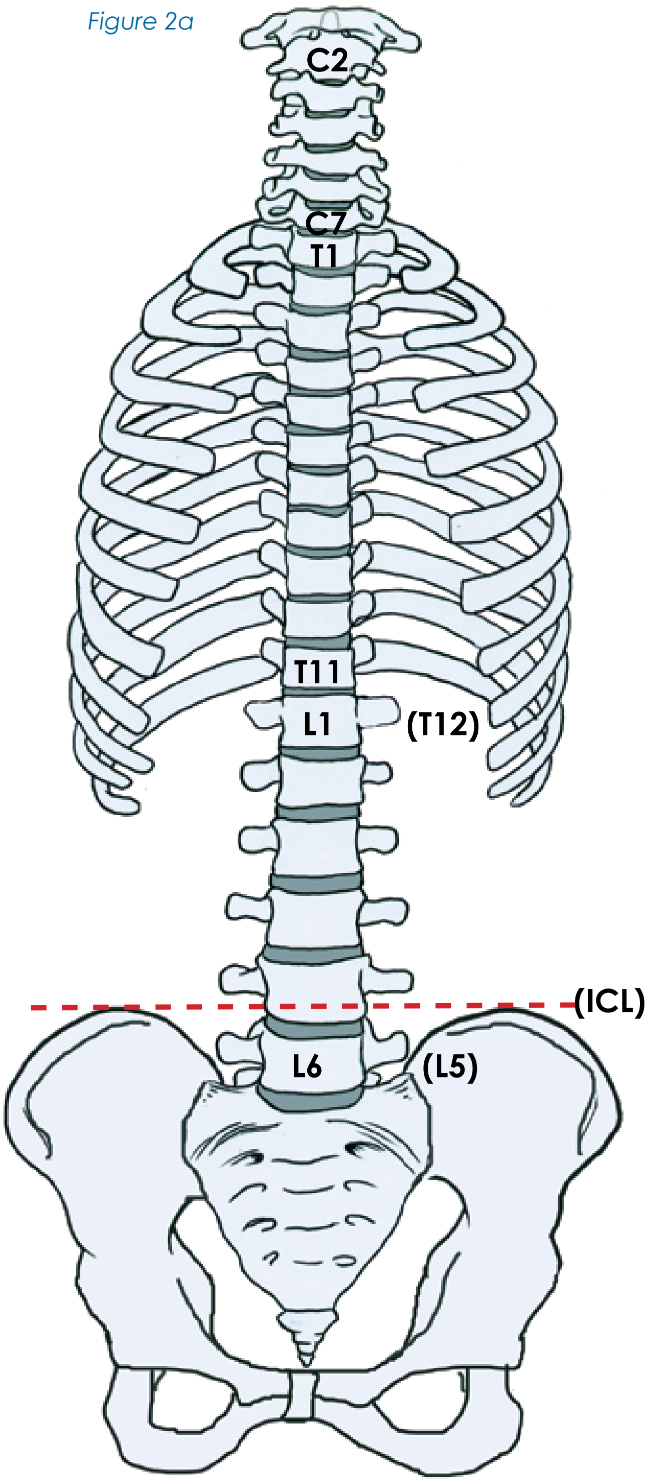
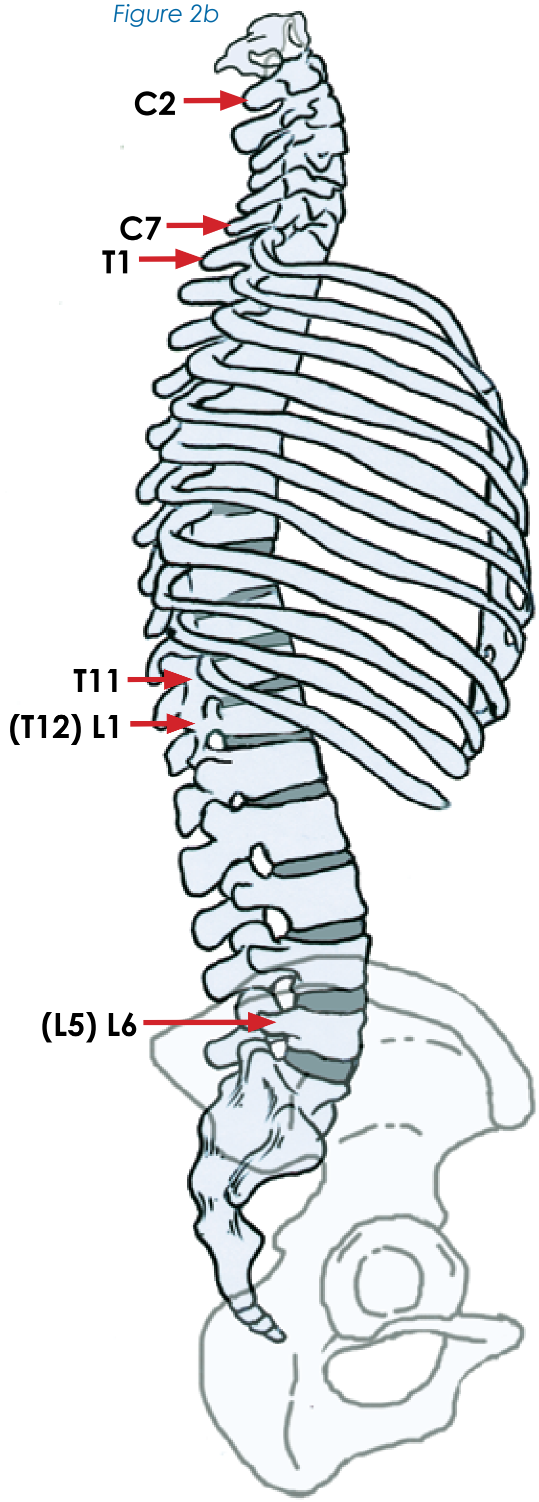


Figure 2b



*If there are 11 definite ribs with 6 vertebrae below and it is not clear if the 12th vertebra has a rib, call it T12 to maintain the 12 Thoracic and 5 Lumbar numbering.

Note that the position of the intercrestal line (ICL) confirms the location of L6 (L5) on AP and lateral x-rays.

Atypical Anatomy
13 Thoracic and 4 Lumbar Vertebrae

Figure 3a

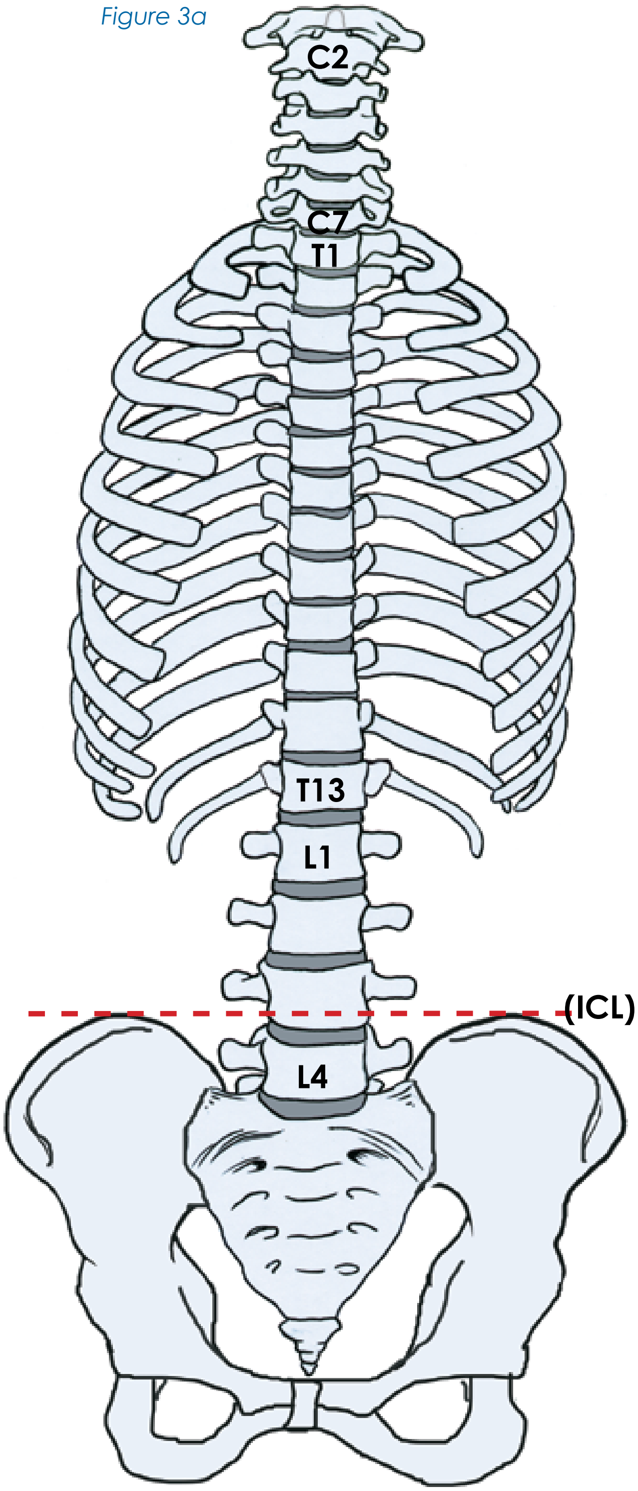
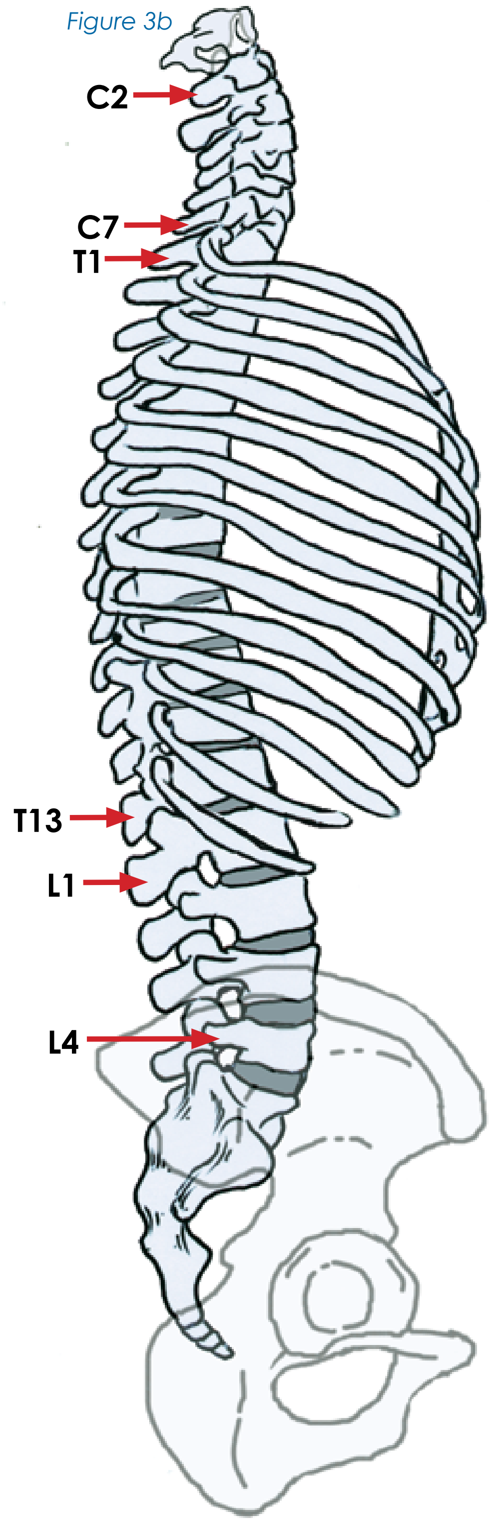


Figure 3b



Note that the position of the intercrestal line (ICL) confirms the location of L4 on AP and lateral x-rays.

Spinal Anatomy and Alignment

Lumbosacral Transitional Vertebrae

Normal

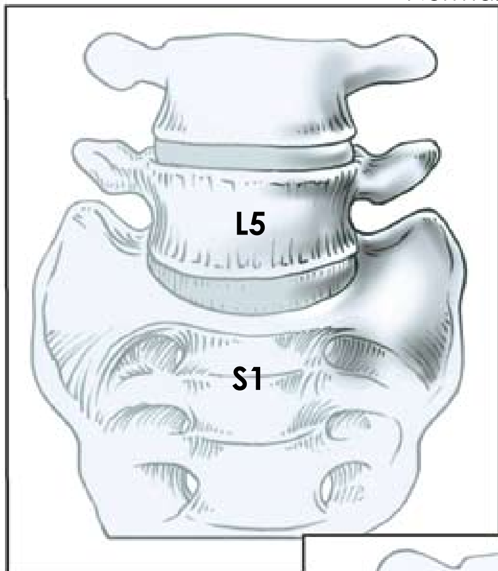


Figure 4a

Castelvi IIA

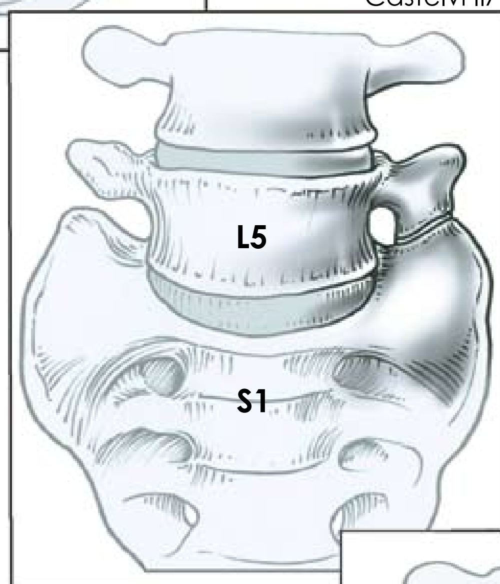


Figure 4b

Castelvi IIIA

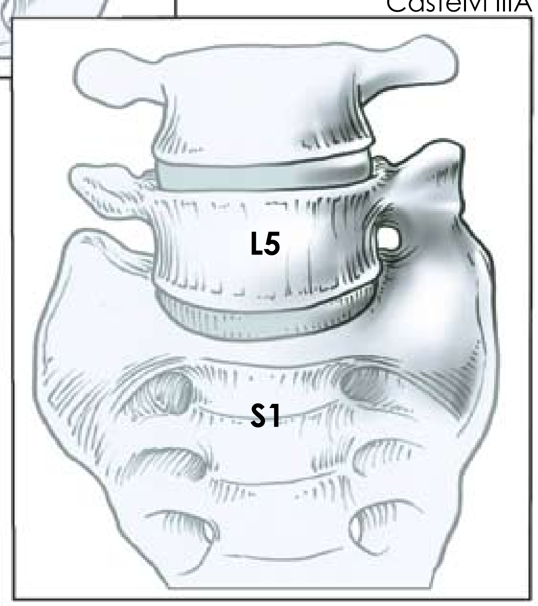
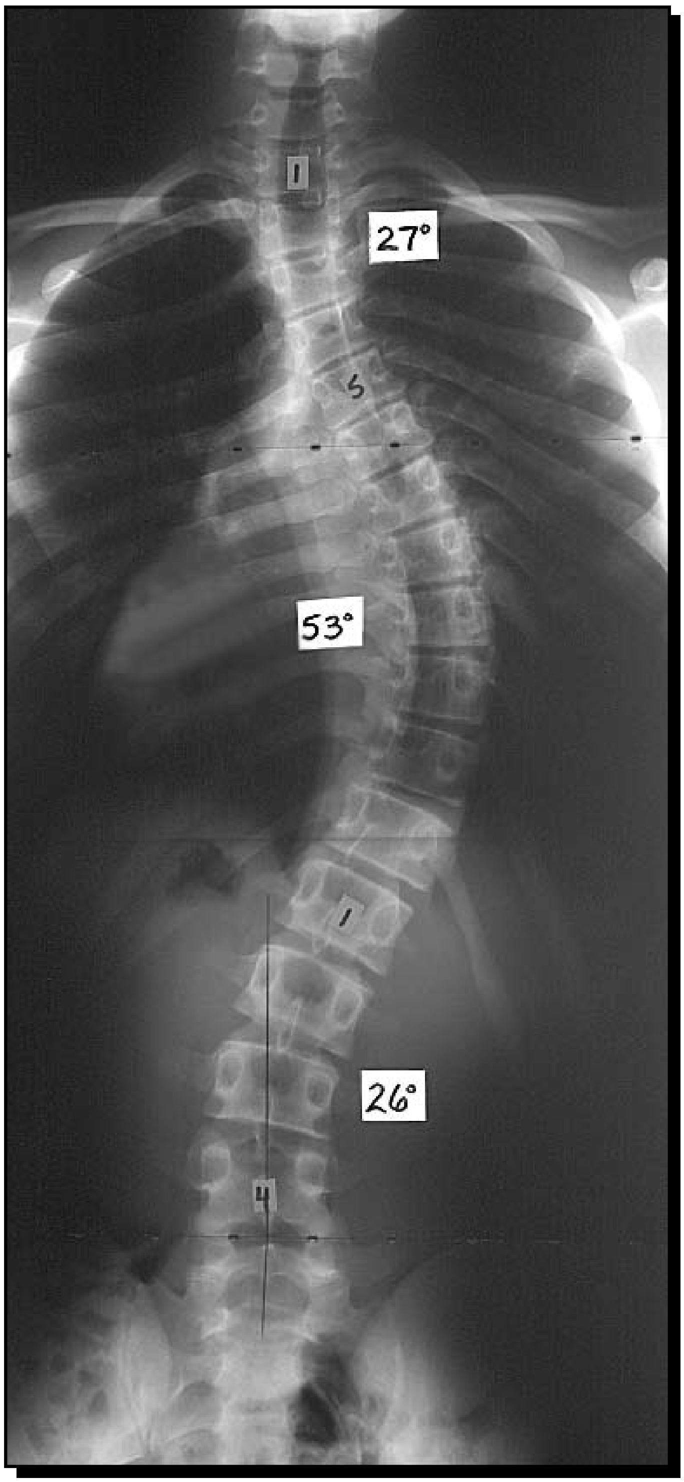


Figure 4c

Castelvi AE, Goldstien LA, Chan DPK. Lumbosacral Transitional Vertebra and their relationship with lumbar extradural defects. *Spine*. 1984;9:493-495.

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity



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Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Producing Radiographic Images

In order to produce a high quality diagnostic film from the cervicothoracic junction to the pelvis for the purpose of evaluating spinal deformities, several factors must be taken into consideration. First, proper distance from the source to the image is important. A distance of 72" produces an acceptable amount of magnification and distortion and is therefore preferred. The use of a compensating filter between the patient and the x-ray beam assures that proper density is maintained between the easily penetrated thoracic cavity and the denser lumbosacral region.

Proper placement of a gonad shield may be utilized to protect the patient but should not cover important osseous anatomy. Variations in grid ratios, film/screen combinations, x-ray machine generators, and patient size and shape make establishing exact recommendations for appropriate exposure of scoliosis films impossible. Since final exposures are dependent on many variables, radiographic quality may vary between institutions and from department to department. Therefore, for the spinal deformity surgeon, it is essential to identify radiology technicians that can reliably manipulate all the variables in order to produce consistent images that clearly delineate the osseous anatomy to be evaluated and measured.

As a reminder, all radiographs, including those for spondylolisthesis, are taken in an upright position to show the true position of the spine. This excludes various flexibility films discussed later in this chapter. If the leg length discrepancy is > 2cm, the x-ray should be taken with a block to level the pelvis.

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Radiographic Methodology

Stance for Scoliosis X-rays

Patients should stand with their knees locked, the feet should be shoulder width apart, looking straight ahead with their elbows bent and knuckles in the supraclavicular fossa bilaterally. This will place the patient's arms at approximately a 45° angle to the vertical axis of the body (Figures 1 – 4). If there is greater than a 2 cm leg length discrepancy, the x-ray should be taken with a block to level the pelvis.

NOTE: Remove rings, bracelets, earrings (all jewelry) before taking x-rays to avoid artifact.

Figure 1

Figure 2

Figure 3

Figure 4

Types of X-rays – Optimal Quality and Unacceptable Views

1) Mandatory Radiographs for Surgical Planning:

a) Standing AP or PA (Figures 5 – 9 Acceptable/Figures 10 – 14 Unacceptable)

b) Supine sidebenders: either two long cassettes or three 14" x 17"s (one each for the proximal thoracic, main thoracic, thoracolumbar/lumbar). All 3 curves must be evaluated for flexibility. (Figures 15 – 17 Acceptable/Figures 18 – 19 Unacceptable)

c) Standing lateral (Figure 20 Acceptable/Figures 21 – 23 Unacceptable)

2) Optional Radiographs (Flexibility):

a) Push-prone (Figures 24 – 29)

b) Supine AP (Figures 30 – 31)

c) Fulcrum bend (thoracic curve) (Figures 32 – 34)

d) Traction AP (Figures 35 – 37)

e) Supine hyperextension crosstable lateral (Figures 38 – 40)

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Mandatory Radiographs:
1a. Standing AP or PA – Acceptable Images

Good quality spinal radiographs will show C7 to the femoral heads and the entire rib cage from right to left. (Figures 5 and 6)

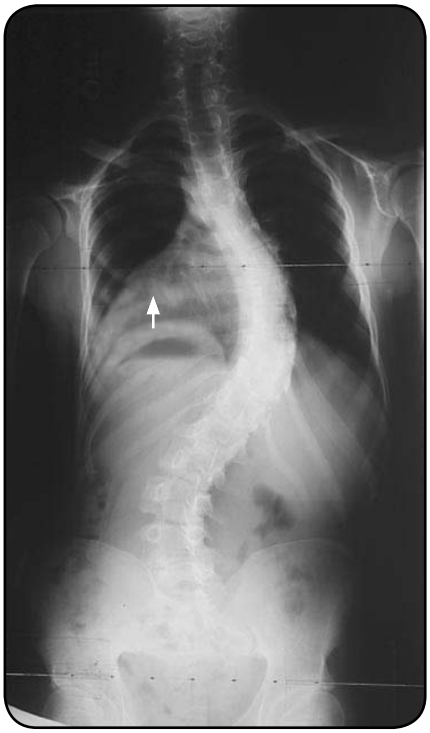


Figure 5

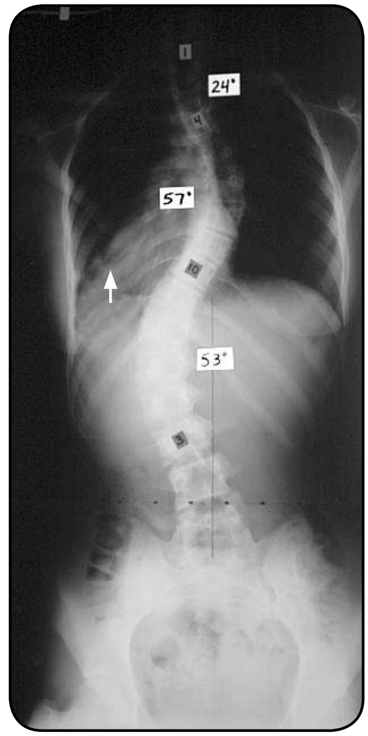


Figure 6

If unable to assess the TRC (triradiate cartilage) on an otherwise acceptable standing AP/PA x-ray, it may be visible on one of the flexibility x-rays.

Figure 7

Figure 8 Supine

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Mandatory Radiographs:
1a. Standing AP or PA – Acceptable Images

It is not uncommon to have a good quality spinal radiograph showing C7 to the sacrum but not the ribcage or triradiate cartilage. All vertebrae must be visible for the radiograph to be deemed acceptable.

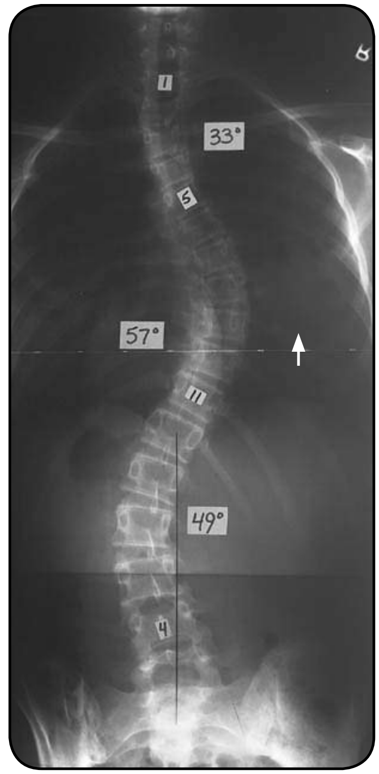


Figure 9

Mandatory Radiographs:
1a. Standing AP or PA – Unacceptable Images

14" x 17" films without a clear and complete view of the pelvis (right and left iliac wings), C7, and S1.

Figure 10

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Mandatory Radiographs:
1a. Standing AP or PA – Unacceptable Images

Image blurred

Figure 11

Image too light or dark or both

Figure 12

Belt buckle, etc. covering critical landmarks

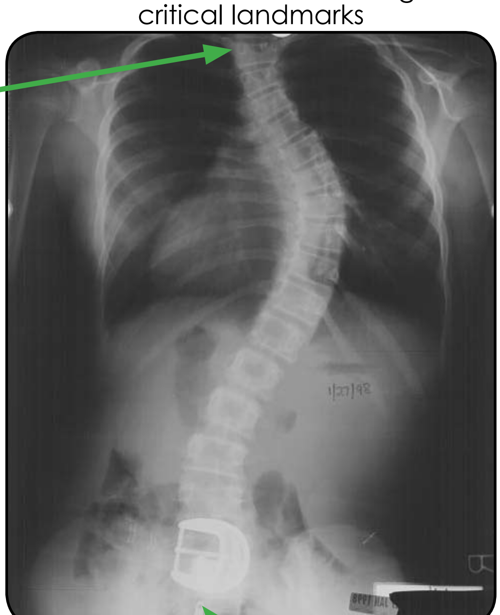


Figure 13

Bad tape job.
(upper part of film flipped and taped incorrectly)

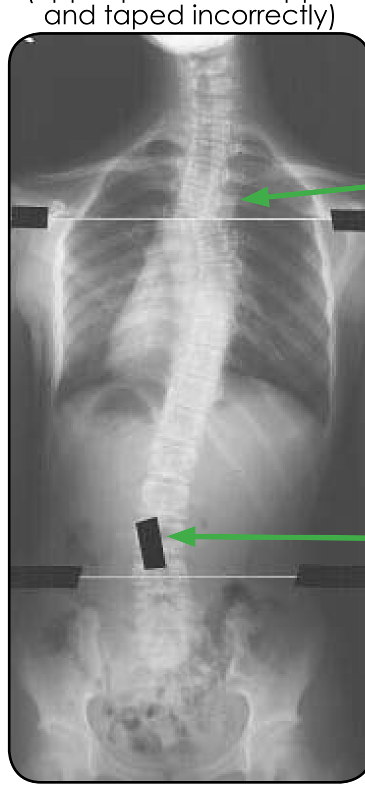


Figure 14

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Mandatory Radiographs:
1b. Supine Sidebenders – Mandatory that all three curves are visualized

Bending films of the proximal thoracic and lumbar curves are seen on the left sidebender for right thoracic curves. Need to see the entire spine.

Main thoracic (typically right sidebender)

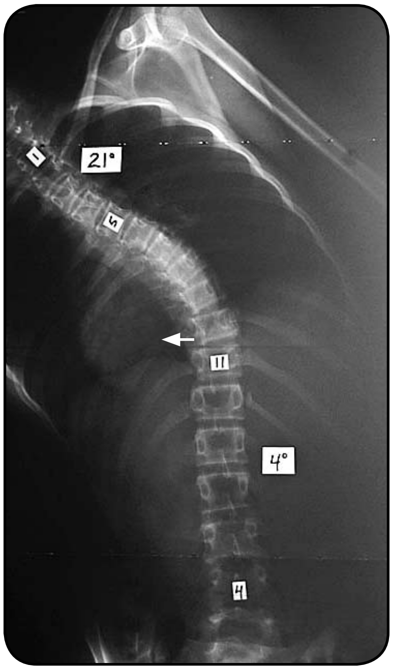


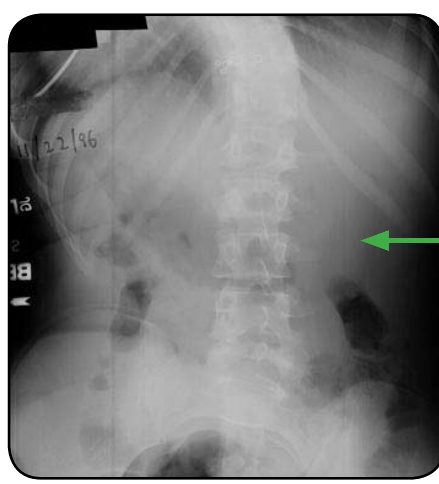
Figure 15

Figure 16

Figure 17

Bending films of all three curves are necessary for accurate curve classification. If minor curves are small (< 25°) on the upright image and the sagittal plane is within normal limits, one can assume that those curves are nonstructural. Conversely, if structural characteristics of a minor curve are suspected (the PT curve in this example) and the sagittal plane is normal, there is no way to determine if that curve is structural without a bending film. (If T2-T5 is ≥ 20° on the upright sagittal film, then the PT curve is structural regardless of the bending measurement.) **It is good practice to have bending films of all three curves to assess flexibility.**

Figure 18



No proximal thoracic bender

Figure 19

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Mandatory Radiographs:
1c. Standing Lateral – Acceptable Image

Radiograph should be obtained with patient's left side against the cassette (patient facing the observer's right). The radiograph should include C7 to S1. The ability to visualize C0–C1 and the hip joints is optimal.

It is not uncommon to have a good quality radiograph where T2 is not clear but all other landmarks (C7, T5, T10, T12, L2, and the sacrum) are visible. The upper thoracic spine is the most difficult area to image.

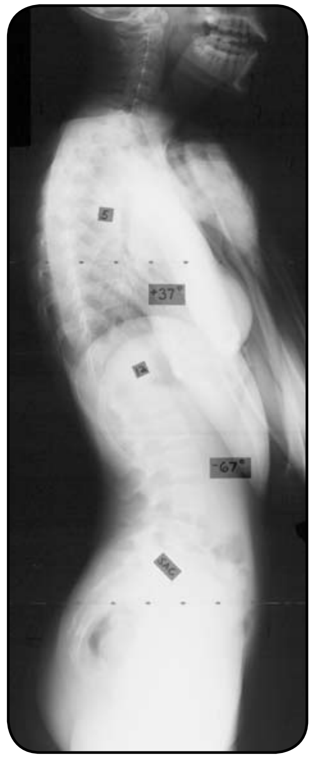


Figure 20

1c. Standing Lateral - Unacceptable Images

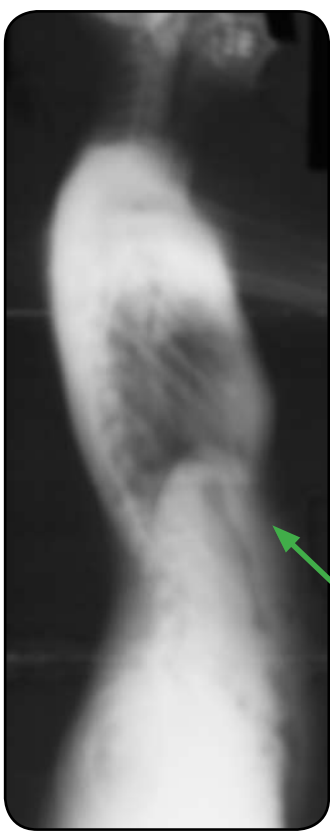


Image blurred

Figure 21

Figure 22

14" x 17" lateral – can't see C7, T2, or S1

Whited out at top

Figure 23

Optional Views:
2a. Push Prone

Apply pressure to push on the structural curve(s) while stabilizing point(s) on the opposite side of the body.

Single curves:

Push on the major curve and stabilize the opposite pelvis and axilla.

Thoracic curves:

Need to push **lower** than horizontal to the apex of the curve – push on ribs that **attach to the apex**. Stabilize the opposite pelvis and axilla.

Thoracolumbar/Lumbar Curves:

Need to push on the curve **between** the rib cage and iliac crest. Stabilize the opposite pelvis and axilla.

UPRIGHT

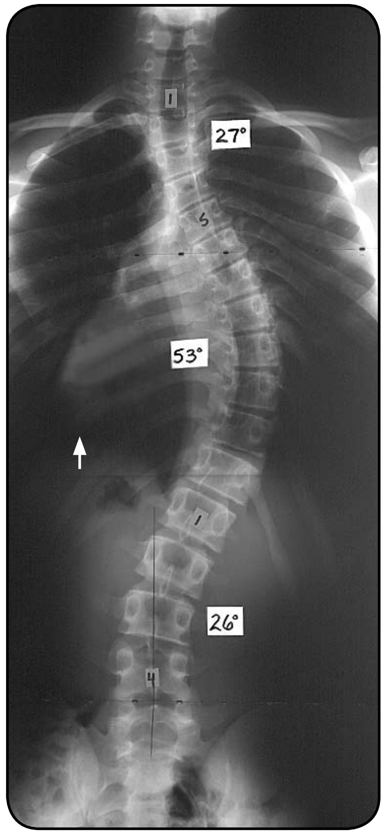


Figure 24

PUSH PRONE

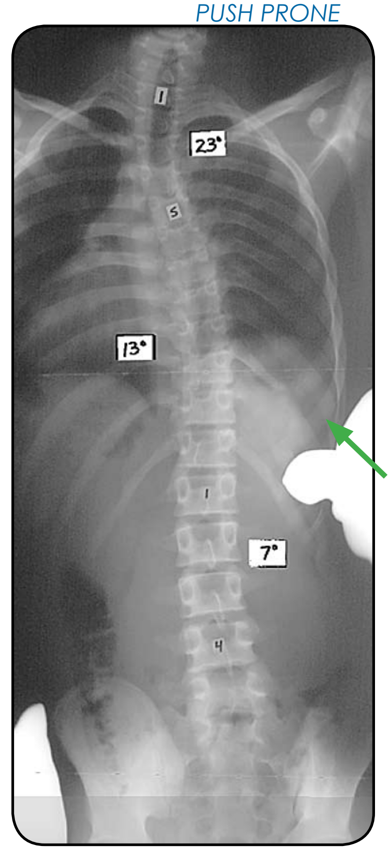


Figure 25

UPRIGHT

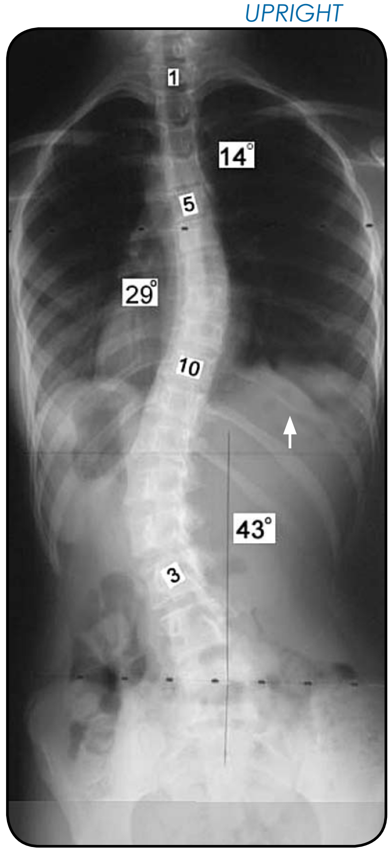


Figure 26

PUSH PRONE

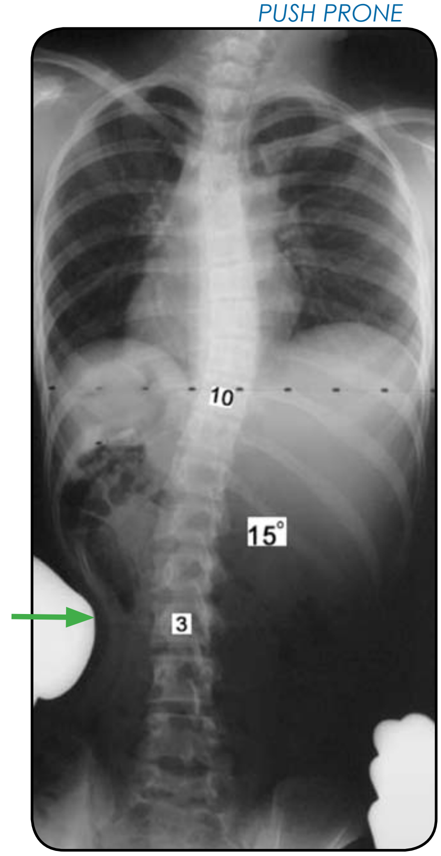


Figure 27

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Optional Views: 2a. Push Prone

Double Major Curves

Push on both curves - stabilize the axilla opposite the MT curve and the pelvis opposite the thoracolumbar/ lumbar curve.

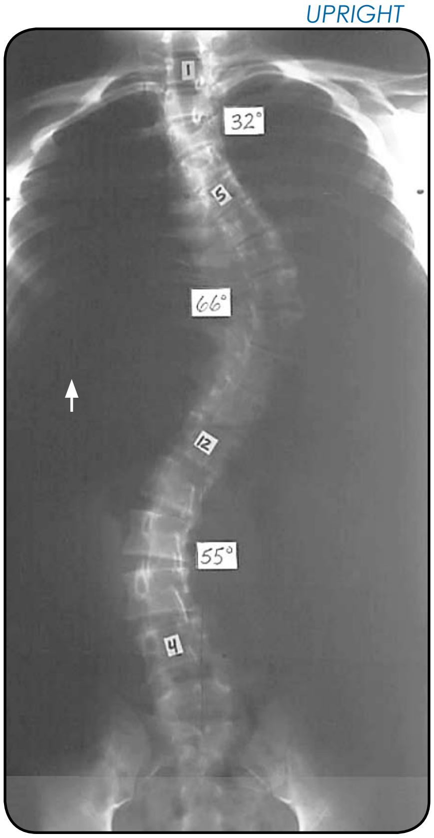


Figure 28

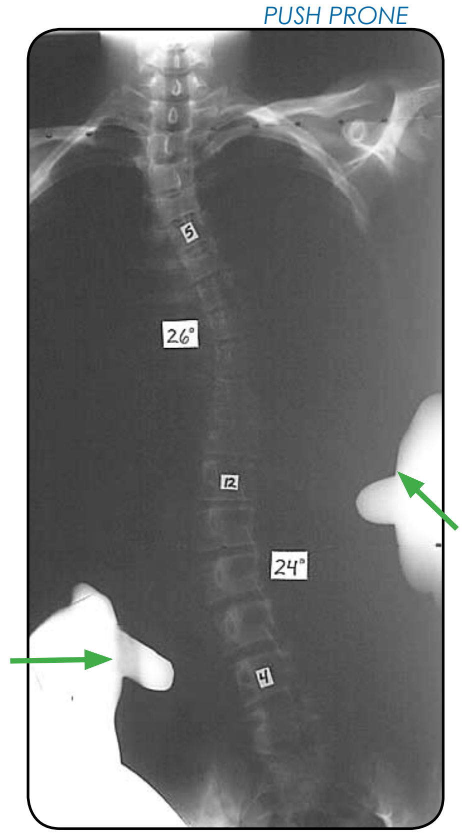


Figure 29

Optional Views: 2b. Supine AP

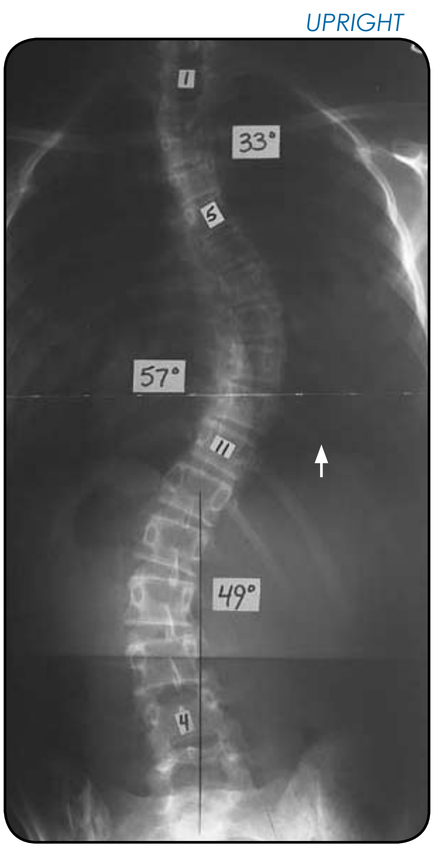


Figure 30

Figure 31

Optional Views:
2c. Fulcrum Bend (Thoracic Curve)

Patient side bending over a bolster positioned under the most prominent part of the ribcage (ribs that attach to apex of curve). The arms are positioned overhead and the body should be relaxed over the bolster, which is firm enough so that the shoulder and hip does not touch the x-ray table.

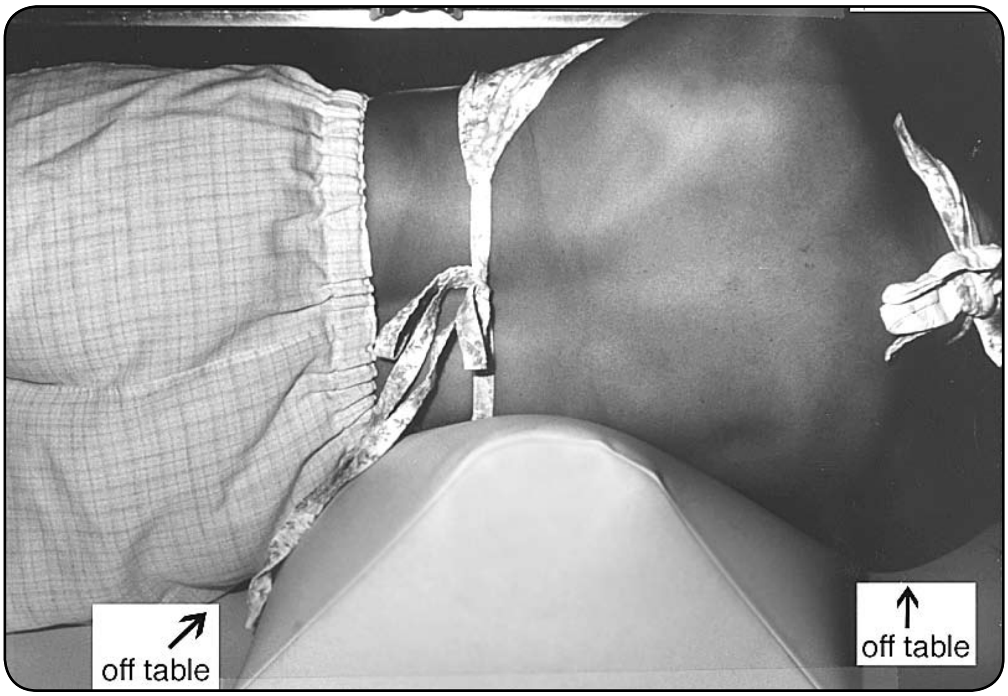


Figure 32

UPRIGHT

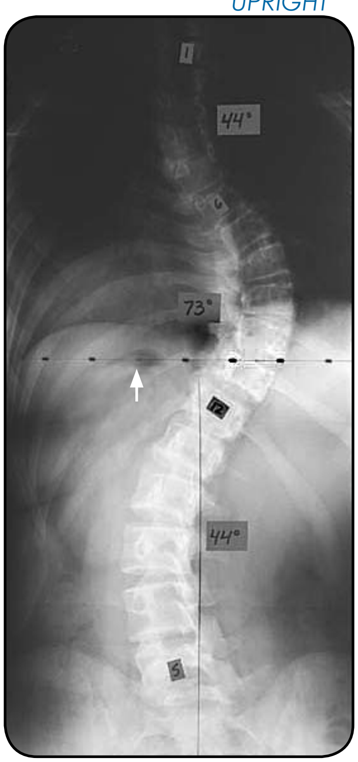


Figure 33

FULCRUM BEND

"X" marks location of bolster

Figure 34

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Optional Views:
2d. Traction AP

Figure 35

UPRIGHT

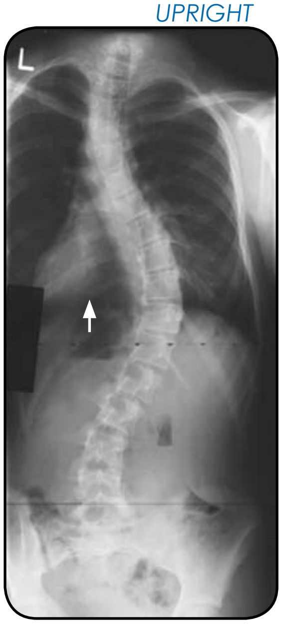


Figure 36

TRACTION FILM

Figure 37

Although bending films are the most common method to assess curve flexibility, traction films may also be useful. Use of a head halter, as shown above, or simply pulling from the axilla of both upper extremities is effective for creating the cephalad vector. The force applied should be firm but not painful.

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Optional Views:
2e. Supine Hyperextension Crosstable Lateral (Bolster under Apex of Kyphosis)

Figure 38

UPRIGHT

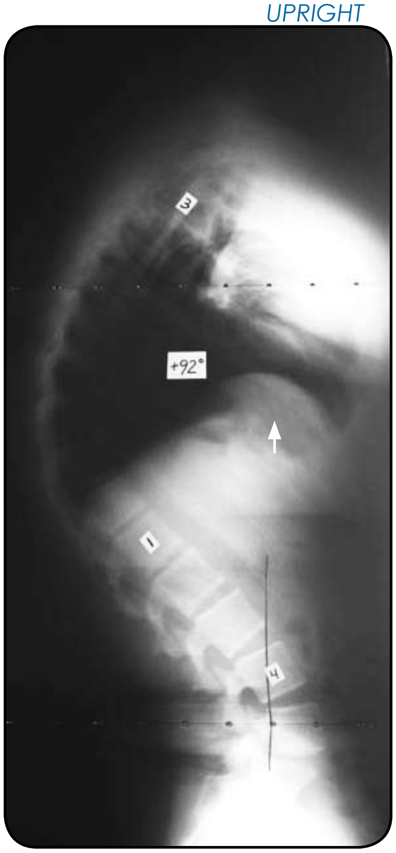
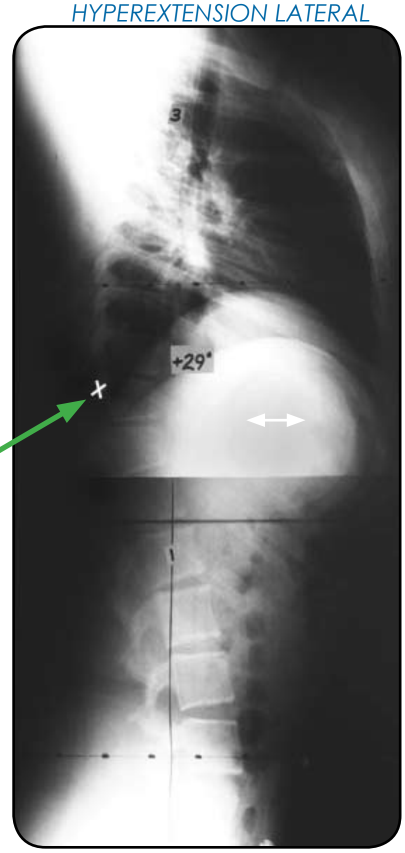


Figure 39

HYPEREXTENSION LATERAL



"X" marks location of bolster

Figure 40

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Clinical Photographs:

Defining a treatment plan for scoliosis is multifactorial. It involves a clinical and a radiographic evaluation and a detailed discussion with the patient and the family. In some cases the treatment option is clear. In other cases there are multiple treatment options with the final plan being determined by the nuances of the deformity and the goals of surgery.

A critical component in the assessment of spinal deformity is the visual inspection of the spine: rib and/or flank prominences, shoulder level, coronal and sagittal balance, and overall balance and appearance. Appropriate clinical photography is the means to catalog this visual inspection. Photography has been used in the clinical setting for nearly 100 years. It is an important component in the routine diagnosis and treatment of patients with spinal deformity and is not primarily an investigational or research tool.

Clinical photography parallels and augments the clinical examination. It allows documentation of subtle visual and structural components of the deformity. Clinical photography also allows multiple clinician input when direct examination of the patient is not possible. It also facilitates accurate serial comparisons over time and allows comparison of preoperative and postoperative spinal alignment. In addition, it provides a research tool that can be used to enhance current and future patient care.

Because the clinical photos require a relative state of undress it is necessary to maintain the patient's privacy and dignity. For this reason, clinical photography should be performed in a respectful fashion and secured as part of the medical record. As part of the medical record, it must be accorded the same confidentiality as other sensitive medical information. The patient's facial appearance adds no value to the spinal deformity evaluation. Therefore, appropriate masking of the face can be performed to assure patient privacy. Patient and parent/guardian consent will be obtained if the patient is a minor.

Ideal Clinical Photos:

Clinical photos should be taken without any clothing on the trunk. Shorts or underwear should be below the waist to allow visualization of the LS junction and iliac crests. Long hair must be up off the shoulders. This allows full visualization/evaluation of all aspects of the deformity. Photos should be cropped to obscure the face to protect patient identity. Females should position their arms to cover their breasts. The best position of the arms for lateral clinical photos has not been documented. Options are arms at the side of the torso, crossed over the chest, or in front of the body at a 30-45° angle.

Photography Views - Optimal (Figures 41-54) and Suboptimal Examples (Figures 55-62)

- Upright posterior trunk – hair off shoulders (mandatory)
- Close forward bend posterior (mandatory)
- Upright lateral – both sides (optional)
- Close forward bend lateral to highlight prominence from both sides if applicable (optional)

On the following pages are three representative cases with acceptable clinical photos.

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Optimal Clinical Photos: Case 1.

Figure 41

Figure 42

Figure 43

Figure 44

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Optimal Clinical Photos: Case 2.

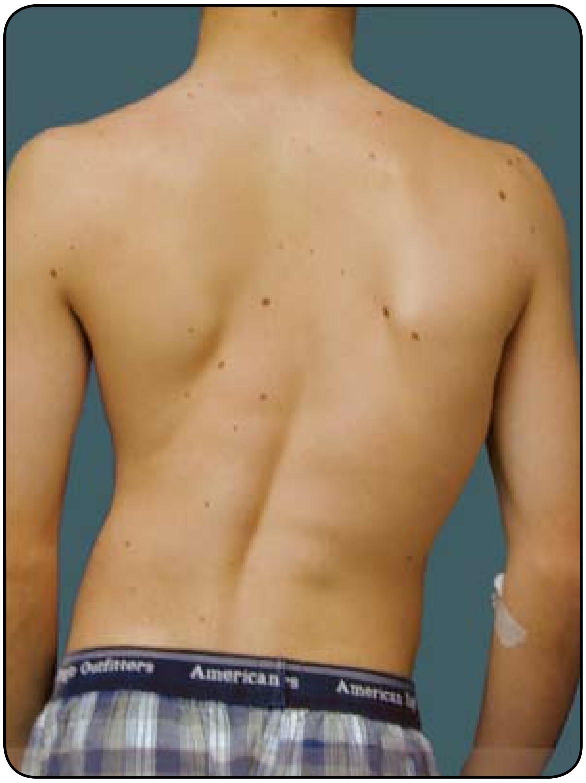


Figure 45

Figure 46

Figure 47

Figure 48

Figure 49

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Optimal Clinical Photos: Case 3.


Figure 50


Figure 51


Figure 52


Figure 53


Figure 54

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Suboptimal Clinical Photos

The bra obscures full appreciation of the thoracic prominence.

Figure 55

Figure 56

A bra, a strap tied in the back, or long hair obscures full appreciation of the thoracic prominence on the forward-bending view.

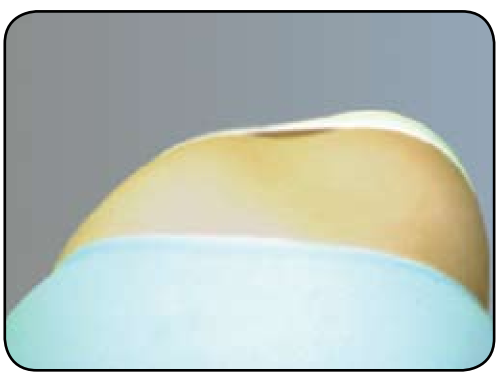


Figure 57

Figure 58

Figure 59

Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

Suboptimal Clinical Photos

Long hair, hospital gowns, bulky halter tops, or shorts positioned above the hips will obscure full appreciation of all aspects of the deformity.

Figure 60

Figure 61

Figure 62

If you are unable to take pictures of female patients without any clothing on the trunk, the following page has information for use of a halter top that does not obscure visualization of the deformity.

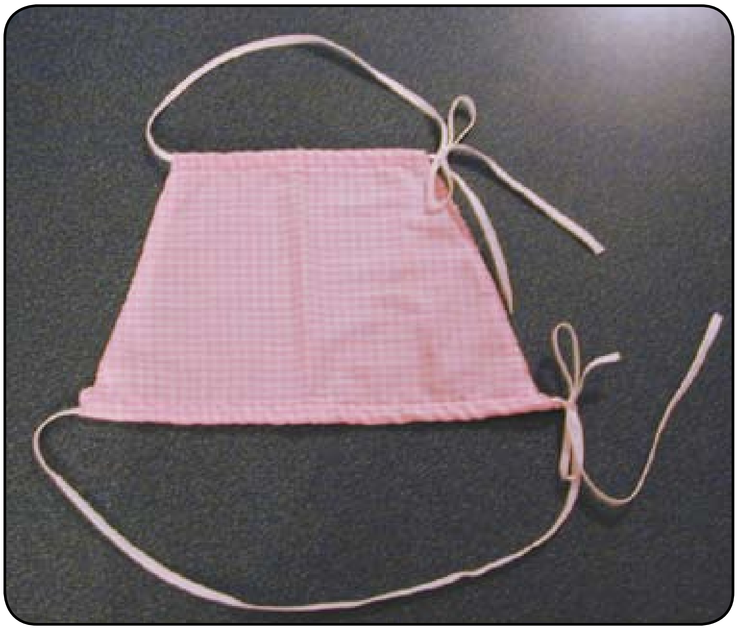
Clinical Photographs and Radiographic Methodology to Evaluate Spinal Deformity

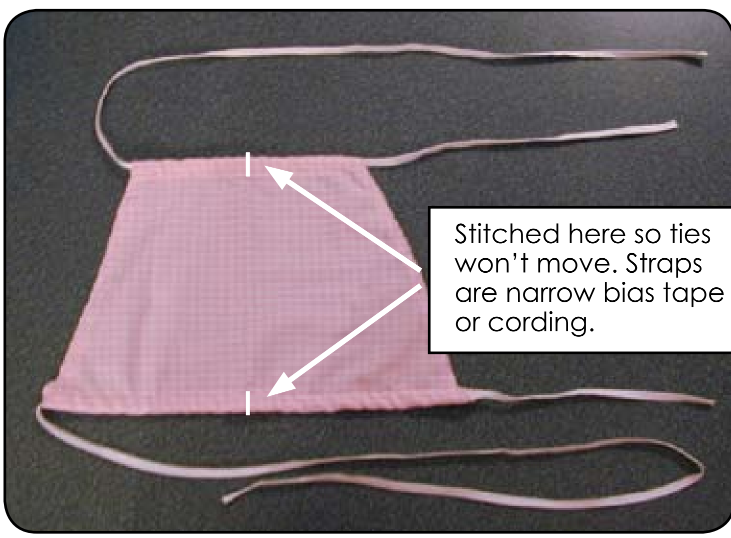
Halter Tops

Straps – Left – 7" top and bottom, Right – 18" top, 36" bottom

Measurements – (cut larger for seams)

	Top Width	Bottom Width	Vertical Length
SM	7"	12"	8"
MED	9"	18"	10"
LG	10"	22"	12"



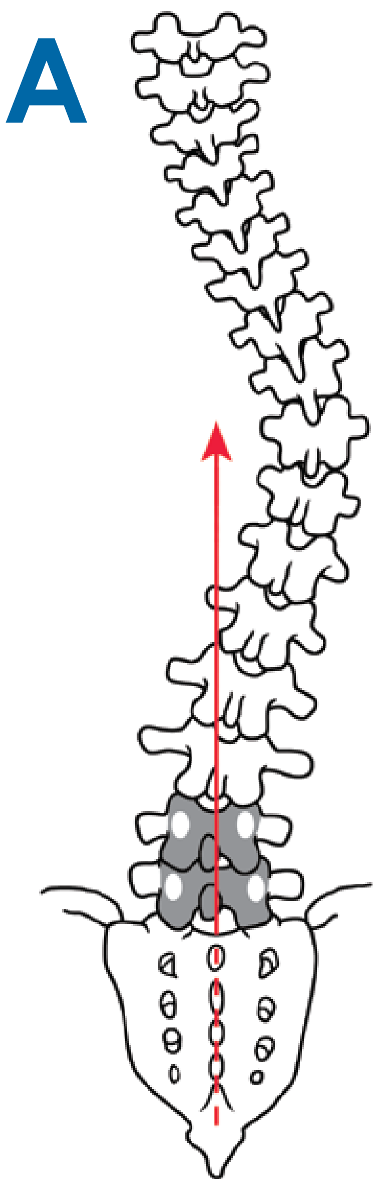


Stitched here so ties won't move. Straps are narrow bias tape or cording.

Front views of halter: The short ties should be on the left side of the halter so when tied, bows are on the patient's left side (since lateral photos are usually taken with the patient facing right). You can untie the waist strap for pictures taken from the back; even if the straps are not untied, they should not obscure the deformity.

The Lenke Classification:

Technique for Analysis and Classification of Operative AIS



Central Sacral
Vertical Line (CSVL)
Between Pedicles
(Apical Vertebra)

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The Lenke Classification:

Technique for Analysis and Classification of Operative AIS

The Lenke Classification is a three-step system that allows a reproducibly accurate classification of adolescent idiopathic scoliosis (AIS). The system's reproducibility stems from its reliance on objective radiographic measurements obtained from standard preoperative radiographs (standing AP and lateral, right and left bending radiographs) that are used to assess regional curve flexibility. The measurements obtained from these radiographs are compared to predetermined numeric values that allow identification of structural and nonstructural curves. The result is an objective classification of AIS that has a high degree of intra- and inter-observer reliability. By virtue of this system's analysis of each curve, the detailed assessment necessary for effective presurgical planning is accomplished during classification.

Step #1: Identification of the Primary Curve (Types 1-6)

First the regional curves are identified. These are the proximal thoracic (PT), main thoracic (MT), and thoracolumbar/lumbar (TL/L) curves. Each curve is defined by the level of its respective apex. The curve designation is then applied according to SRS nomenclature committee definitions (Figure 1).

Figure 1

Location of Apex (SRS Definition)	
Curve	**Apex**
Thoracic	T2 through the T11–T12 disc*
Thoracolumbar	T12 to L1
Lumbar	L1–L2 disc through L4**

***** Regardless of the number of thoracic vertebrae, the disc below T11 is always a thoracic apex.

****** In some type A curves the apex can be L5 (most horizontal segment). Technically L5 is a lumbosacral apex but that is not measured for AIS.

To begin the classification, the structural or non-structural quality of each of the three curves must be determined. The first structural curve will be identified by making a determination as to which curve is the "major curve." The major curve will always be the MT or TL/L, whichever is the largest curve. In very rare cases where the PT is the largest Cobb measurement, default to the MT as the major curve. The major curve will always be considered structural. The MT curve will be the major curve in types 1-4 and the TL/L curve will be the major curve in types 5 and 6. In type 4 curves (triple major), either the MT or TL/L curve can be the major curve depending on which has the largest Cobb measurement. If MT and TL/L are equal in magnitude, the MT will be considered the major curve.

The "minor curves" (the other two curves) may be structural or nonstructural. Curves are considered structural if they are ≥ 25° on the standing AP radiograph and do not bend out to < 25° on the side-bending radiographs. Minor curves < 25° on the standing AP radiograph by definition will be nonstructural. However, minor curves may be deemed structural if their regional sagittal profile reveals a kyphosis ≥ +20°. The T2-T5 sagittal alignment is evaluated in conjunction with the proximal thoracic spine. Therefore, even if the PT curve is not structural by coronal criteria (i.e., it bends out to < 25°), but the regional kyphosis between T2-T5 is ≥ +20°, the curve will be considered structural. The sagittal alignment from T10-L2 is evaluated in conjunction with the MT and the TL/L regions in a similar fashion. A kyphotic sagittal alignment from T10-L2 of ≥ +20° will cause the TL/L or main thoracic curve to be considered structural even if it does not meet structural criteria in the frontal (coronal) plane. After determining the "structural" or "nonstructural" nature of each regional curve, the Lenke type (1-6) can be assigned (Figure 2).

The Lenke Classification:
Technique for Analysis and Classification of AIS

Figure 2

Type	Proximal Thoracic	Main Thoracic	Thoracolumbar/Lumbar	Curve Type
1	Non-Structural	Structural (Major*)	Non-Structural	Main Thoracic (MT)
2	Structural	Structural (Major*)	Non-Structural	Double Thoracic (DT)
3	Non-Structural	Structural (Major*)	Structural	Double Major (DM)
4	Structural	Structural (Major*)	Structural (Major*)	Triple Major (TM) §
5	Non-Structural	Non-Structural	Structural (Major*)	Thoracolumbar/Lumbar (TL/L)
6	Non-Structural	Structural	Structural (Major*)	Thoracolumbar/Lumbar-Main Thoracic (TL/L – MT)
Minor Curve Structural Criteria	Side Bending Cobb ≥ 25° T2-T5 Kyphosis ≥ +20°	Side Bending Cobb ≥ 25° T10-L2 Kyphosis ≥ +20°	Side Bending Cobb ≥ 25° T10-L2 Kyphosis ≥ +20°	

***Major** = Largest Cobb measurement – always structural.
Minor = All other curves – may be structural or non-structural.

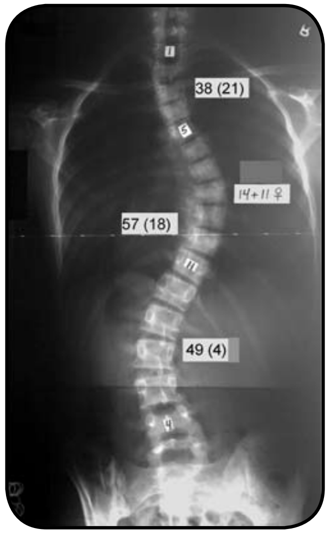
§ In type 4 curves (triple major), either the MT or the TL/L curve can be major, depending on the largest Cobb measurement. If the MT and TL/L are equal in magnitude, the MT will be considered the major curve.

Minor Curve Structural Criteria

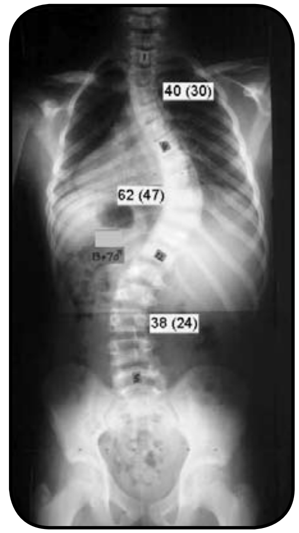
	Coronal S.B.	Sagittal
PT	≥ 25°	≥ +20° (T2-T5)
MT	≥ 25°	≥ +20° (T10-L2)
TL/L	≥ 25°	≥ +20° (T10-L2)

The Lenke Classification:
Technique for Analysis and Classification of AIS

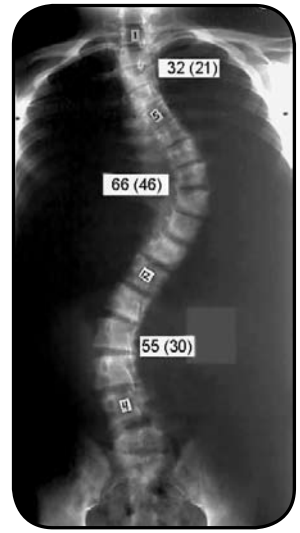
Bending measurements in parentheses on x-ray images



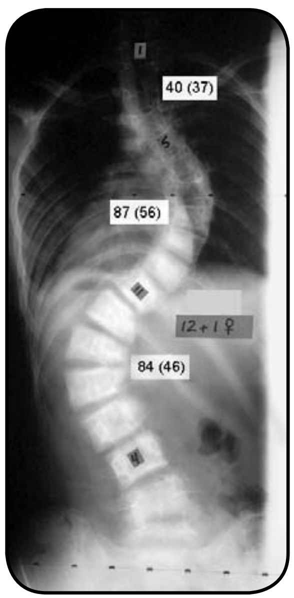
TYPE 1 MT



TYPE 2 DT

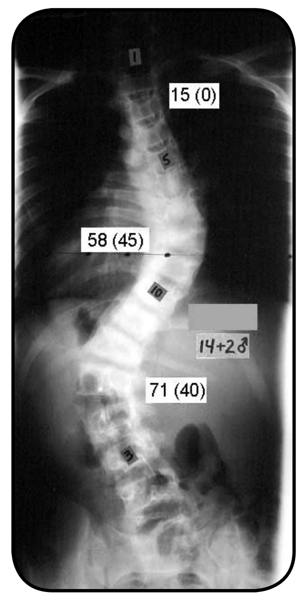


TYPE 3 DM



TYPE 4 TM

TYPE 5 TL/L



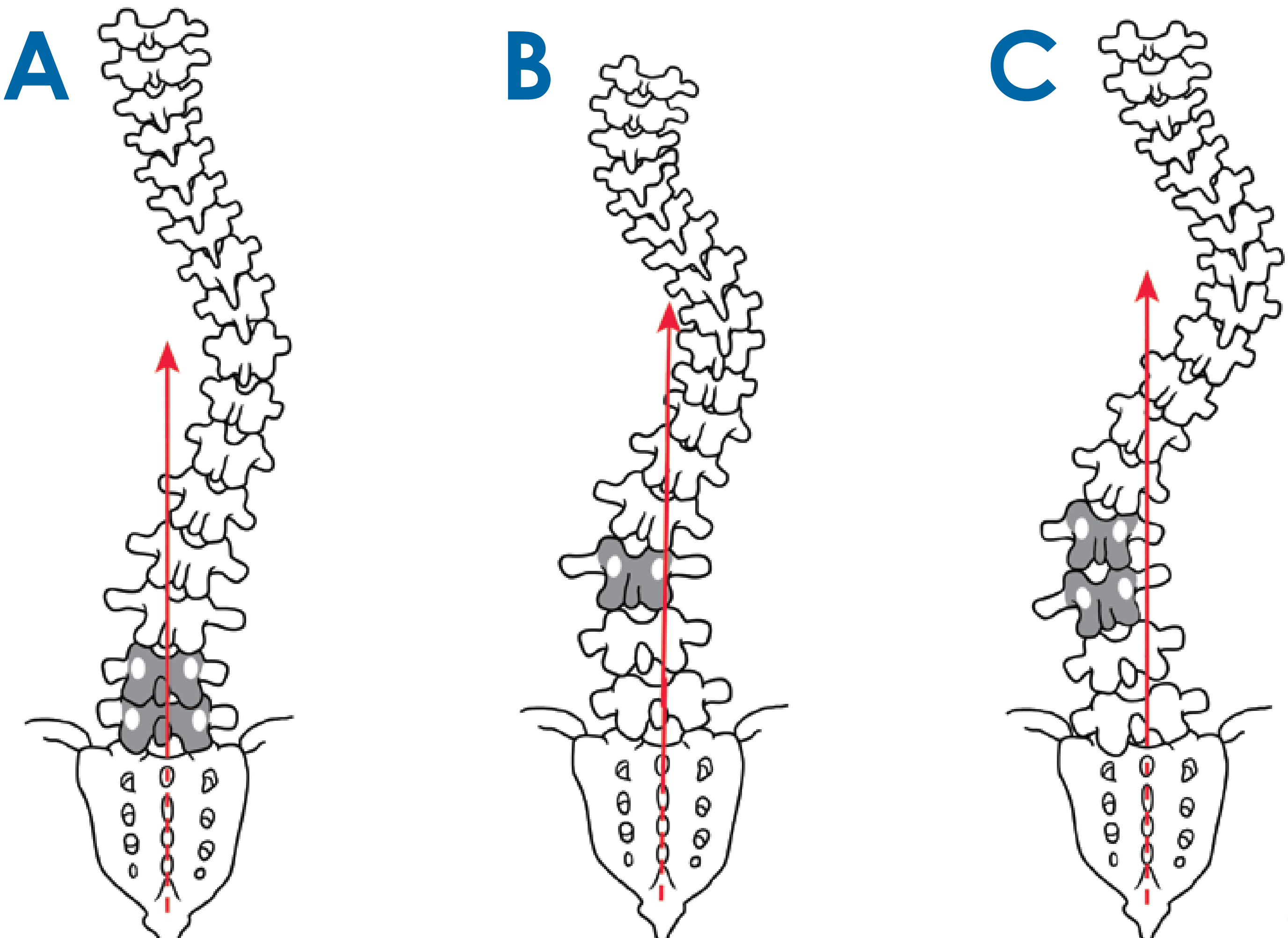
TYPE 6 TL/L-MT

The Lenke Classification:
Technique for Analysis and Classification of AIS

Step #2: Assignment of Lumbar Modifier (A,B,C)

If the Center Sacral Vertical Line (CSVL) passes between the pedicles of the apical lumbar vertebra, the lumbar modifier A is assigned. If the CSVL falls between the medial edge of the concave pedicle and the lateral vertebral body on the apical lumbar vertebra, the lumbar modifier B is assigned. If the CSVL does not touch the lateral edge of the apical lumbar vertebra, the lumbar modifier C is assigned. Occasionally it will be difficult to decide between an A and B modifier, or a B and C modifier. In either situation, a B modifier should be assigned if a clear distinction cannot be made. When the apex is a disc, the lumbar modifier is determined by the position of the CSVL in relation to the vertebra immediately above **and** below the apical disc (Figures 3 and 5a-5c).

Figure 3



CSVL Between Pedicles (Apical Disc)

*** See stacker algorithm on page 36**

CSVL Touches Apical Pedicle (Apical Body)

The apical vertebral bodies are completely lateral to the CSVL (Apical Disc)

The Lenke Classification:
Technique for Analysis and Classification of AIS

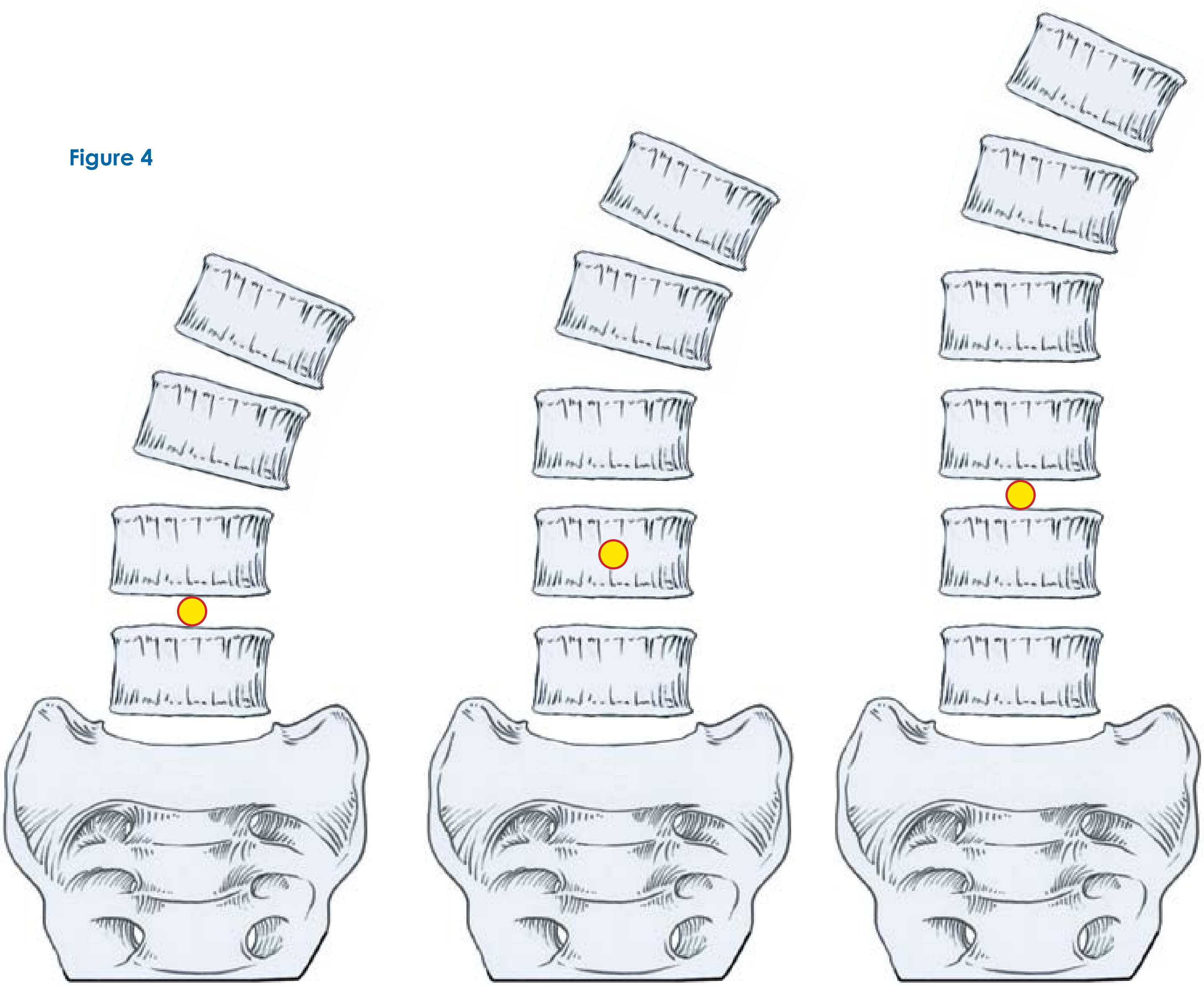
Identifying the Lumbar Apex: To assign the lumbar modifier, the lumbar apex must be identified. The CSVL is erected from the midpoint of S1.

The apex is the most horizontal and in some cases the most laterally deviated vertebra or disc from the midline (CSVL). If the lumbar curve does not cross the midline (i.e., Type A Modifier) the apex will be the most horizontal segment. If the lumbar curve partially crosses the midline (i.e., Type B Modifier) or completely crosses the midline (Type C Modifier), the apex will be the most horizontal **and** most laterally deviated segment from the CSVL.

Identifying the Apical Vertebra/Disc for Lumbar A Curves (Figure 4)

For type A modifiers in cases where everything is in the midline and two or more vertebrae are equally horizontal then the following will be selected as the apex:

Figure 4



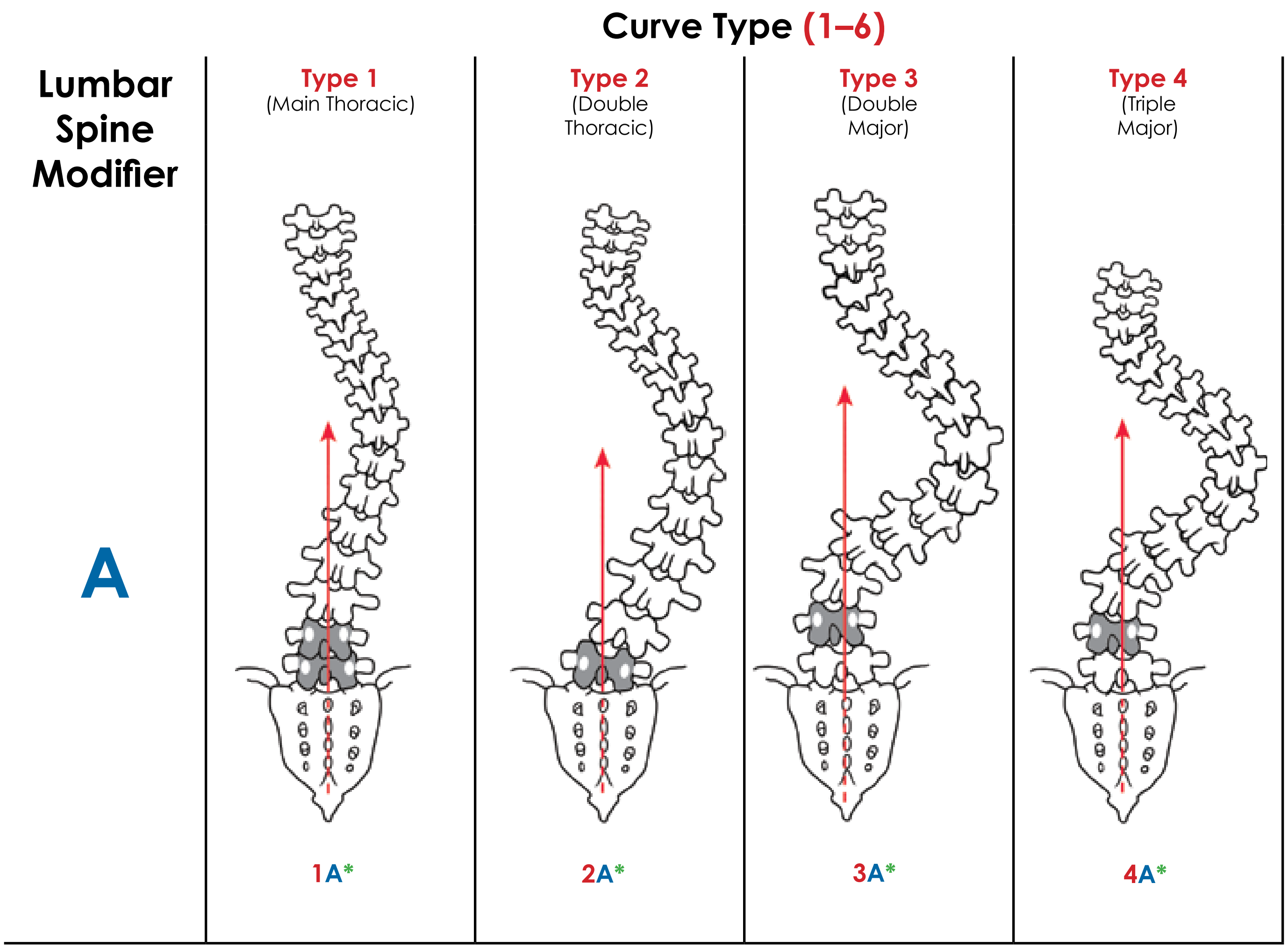
Two Stacked Vertebrae (Apex = Disc)

Three Stacked Vertebrae (Apex = Middle Vertebra)

Four Stacked Vertebrae (Apex = Middle Disc)

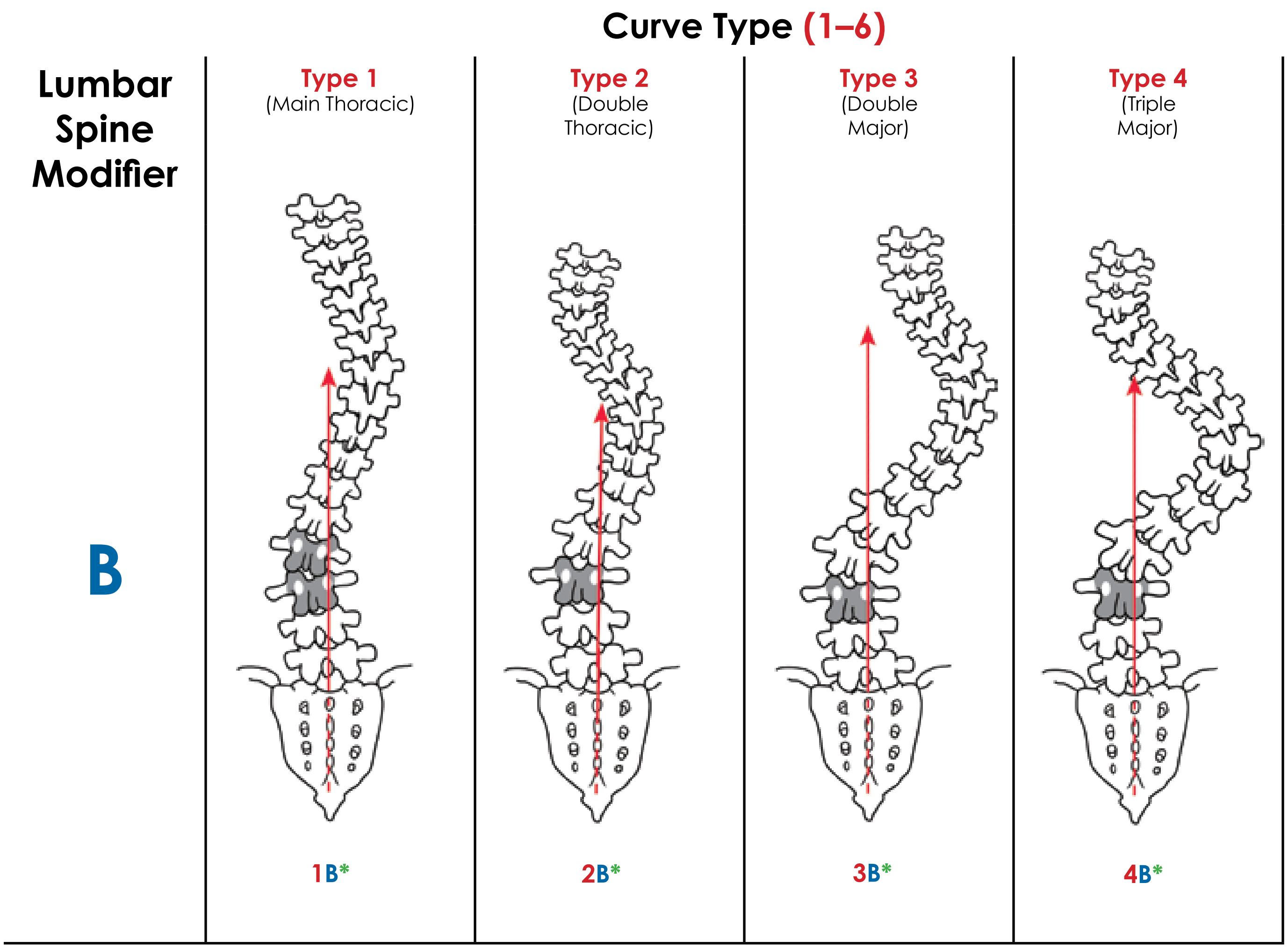
The Lenke Classification:
Technique for Analysis and Classification of AIS

Figure 5a



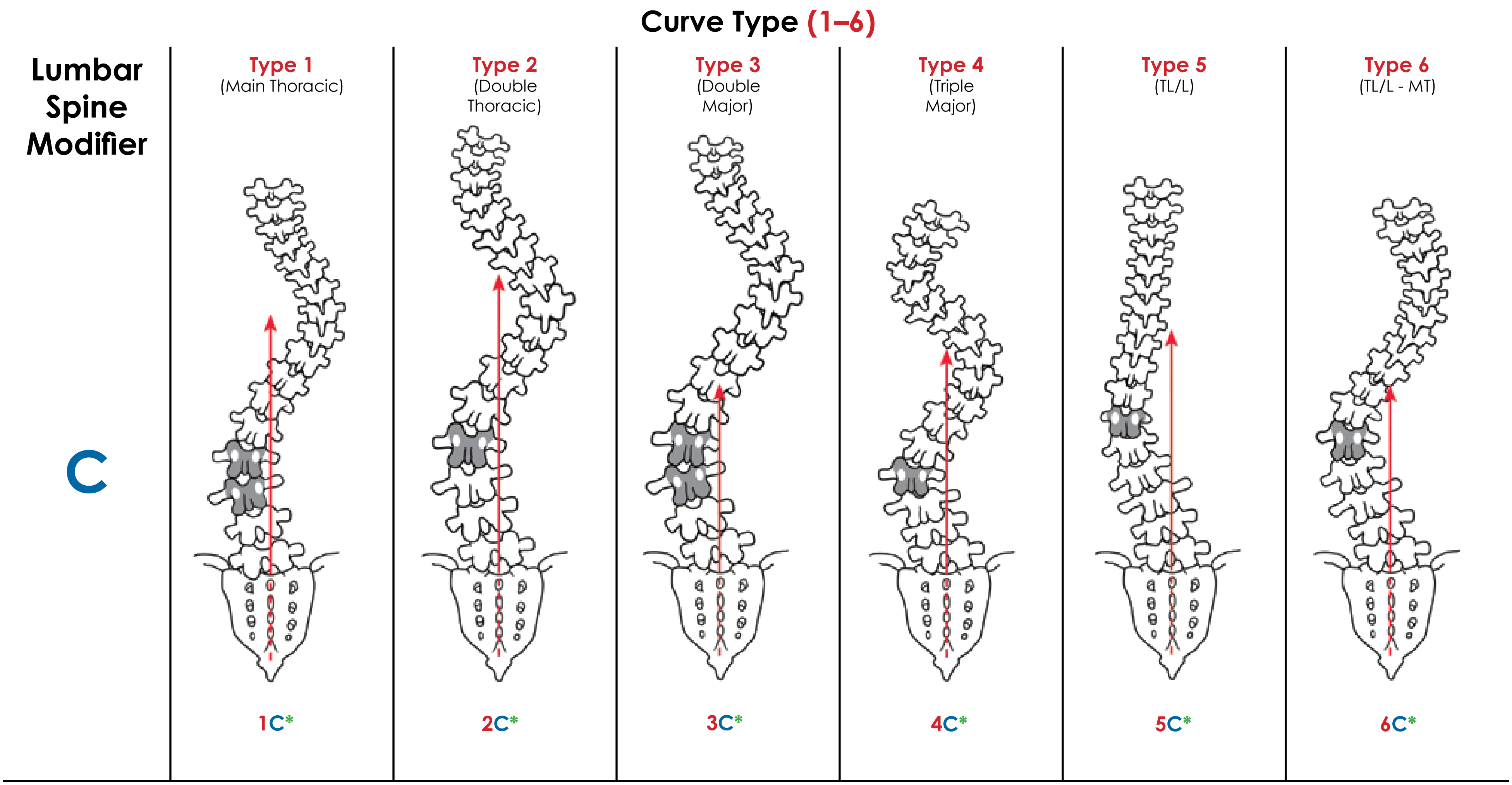
The Lenke Classification:
Technique for Analysis and Classification of AIS

Figure 5b



The Lenke Classification:
Technique for Analysis and Classification of AIS

Figure 5c



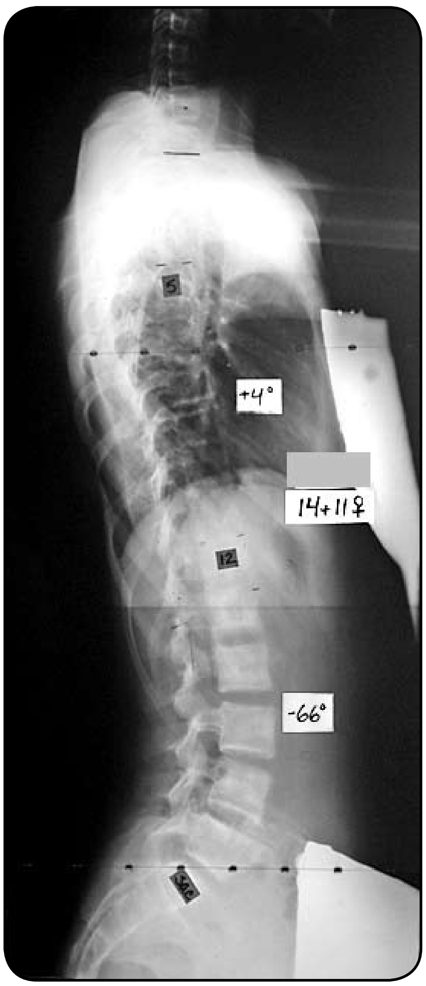
Step #3: Assignment of Sagittal Thoracic Modifier (–, N, +)

The thoracic sagittal modifier is determined by evaluating the sagittal Cobb measurement between T5 and T12. If the T5-T12 sagittal Cobb is less than 10 degrees, the sagittal thoracic alignment is considered hypokyphotic and is assigned a minus modifier (-). If the sagittal Cobb is between 10 and 40 degrees, the sagittal alignment is considered normal (N). If the sagittal Cobb measurement between T5 and T12 is greater than 40 degrees, the sagittal alignment is considered hyperkyphotic and is assigned a plus modifier (+) (Figures 6a and 6b).

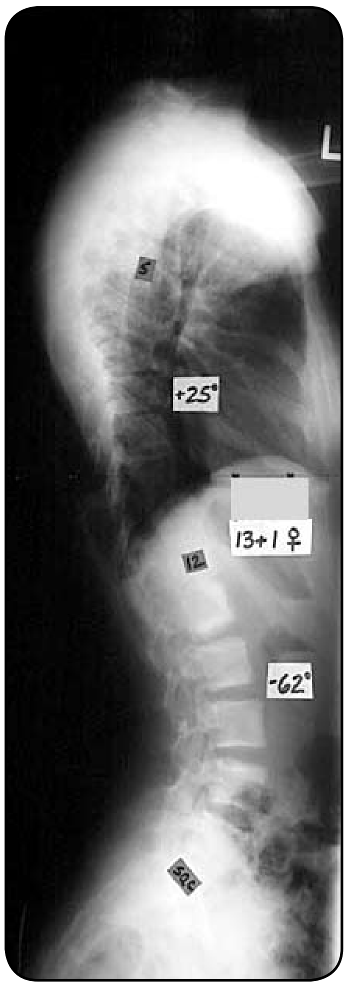
Figure 6a

Thoracic Sagittal Profile T5-T12	
– (Hypo)	< $^{+}10°$
N (Normal)	$^{+}10°$ - $^{+}40°$
+ (Hyper)	>$^{+}40°$

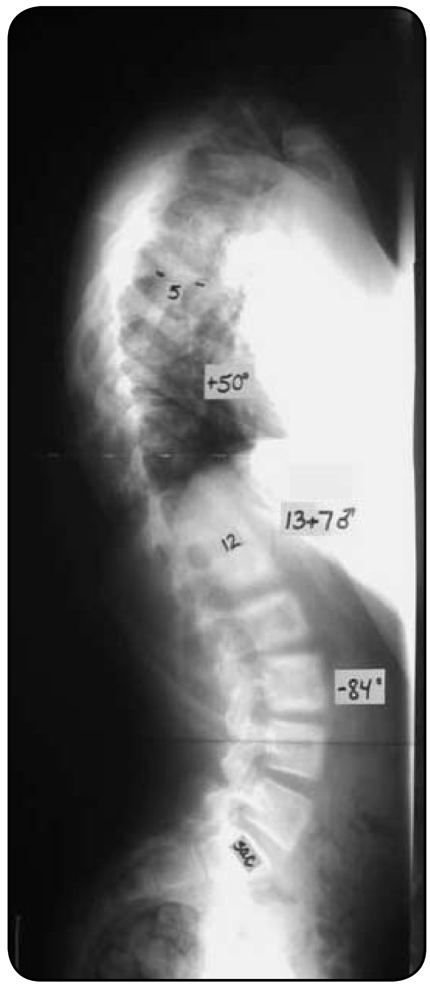
Sagittal Thoracic Modifier



–: <10°



N: 10-40°



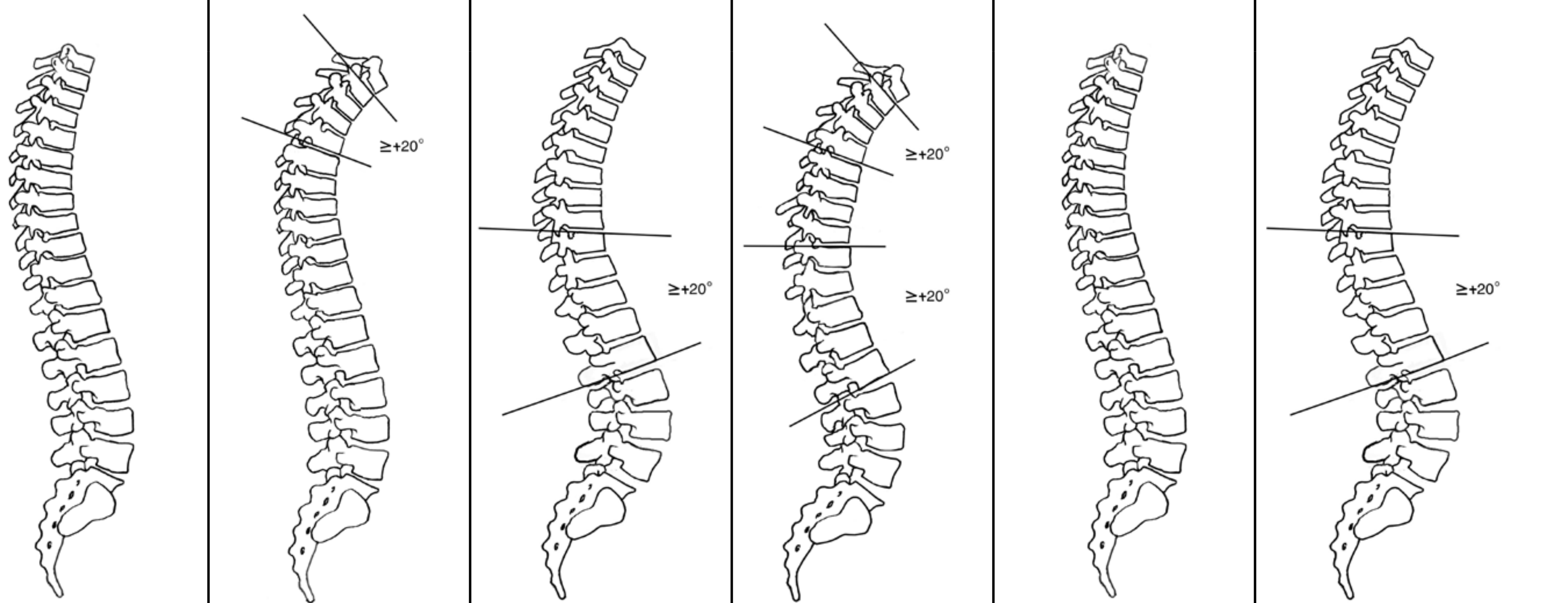
+: >40°

The Lenke Classification:
Technique for Analysis and Classification of AIS

Figure 6b

Curve Type (1–6)

	Type 1 (Main Thoracic)	Type 2 (Double Thoracic)	Type 3 (Double Major)	Type 4 (Triple Major)	Type 5 (TL/L)	Type 6 (TL/L - MT)
Possible sagittal structural criteria (To determine specific curve type)	Normal	PT Kyphosis	TL Kyphosis	PT and TL Kyphosis	Normal	TL Kyphosis



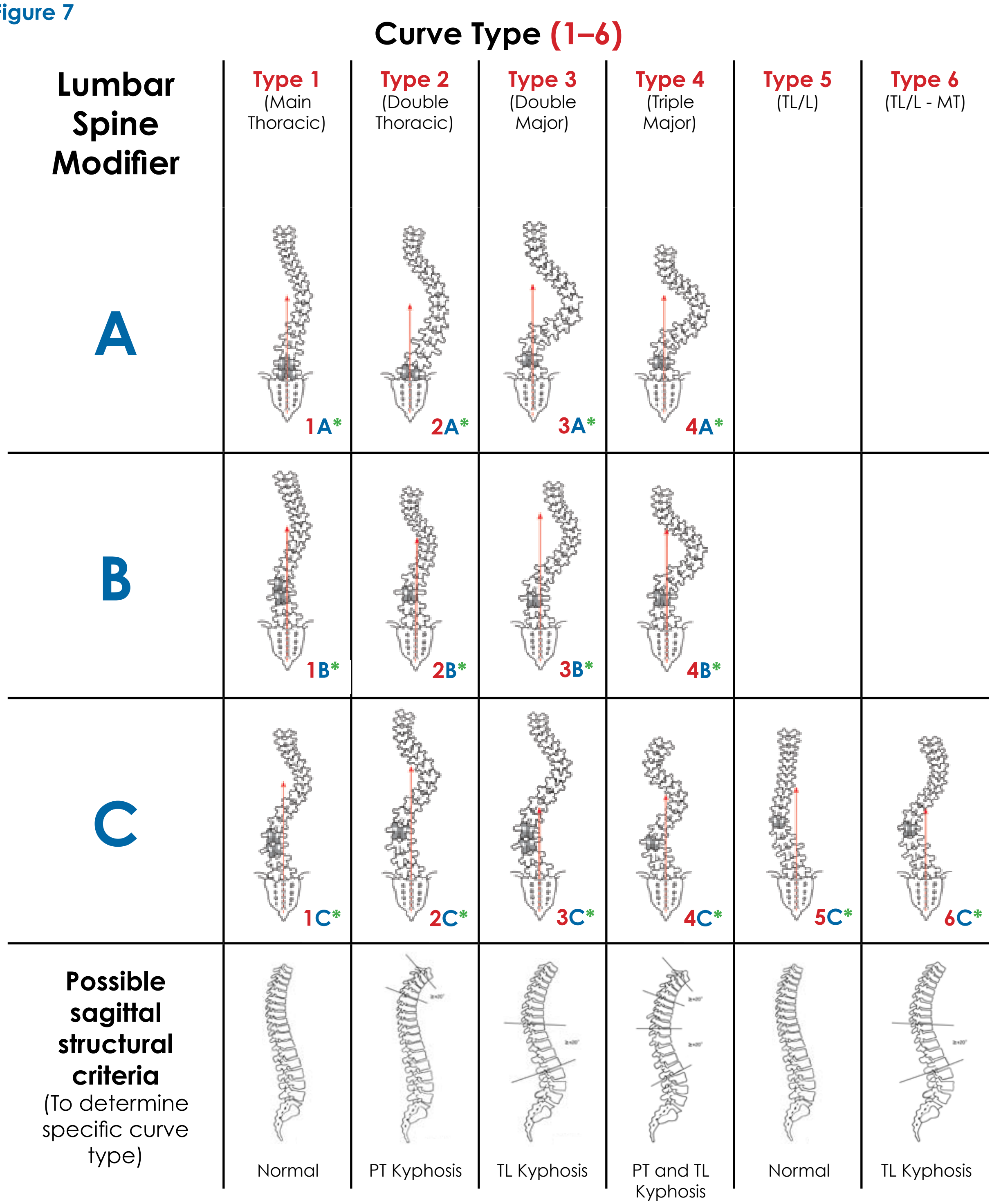
*T5-12 sagittal alignment modifier: –, N, or +

–: <10°
N: 10-40°
+: >40°

The Lenke Classification:
Technique for Analysis and Classification of AIS

Using these three simple steps and carefully adhering to the radiographic parameters for structural and nonstructural curves, 42 discrete curve classifications can be identified (Figure 7- excluding sagittal thoracic modifiers). Because the system leaves little room for "artistic license" in evaluating and classifying the curve, it has shown excellent intra- and interobserver reliability. Our ability to reliably classify AIS into specific subgroups (compare apples to apples) will be mandatory if we are going to evaluate the outcome of our interventions.

Figure 7



*T5-12 sagittal alignment modifier: –, N, or +

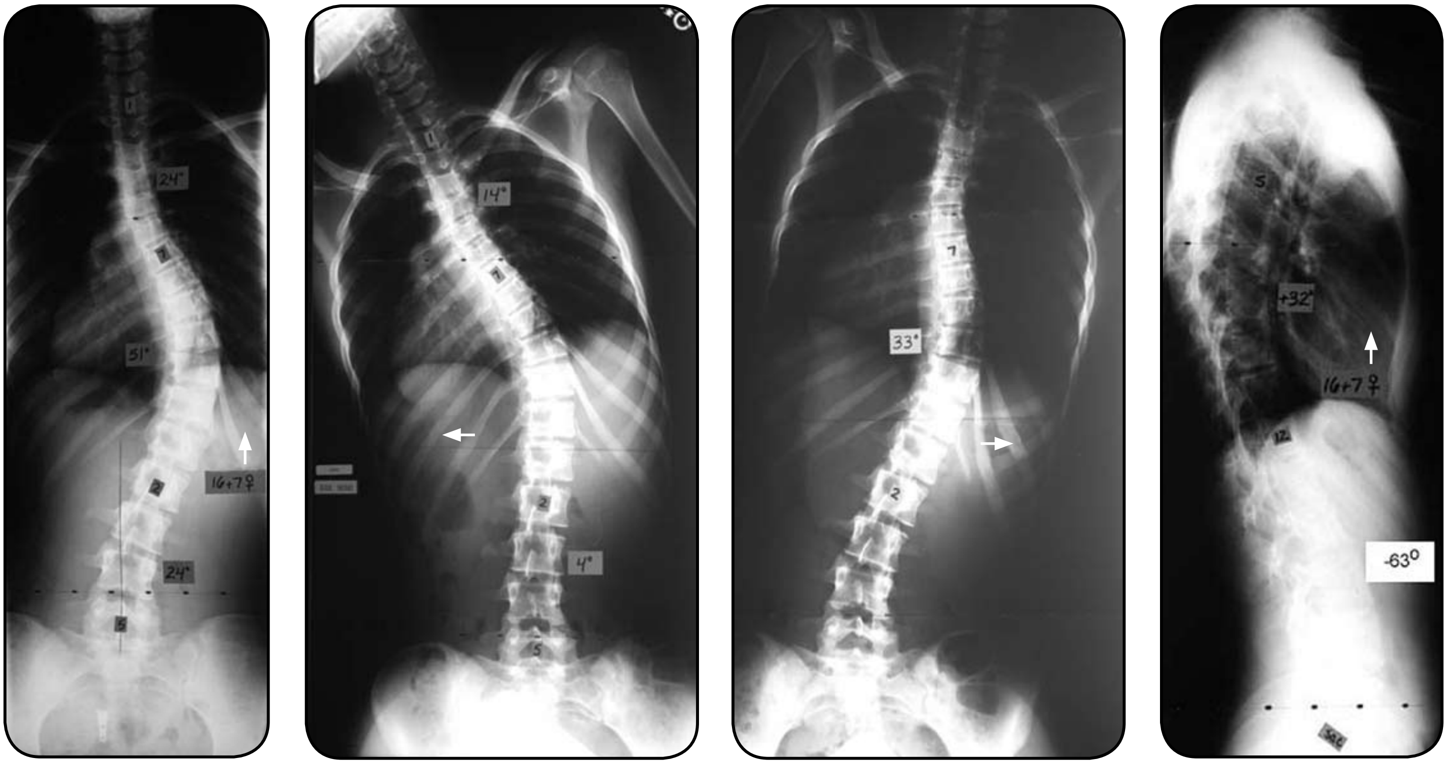
–: <10°

N: 10-40°

+: >40°

The Lenke Classification:
Technique for Analysis and Classification of AIS

Classification Examples:



Curve Type 1: Thoracic curve major, other curves non-structural (bend out to <25°)

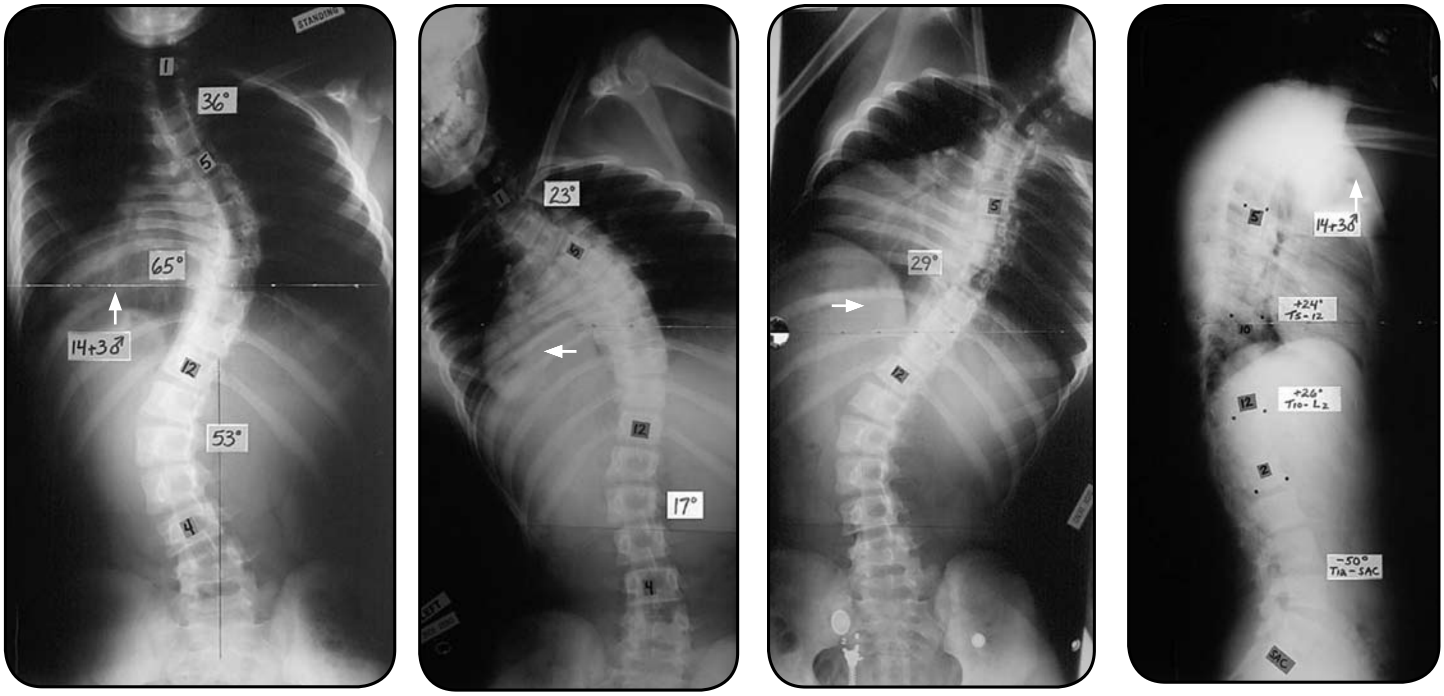
Lumbar Modifier A: CSVL between pedicles at apex (L5)

Sagittal Modifier N: T5-T12 in the 10-40° range

Therefore, classification is **Type 1AN**

The Lenke Classification:
Technique for Analysis and Classification of AIS

Classification Examples:



Curve Type 3: Thoracic curve major, lumbar curve structural – bends out to <25° **BUT** TL kyphosis is >20°!

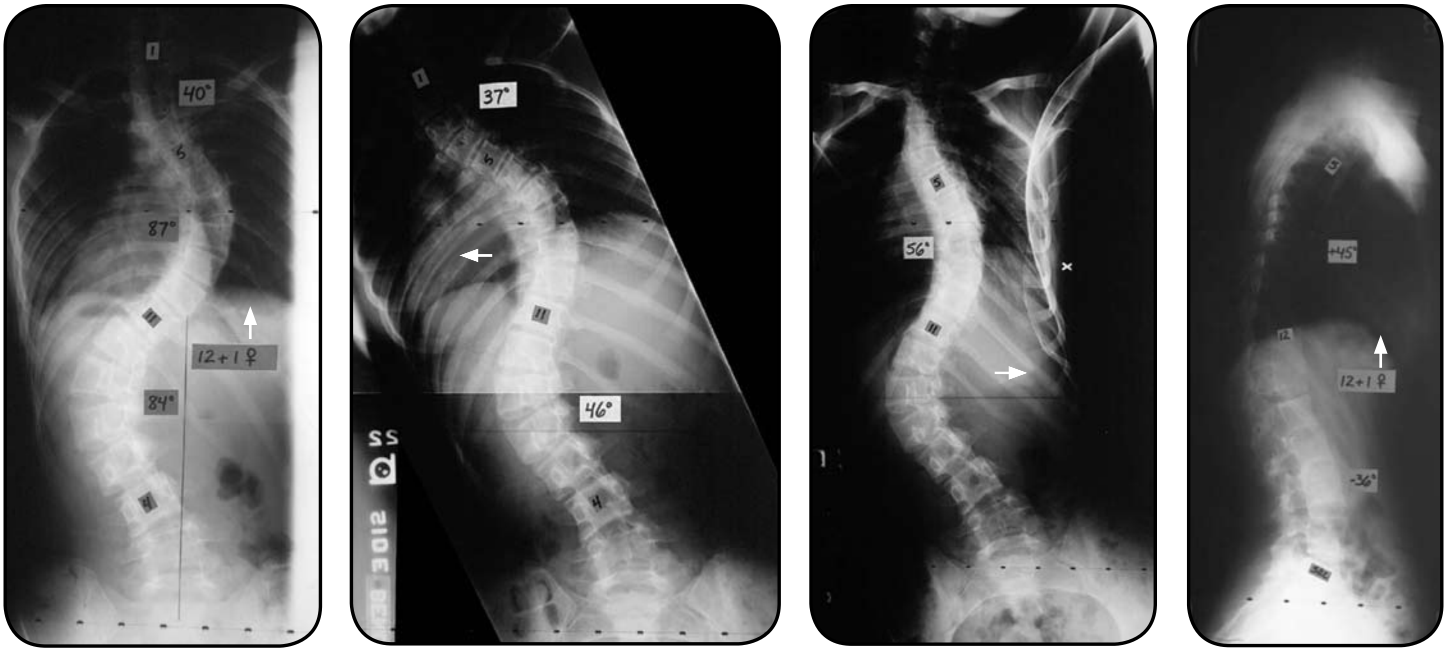
Lumbar Modifier C: CSVL does not touch apex of lumbar curve (apex - L2 vertebral body)

Sagittal Modifier N: T5-T12 between 10-40°

Therefore, classification is **Type 3CN**

The Lenke Classification:
Technique for Analysis and Classification of AIS

Classification Examples:



Curve Type 4: Thoracic curve major, other curves structural, i.e., do not bend out to less than 25°

Lumbar Modifier C: CSVL does not touch apex of lumbar curve (apex - L1-L2 disc)

Sagittal Modifier +: T5-T12 >40°

Therefore, classification is **Type 4C+**

The Lenke Classification:
Technique for Analysis and Classification of AIS

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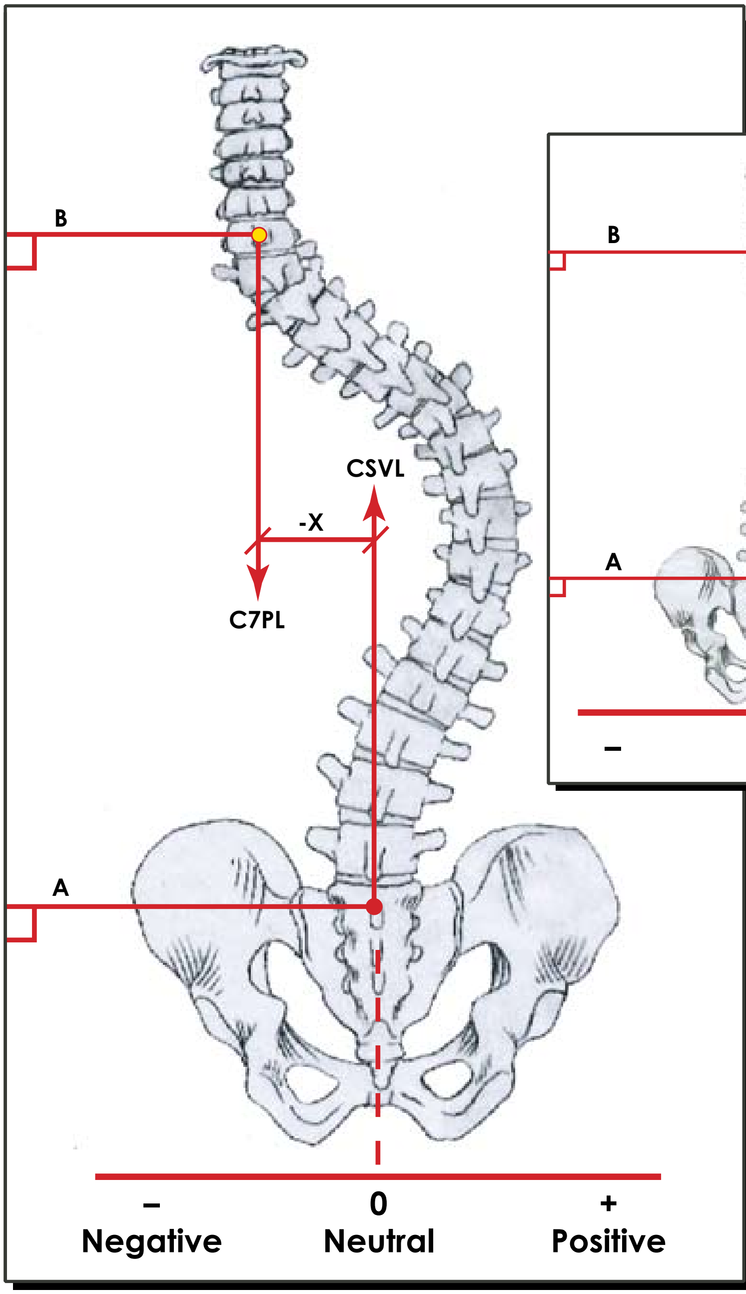
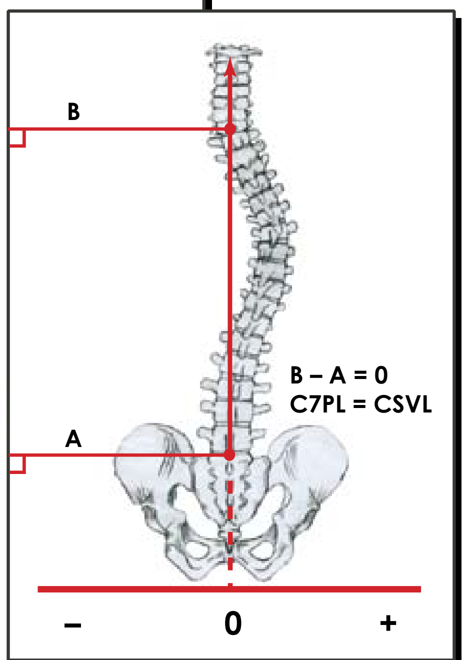
4. Lenke LG, Betz RR, Clements D, et al. Curve prevalence of a new classification of operative adolescent idiopathic scoliosis: Does classification correlate with treatment? *Spine*. 2002;27(6):604-11.

Adolescent Idiopathic Scoliosis





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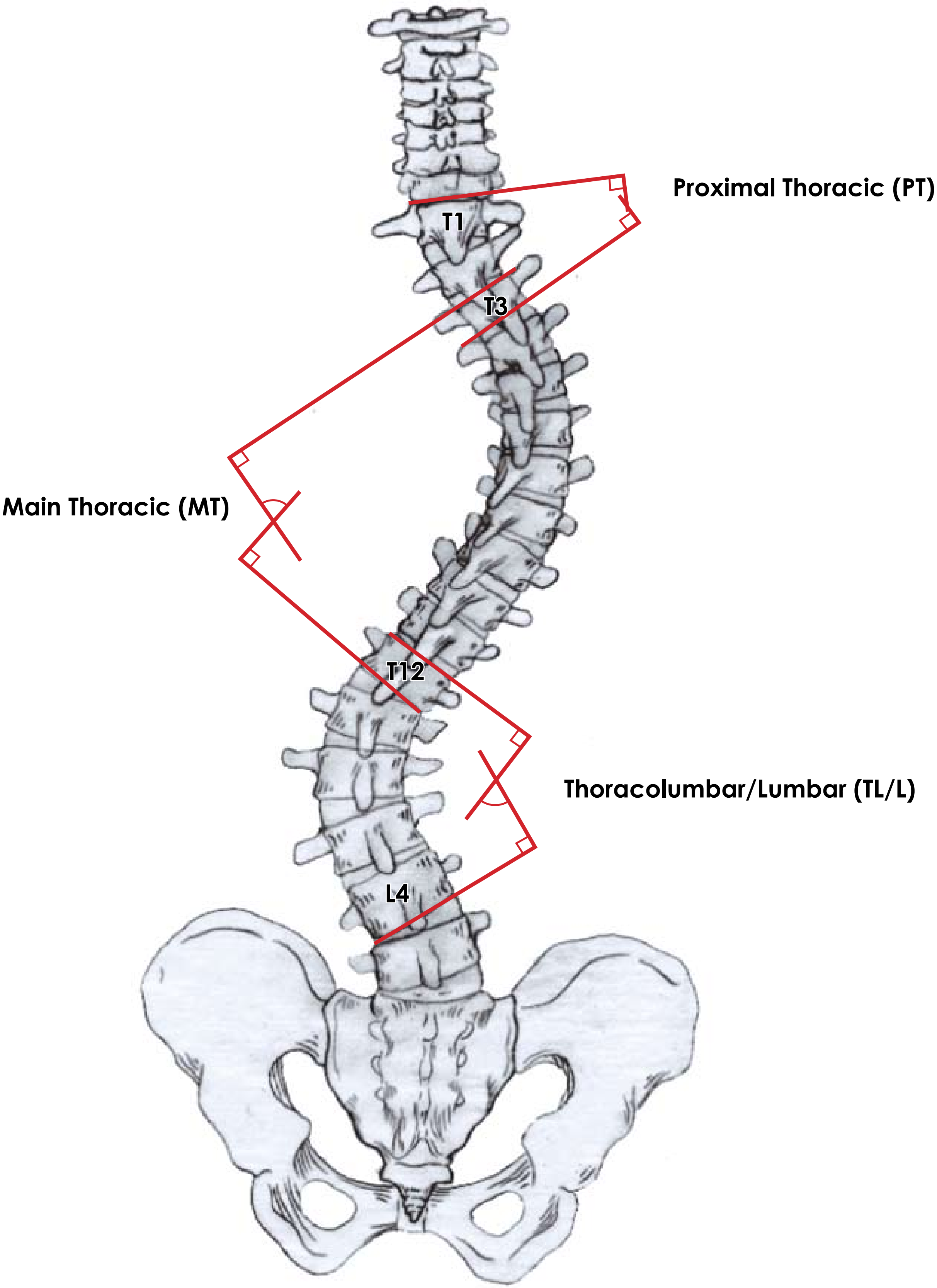
Adolescent Idiopathic Scoliosis

Coronal Cobb Measurements:
Proximal Thoracic (PT), Main Thoracic (MT), and Thoracolumbar/Lumbar (TL/L) Curves



Determination of Centroids

Several techniques for identification of the centroid of a vertebral body or disc have been described. The "x" technique has commonly been employed (Figure 1).

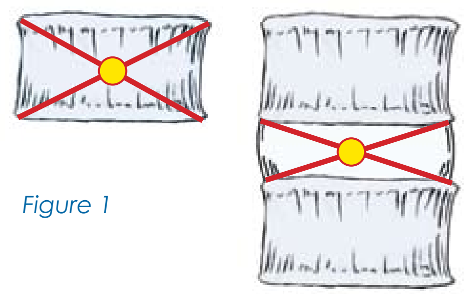


Figure 1

For a relatively rectangular structure, this works well. However, as the vertebrae or discs become increasingly trapezoidal, this technique can be inaccurate (Figure 2).

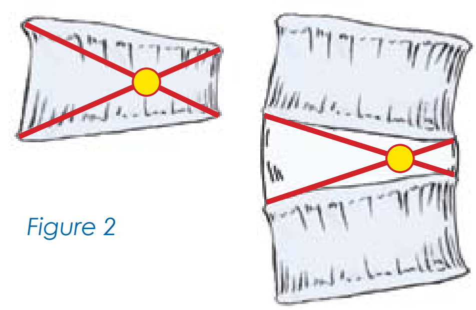


Figure 2

Therefore, the DRPro software utilizes a new technique that allows the centroids of vertebrae and discs to be identified, as a matter of course, during the radiographic measurement process. For the vertebrae, the software will utilize four points selected (Figure 3) to identify the vertebral body in space.

Figure 3

The software will automatically determine the centroid from the intersection of the midpoints of the lines derived from these selected points (Figure 4).

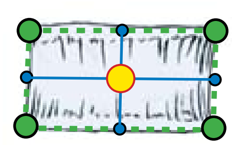


Figure 4

This technique works equally well for trapezoidal and rectangular shapes, whether it is a vertebra or a disc (Figure 5). Throughout this text, centroids are represented as a distinctive yellow dot.

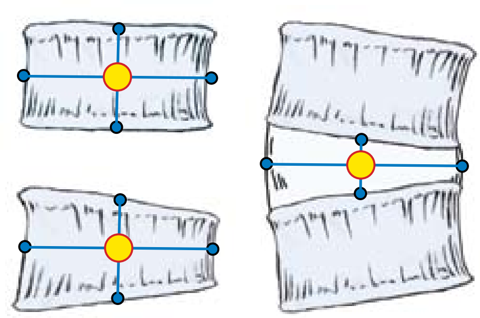


Figure 5

Identification of Apical Vertebra (or Disc) and Technique for Measuring Apical Vertebral Translation in the Proximal Thoracic, Main Thoracic, and Thoracolumbar/Lumbar Curves

The "C7 plumbline" (C7PL) is dropped from the middle of the C7 vertebral body and is drawn parallel to the vertical edge of the radiograph. The center sacral vertical line (CSVL) is drawn from the middle of S1 upwards and parallels the vertical edge of the radiograph. Identify the apex for each curve (see Chapter 3). When the C7PL and the CSVL coincide, AVT is measured as shown below (left).

Figure 1

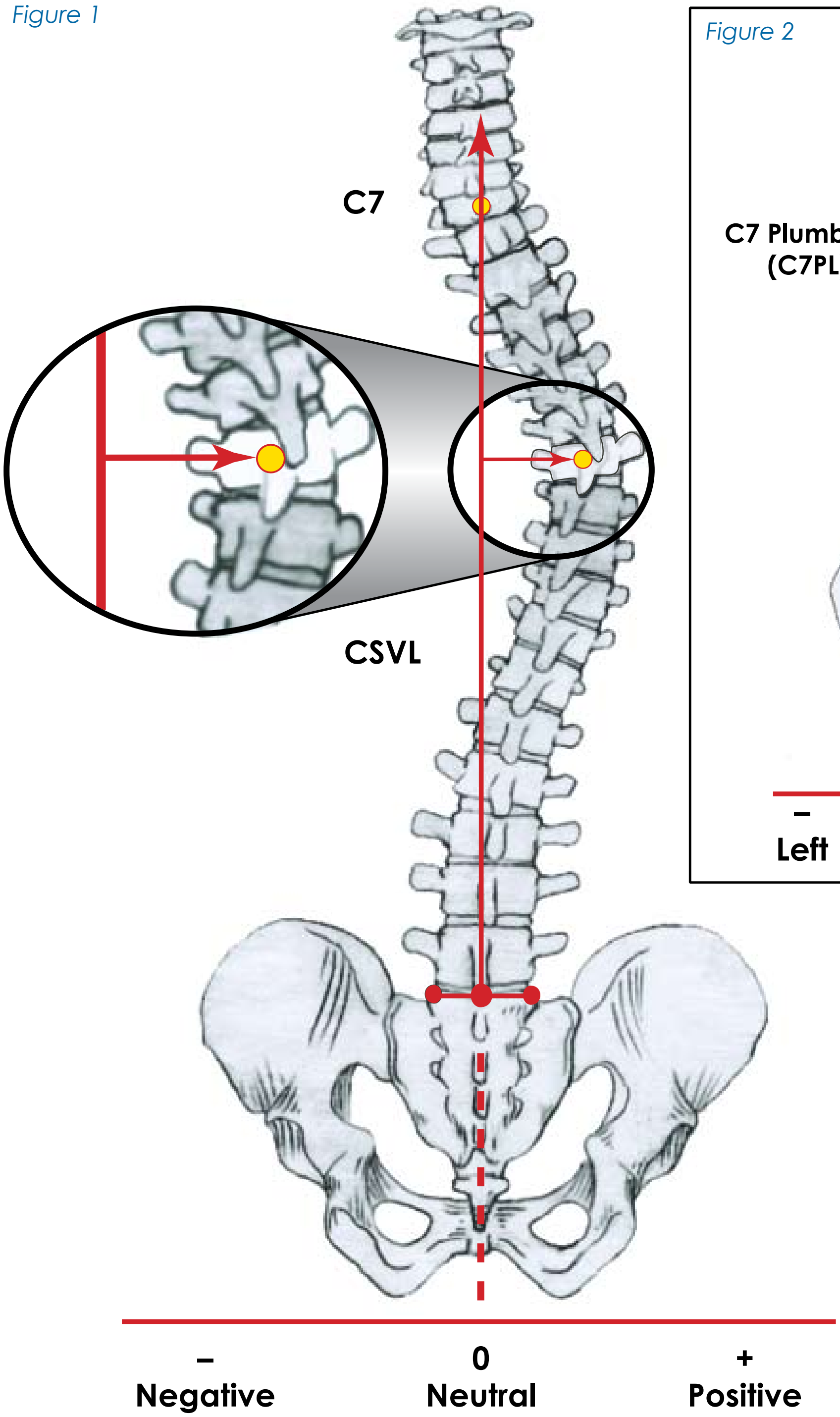
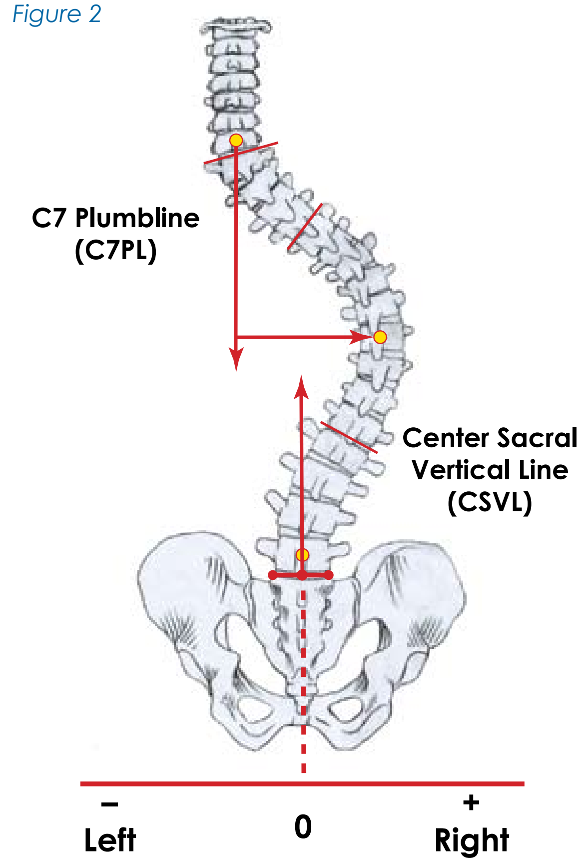


Figure 2



In the case of coronal decompensation where the C7PL and the CSVL **do not** coincide, the AVT for thoracic curves (proximal and main) are measured from the C7PL, as shown above (right). For thoracolumbar and lumbar curves, it is measured from the CSVL (see Figures 3 and 4 on page 52).

Identification of Apical Vertebra (or Disc) and Technique for Measuring Apical Translation in Proximal Thoracic, Main Thoracic, and Thoracolumbar/Lumbar Curves

Figure 3

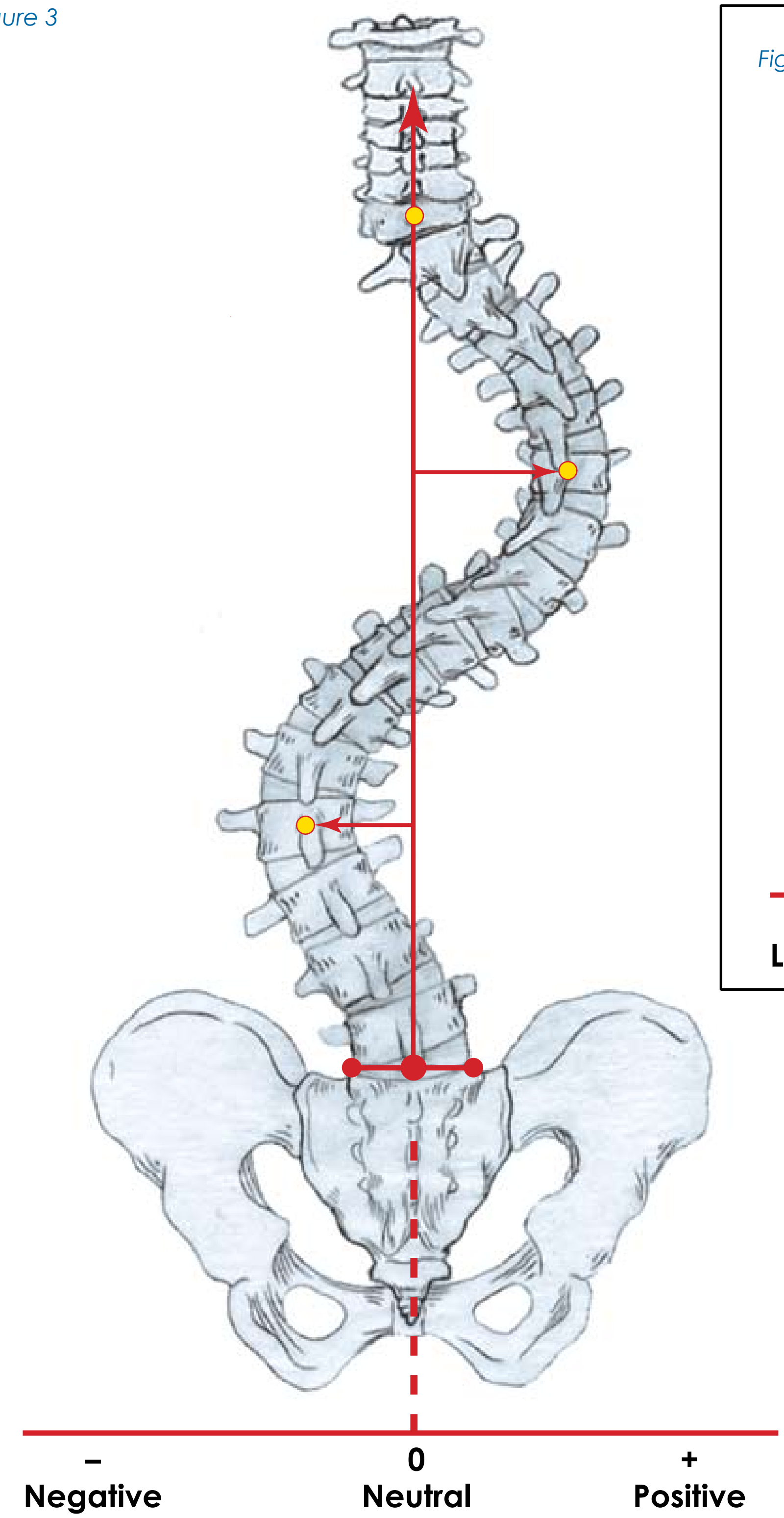
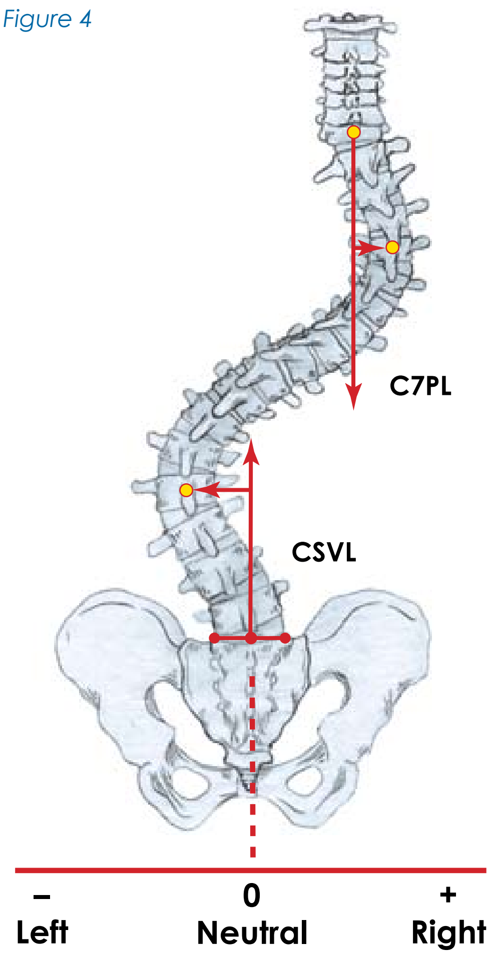
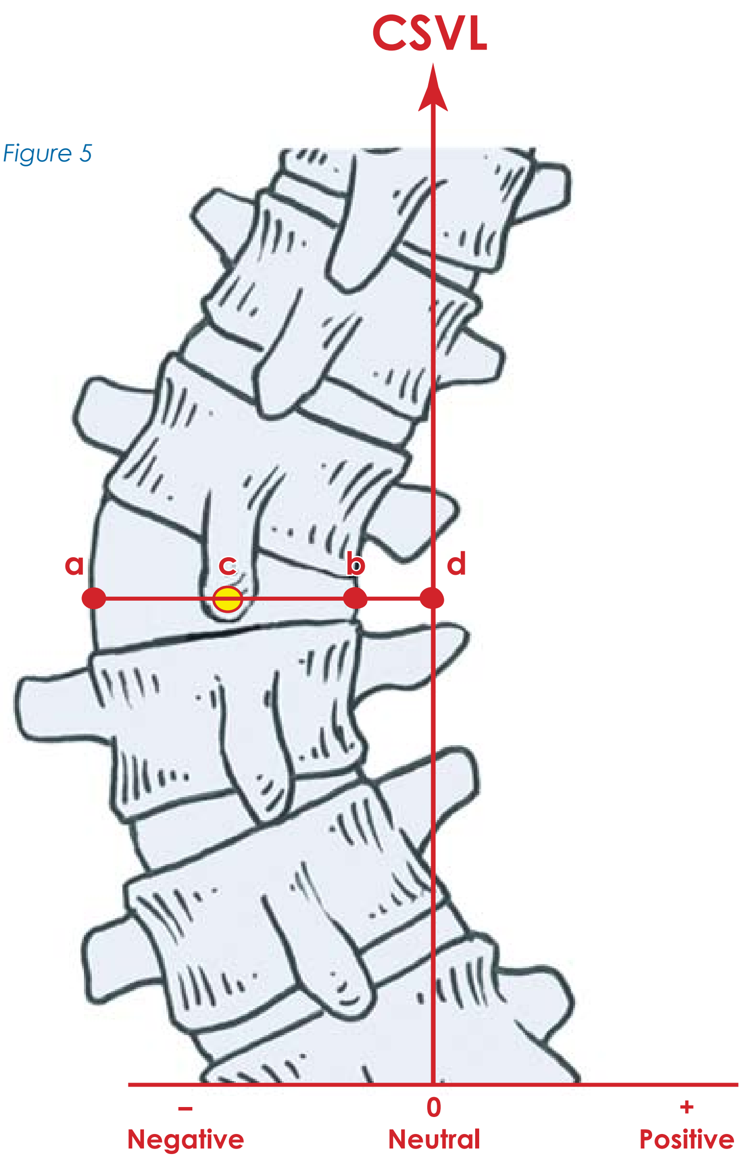


Figure 4



Identification of Apical Vertebra (or Disc) and Technique for Measuring Apical Translation in Proximal Thoracic, Main Thoracic, and Thoracolumbar/Lumbar Curves

Figure 5

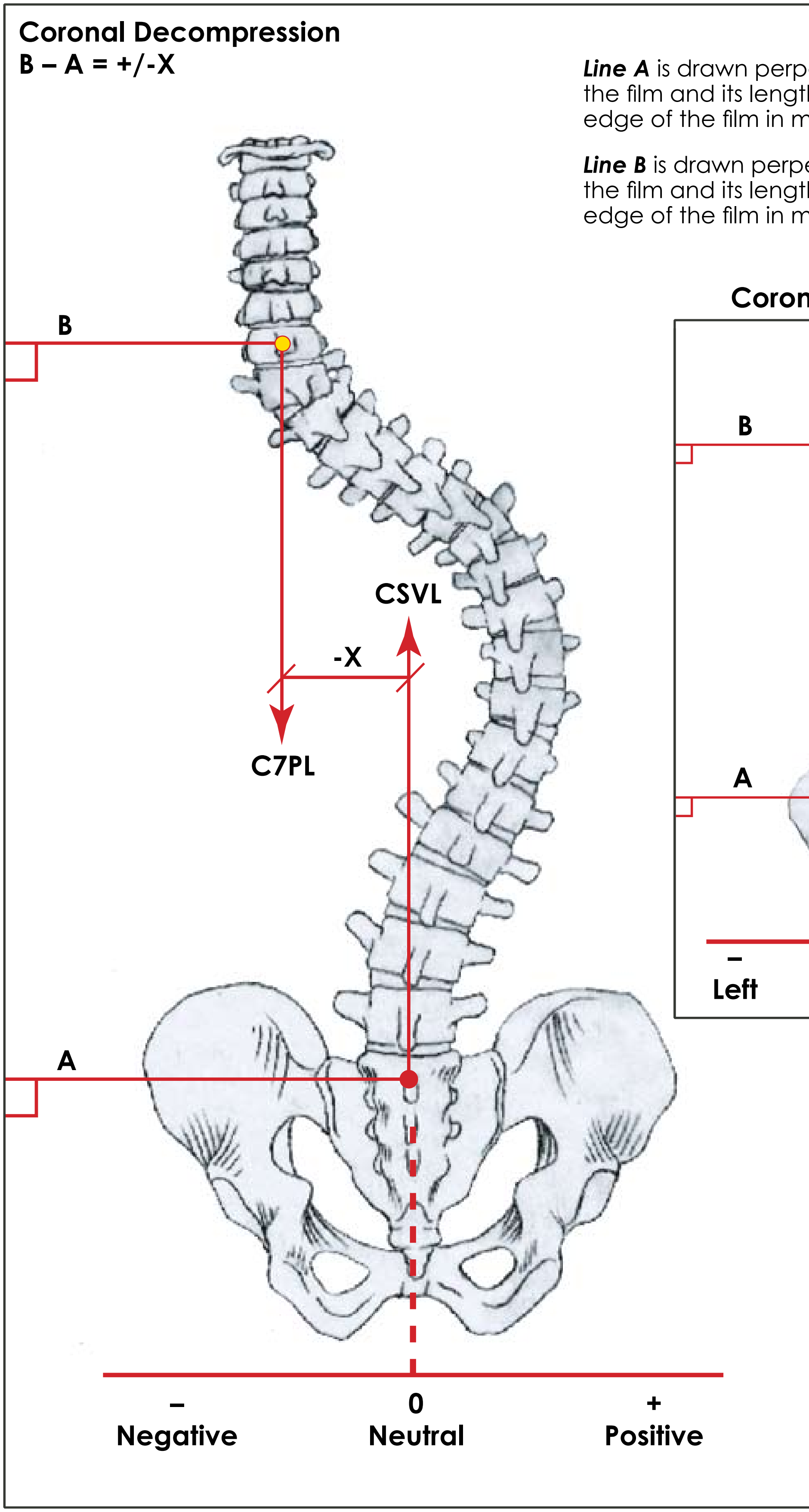


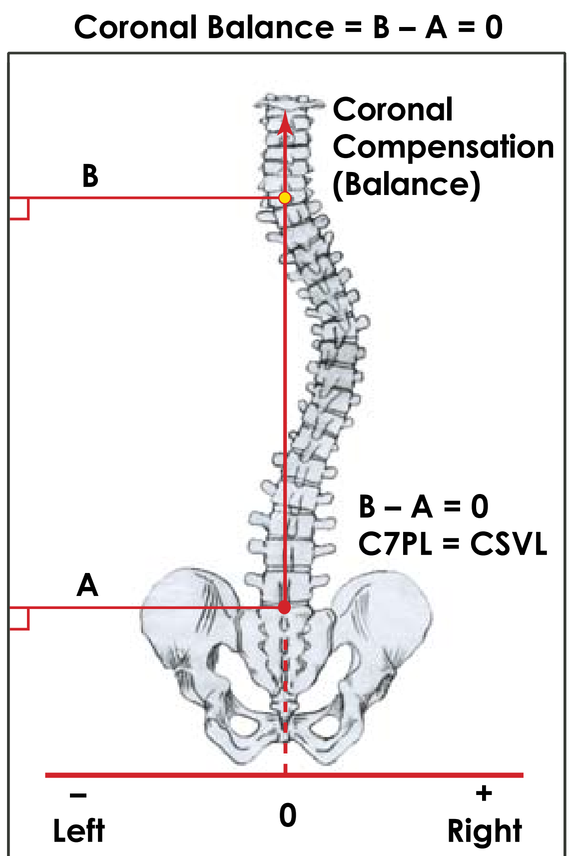
When a disc is identified as the apex of the curve, the center of the disc is identified by drawing a horizontal line through the disc at its cephalad-caudal midpoint ($\overline{ab}$), and the center of that line (c) is identified as the center of the disc (see Figure 5 above and Figure 5, page 50). Apical translation of the disc is measured from the disc centroid to the CSVL ($\overline{cd}$).

Coronal Balance (Alignment of C7PL in Relation to the CSVL)

Line A is drawn perpendicular to the vertical edge of the film and its length is measured from the lefthand edge of the film in millimeters to the center of S1.

Line B is drawn perpendicular to the vertical edge of the film and its length is measured from the lefthand edge of the film in millimeters to the center of C7.

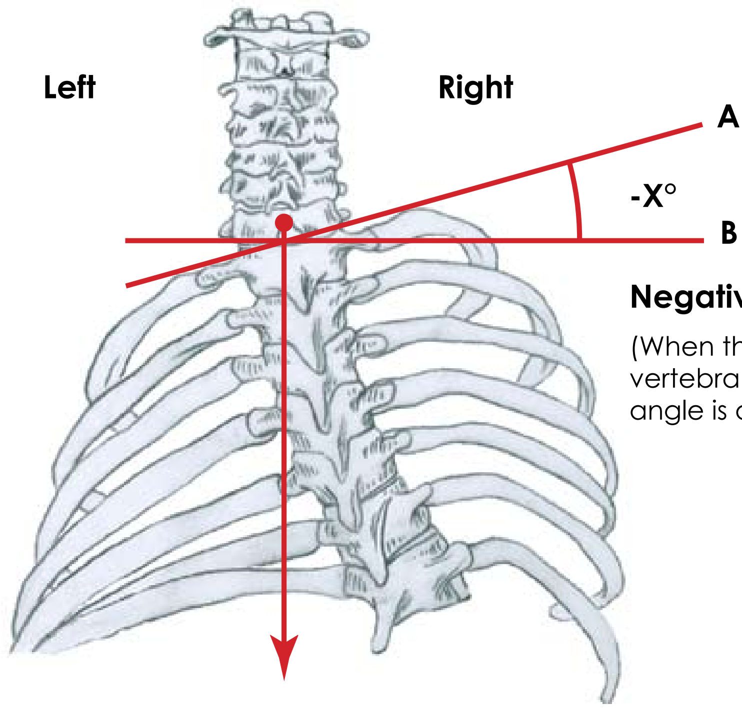




T1 Tilt Angle

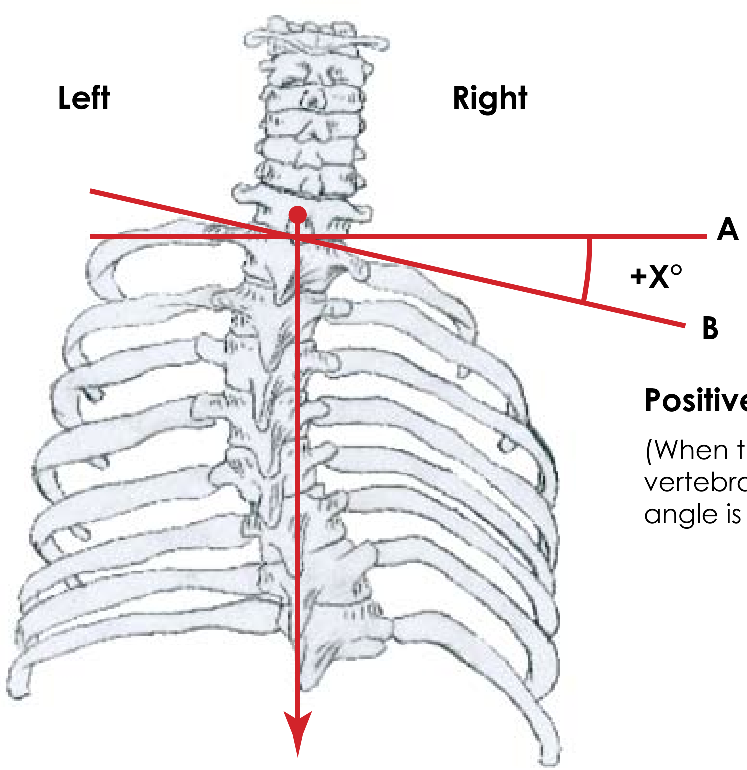
Line A is drawn along the cephalad end plate of T1 or along the zenith of both first ribs if the T1 end plate is not well visualized.

Line B is drawn perpendicular to the vertical edge of the radiograph and intersects the C7PL and line A in the midline.



Negative T1 Tilt

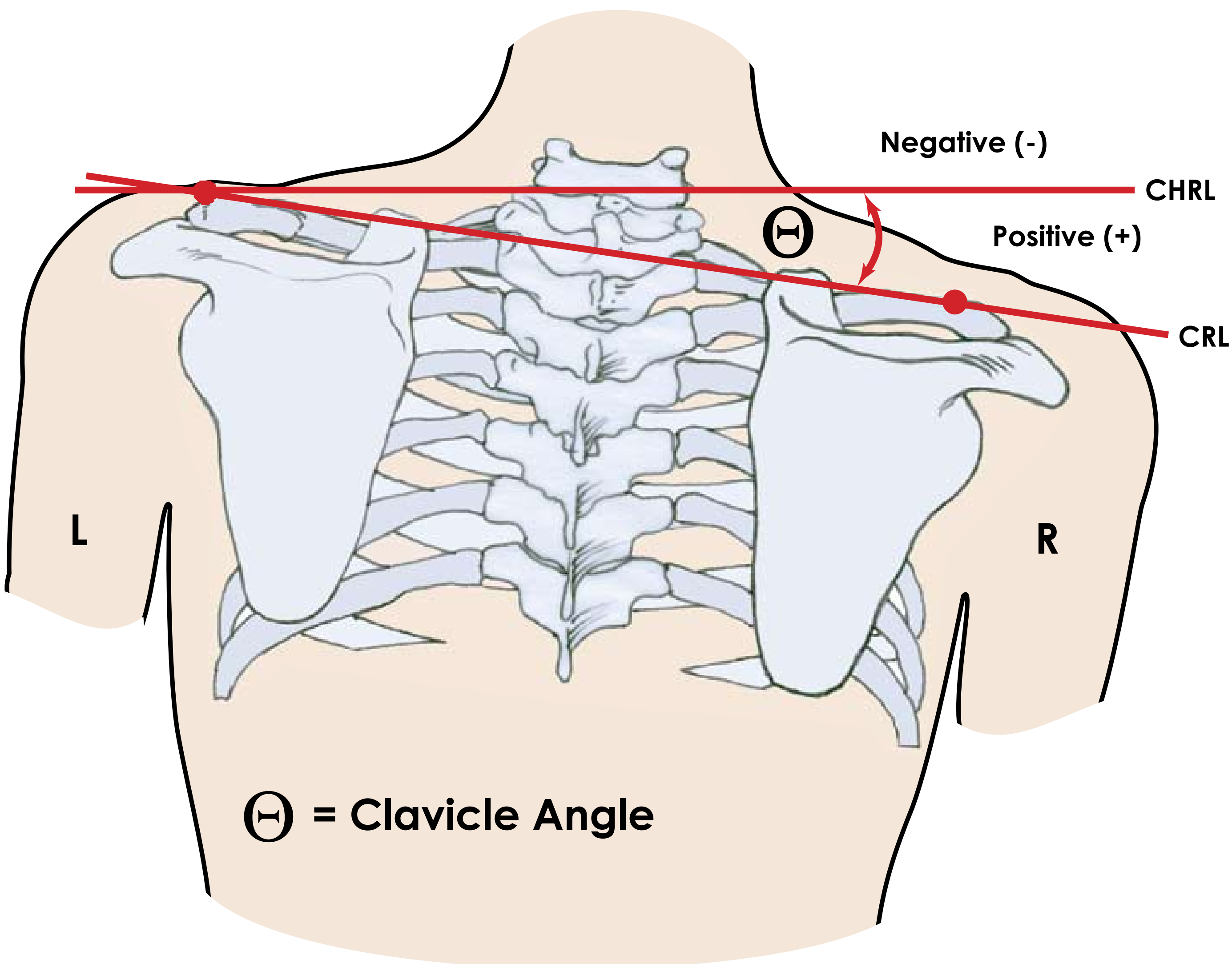
(When the right edge of the vertebral body is up, the tilt angle is defined as negative)



Positive T1 Tilt

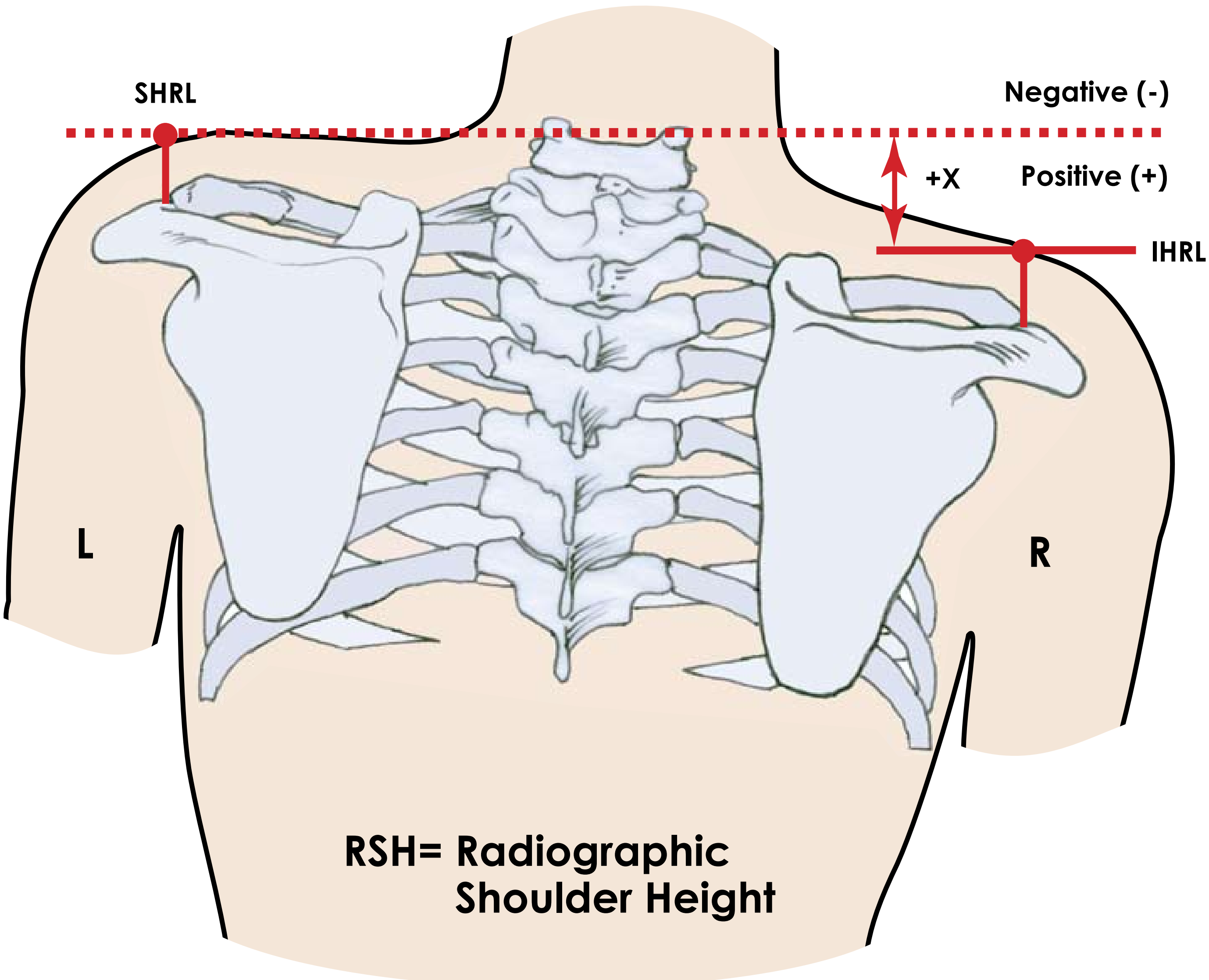
(When the left edge of the vertebral body is up, the tilt angle is defined as positive)

Clavice Angle



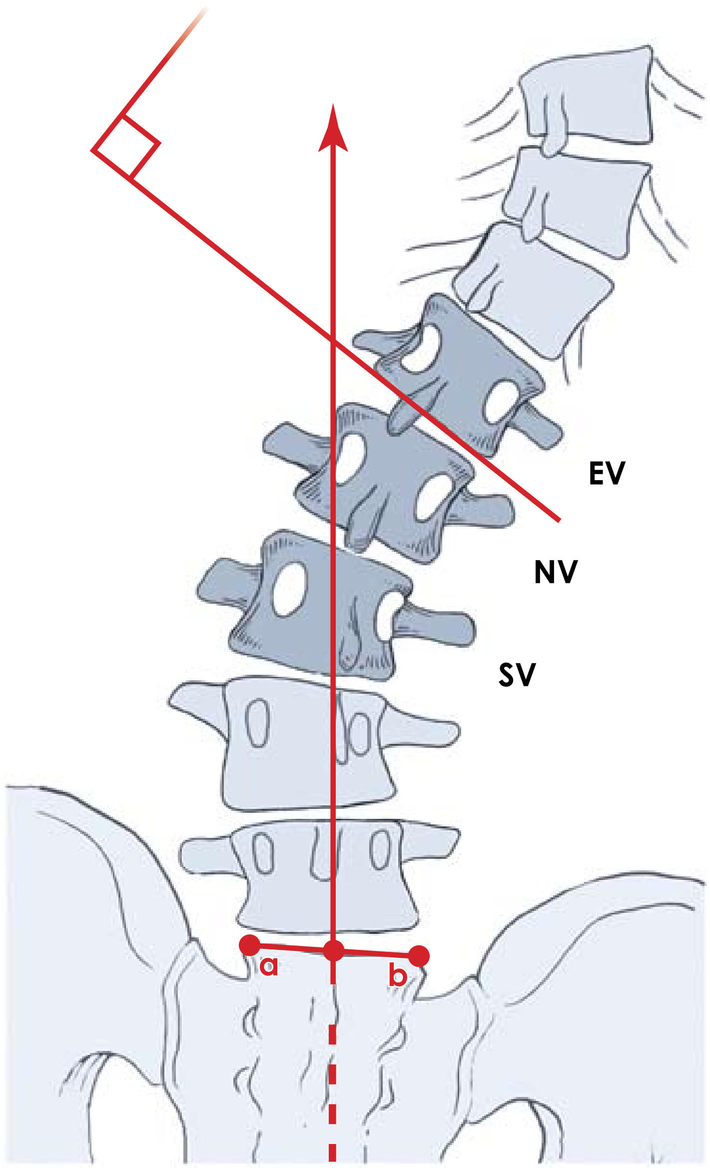
The clavicle angle is the angle that is subtended between a horizontal reference line – clavicle horizontal reference line (CHRL), which is drawn perpendicular to the lateral edge of the radiograph and touches the most cephalad portion of the elevated clavicle and a line which touches the most cephalad aspect of both the right and left clavicles (clavicle reference line [CRL]). By convention, angles subtended with the left shoulder up are positive and angles subtended with the right shoulder up are negative (consistent with directionality of the T1 tilt angle).

Radiographic Shoulder Height



Radiographic shoulder height is defined as the linear distance measured in millimeters between the superior horizontal reference line (SHRL), which passes through the intersection of the soft tissue shadow of the shoulder and a line drawn vertically up from the acromial clavicular joint of the cephalad shoulder, and the inferior horizontal reference line (IHRL) constructed in a similar fashion over the caudal acromial clavicular joint. The distance "X" is the radiographic shoulder height (RSH). The linear distance "X" is positive if the left shoulder is up and negative if the right shoulder is up (directionality consistent with T1 tilt angle and clavical angle). By convention, left up is always positive and right up is always negative.

End, Neutral, and Stable Vertebrae



The ***end*** vertebrae (EV) are the most tilted vertebrae at the cephalad and caudal ends of a curve. The ***neutral*** vertebra (NV) is the most cephalad vertebra below the apex of the major curve whose pedicles are symmetrically located within the radiographic silhouette of the vertebral body. To identify "the stable vertebra," first, a vertical reference line (CSVL) is erected from the midportion of S1. The most cephalad vertebra immediately below the end vertebra of the major curve that is most closely bisected by the CSVL is the ***stable*** vertebra (SV). Typically, the end, neutral, and stable vertebrae are different vertebral segments. However, the end, neutral, and/or stable vertebrae may occasionally overlap in the same vertebra.

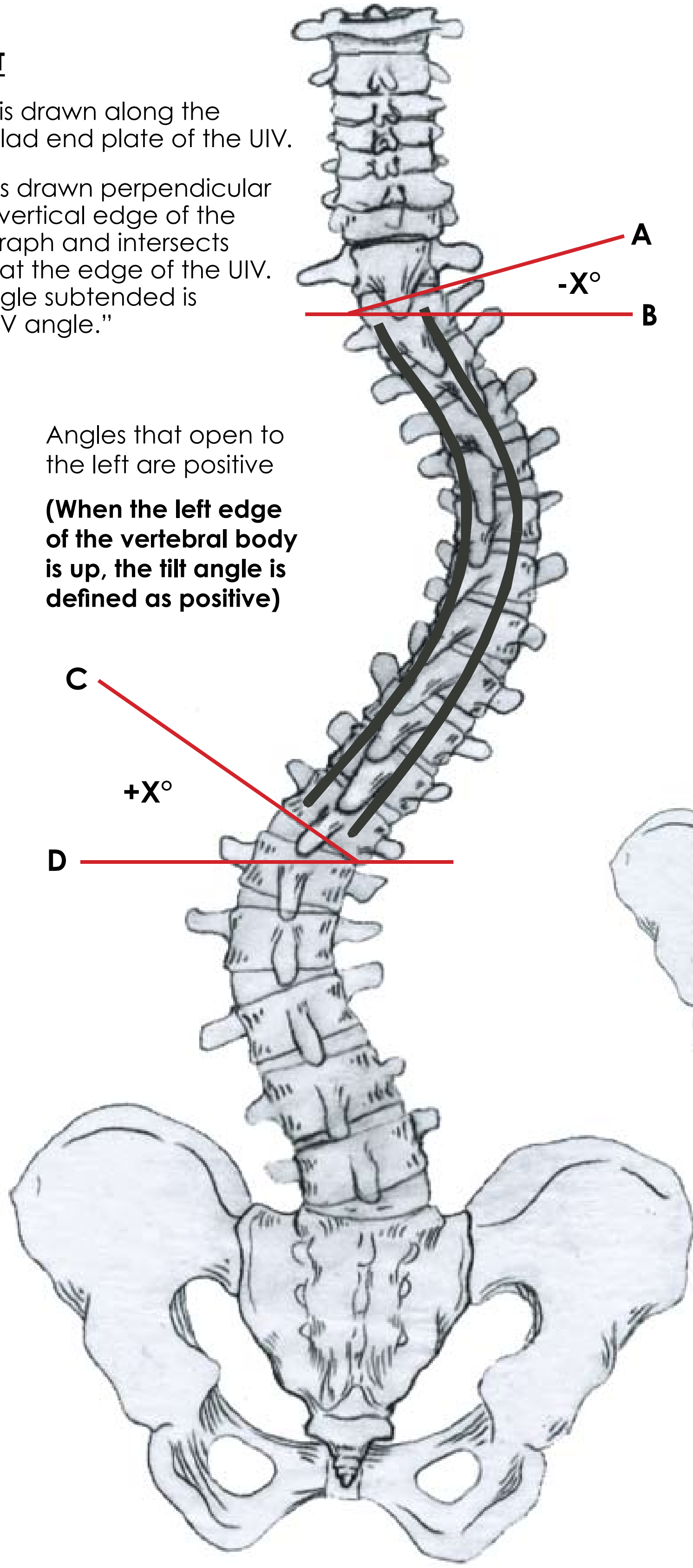
The CSVL depicts the coronal position of the spine in relation to the pelvis. The CSVL is a vertical line drawn parallel to the radiograph edge and may not be perpendicular to the sacral end plate (line $\overline{ab}$). This non-perpendicular alignment may occur when sacral or pelvic obliquity exists.

LIV and UIV Tilt Angles
Lowest Instrumented Vertebra (LIV) Tilt to the Horizontal and Upper Instrumented Vertebra (UIV) Tilt to the Horizontal

UIV TILT

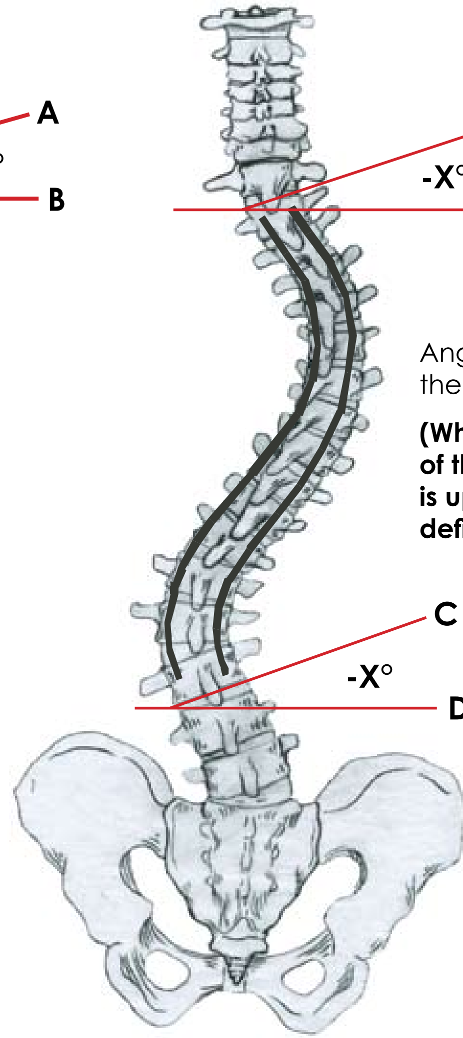
Line A is drawn along the cephalad end plate of the UIV.

Line B is drawn perpendicular to the vertical edge of the radiograph and intersects ***Line A*** at the edge of the UIV. The angle subtended is the "UIV angle."



Angles that open to the left are positive

(When the left edge of the vertebral body is up, the tilt angle is defined as positive)



Angles that open to the right are negative

(When the right edge of the vertebral body is up, the tilt angle is defined as negative)

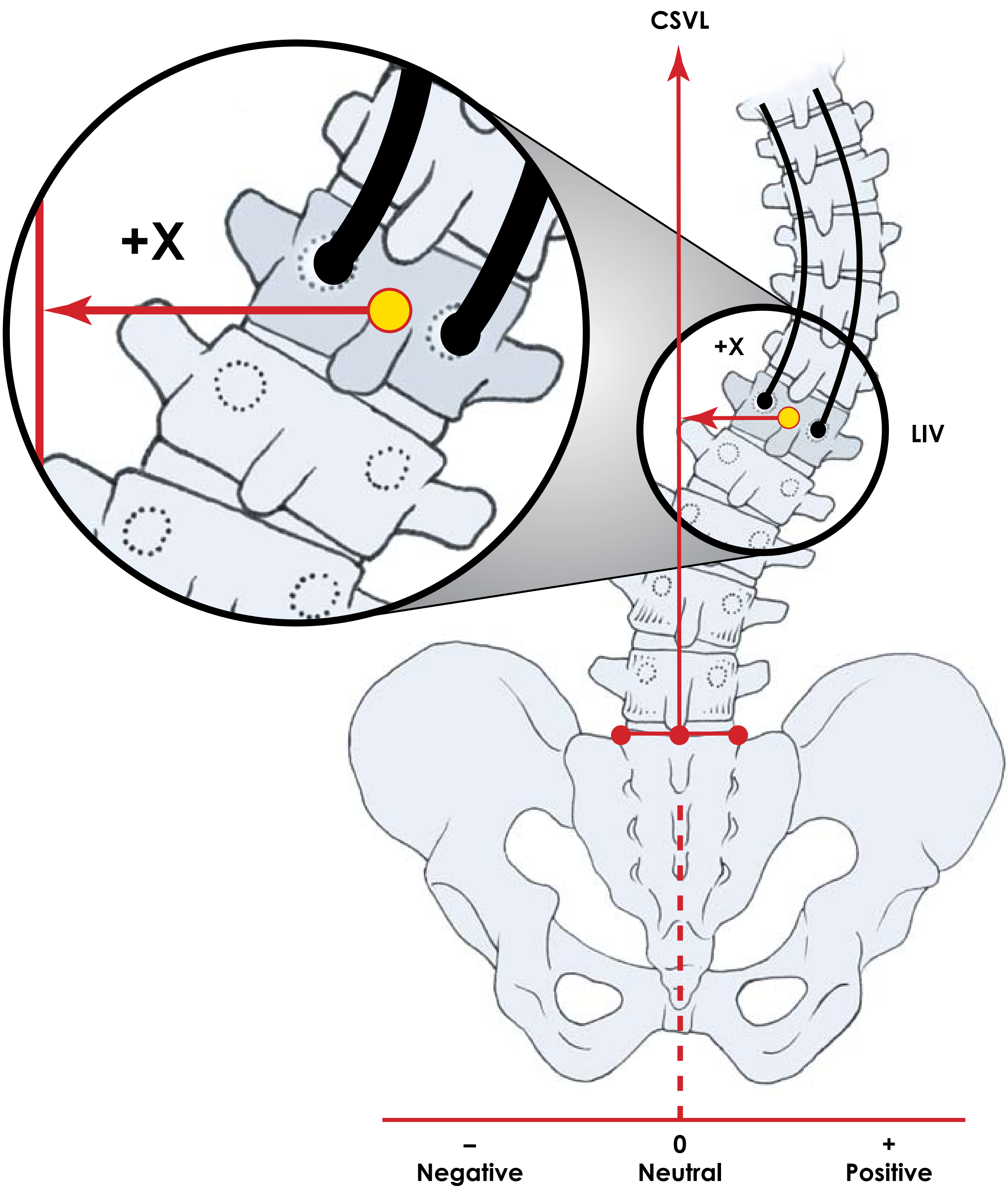
LIV TILT

Line C is drawn along the caudal end plate of the LIV.

Line D is drawn perpendicular to the vertical edge of the radiograph and intersects ***Line C*** at the edge of the LIV. The angle subtended is the "LIV angle."

Coronal Position of LIV

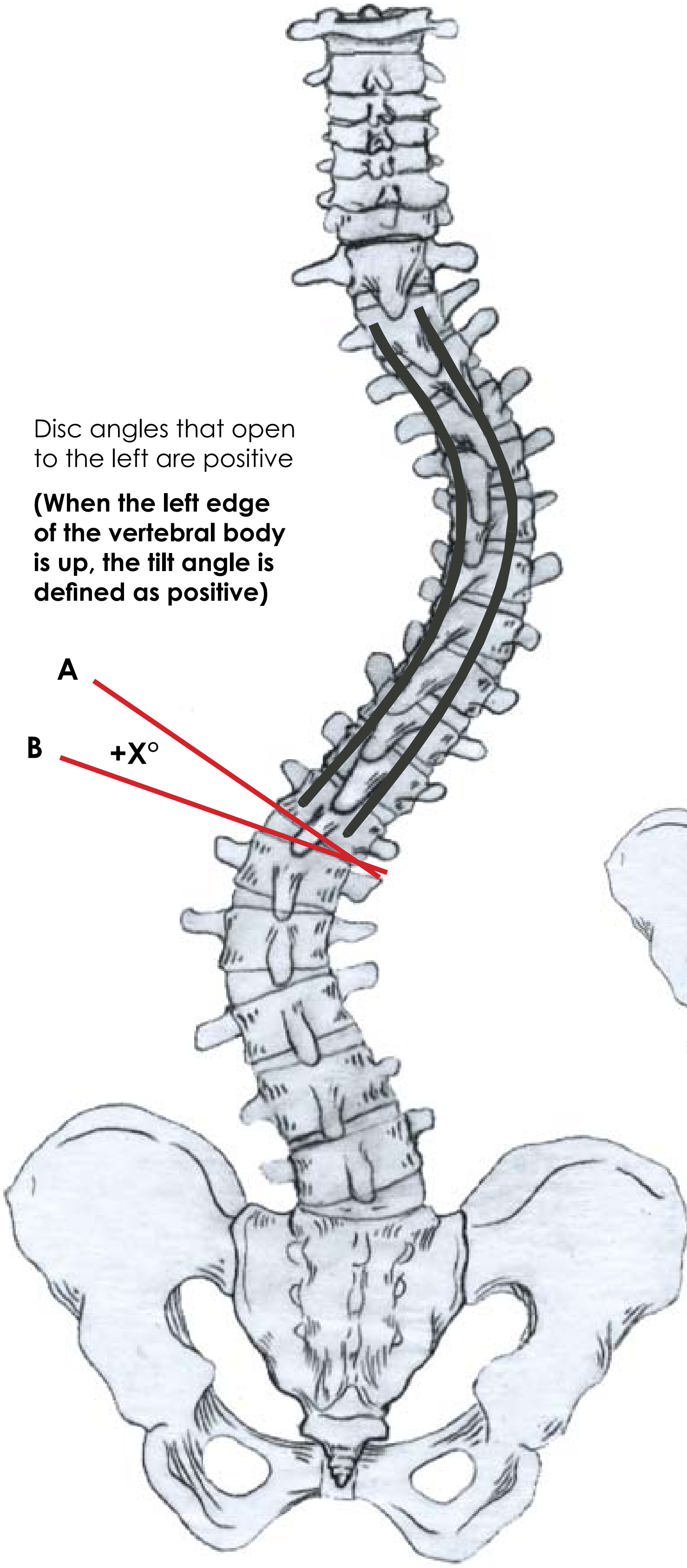
The position of the lowest instrumented vertebra (LIV) is the measured horizontal distance in millimeters from the centroid of the vertebral body to the CSVL. Measurements to the right of the CSVL are positive, and measurements to the left are negative.



Coronal Angulation of Disc Below LIV

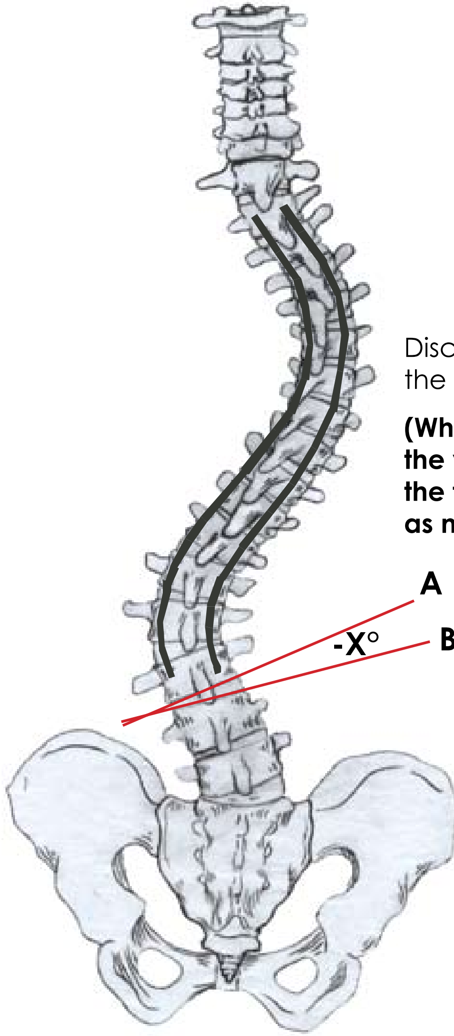
Disc angles that open to the left are positive

(When the left edge of the vertebral body is up, the tilt angle is defined as positive)



Disc angles that open to the right are negative

(When the right edge of the vertebral body is up, the tilt angle is defined as negative)



Line A is drawn along the caudal end plate of the LIV.

Line B is drawn along the cephalad end plate of the vertebra below the LIV. The angle subtended is the "coronal angulation of the disc below the LIV."

Adolescent Idiopathic Scoliosis

Risser Grade

Risser 0 – No iliac apophysis visible

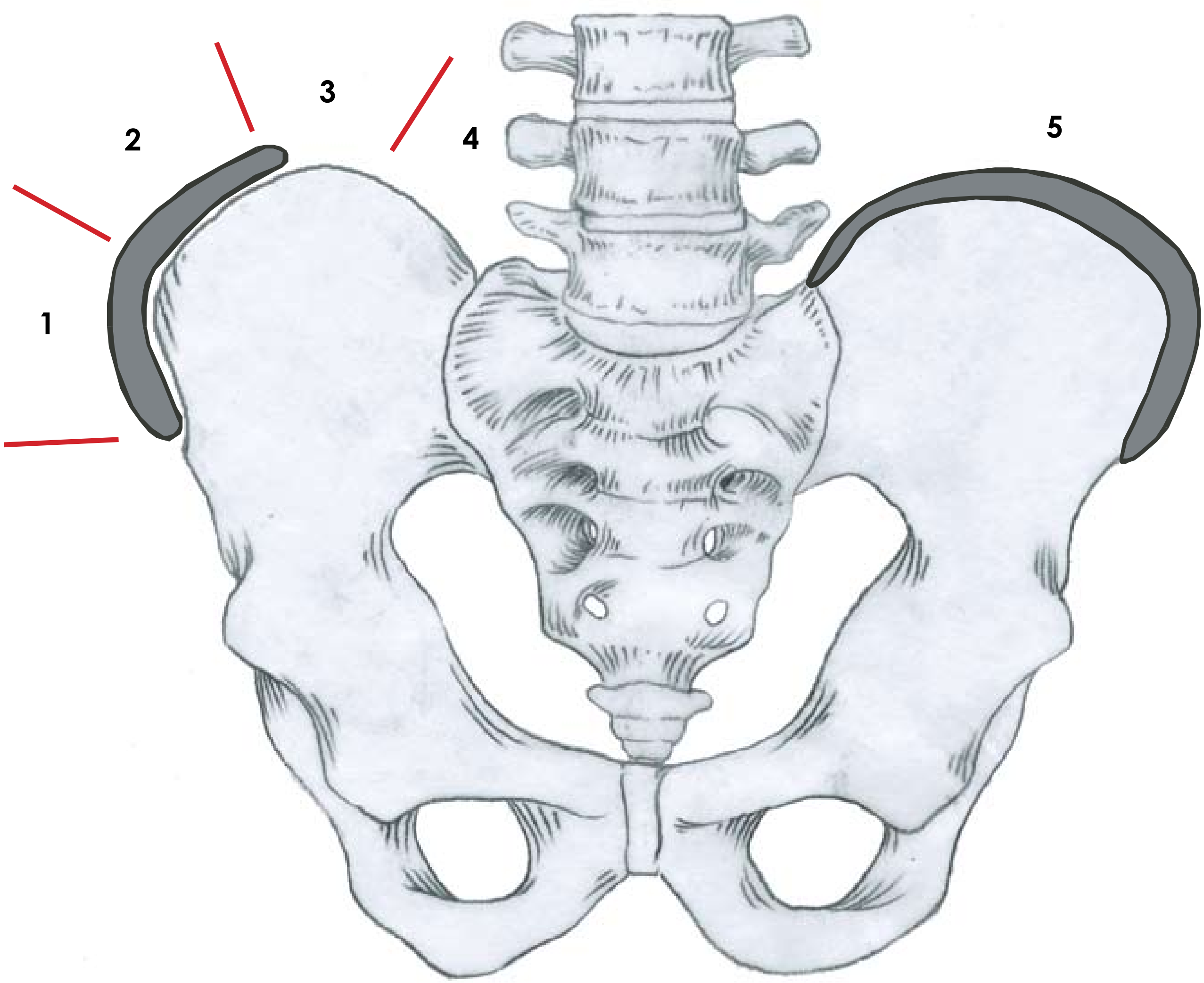
Risser 1 – Initial appearance of ossification of the iliac apophysis

Risser 2 – Migration halfway across the top of the iliac wing

Risser 3 – Three-fourths of the distance

Risser 4 – Ossification crossing the iliac wing, but not fused to the ilium

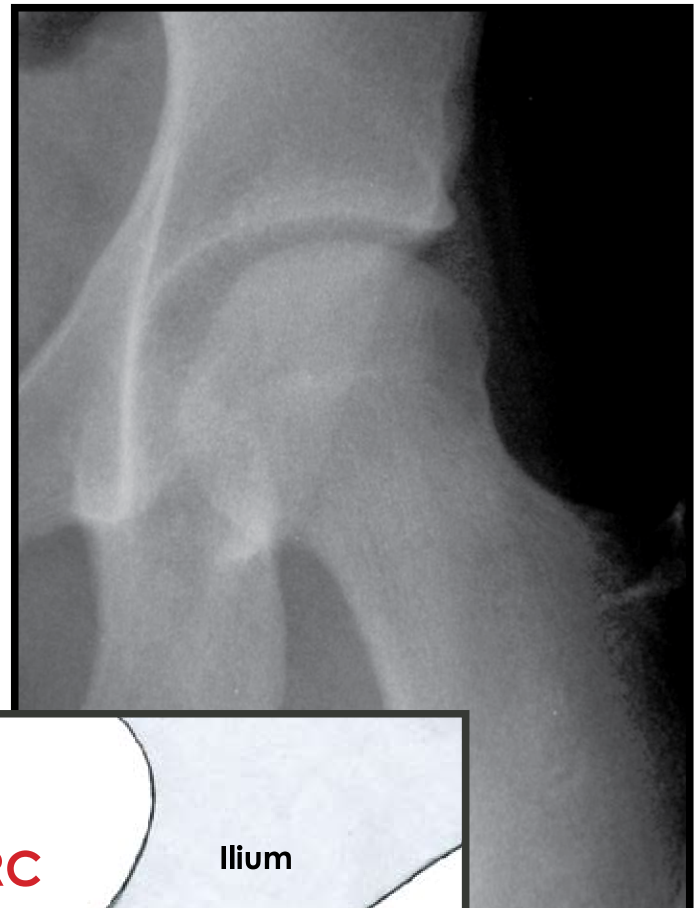
Risser 5 – Complete ossification of the iliac apophysis with fusion to the ilium

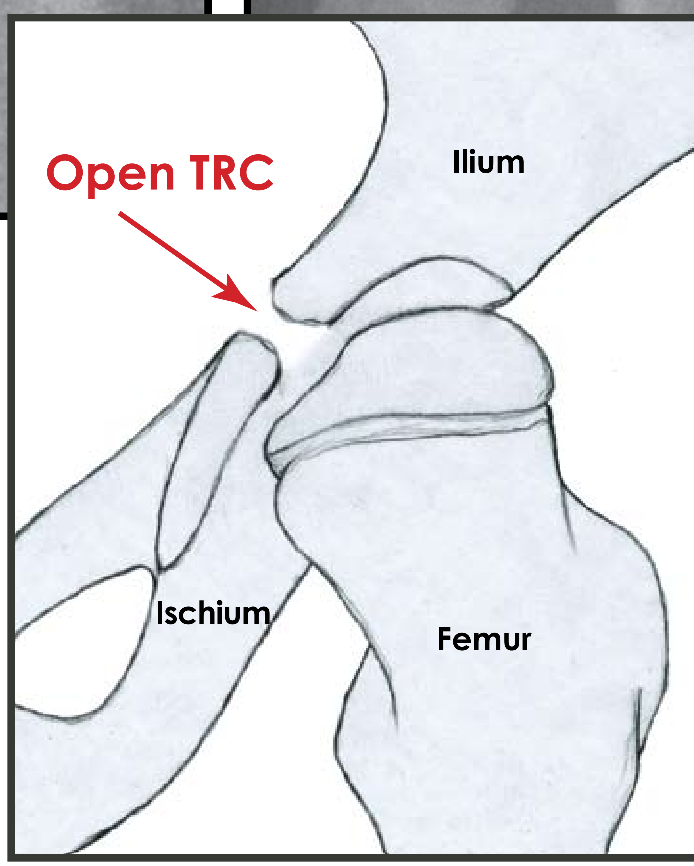


Triradiate Cartilage (Open versus Closed)

OPEN

CLOSED

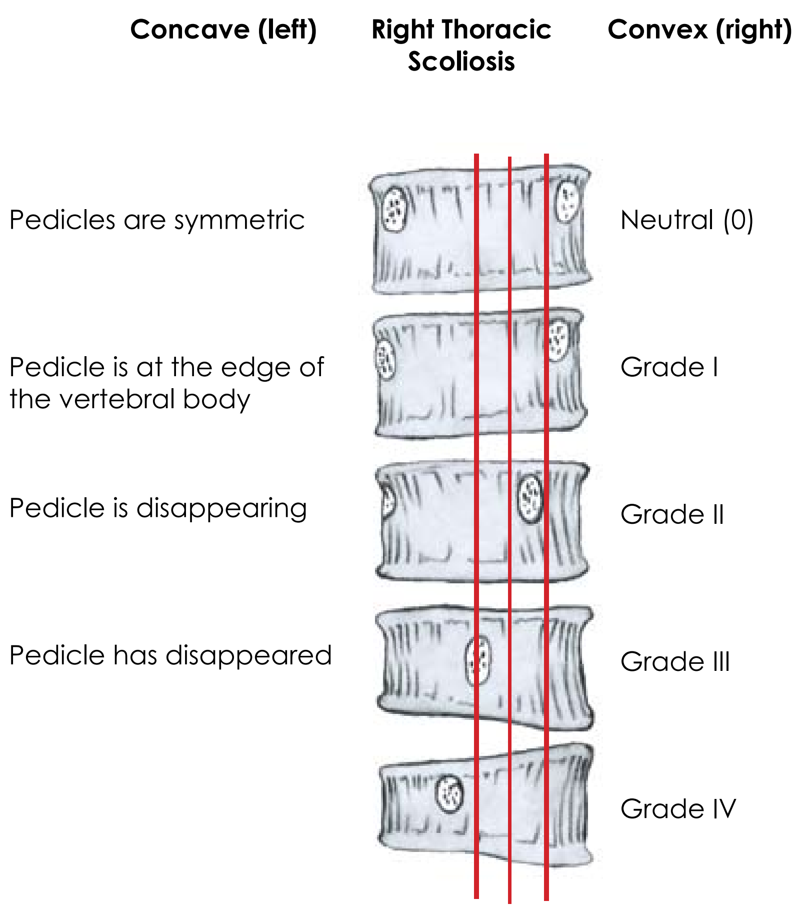


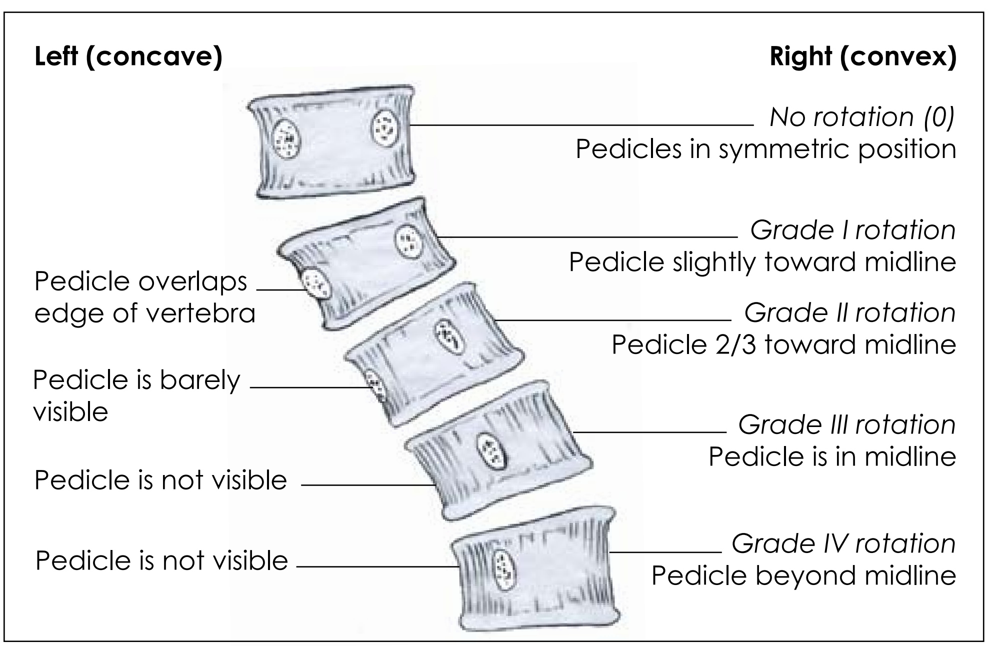


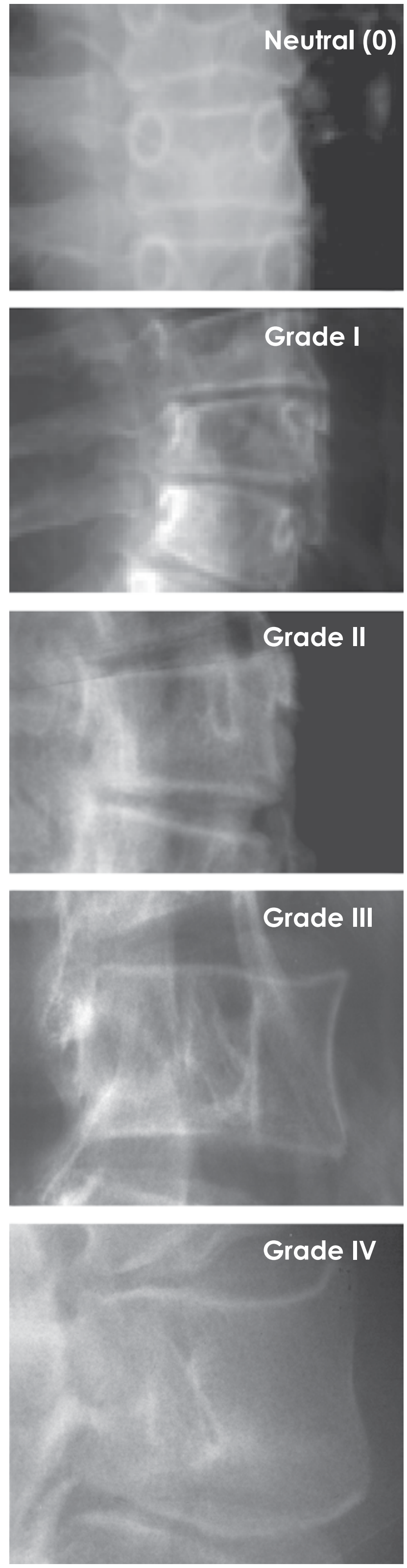
Any non-fused remnant of the Triradiate Cartilage (TRC) is considered open

Adolescent Idiopathic Scoliosis

Nash-Moe Rotation/Apical Vertebral Rotation (Apex of All Curves)

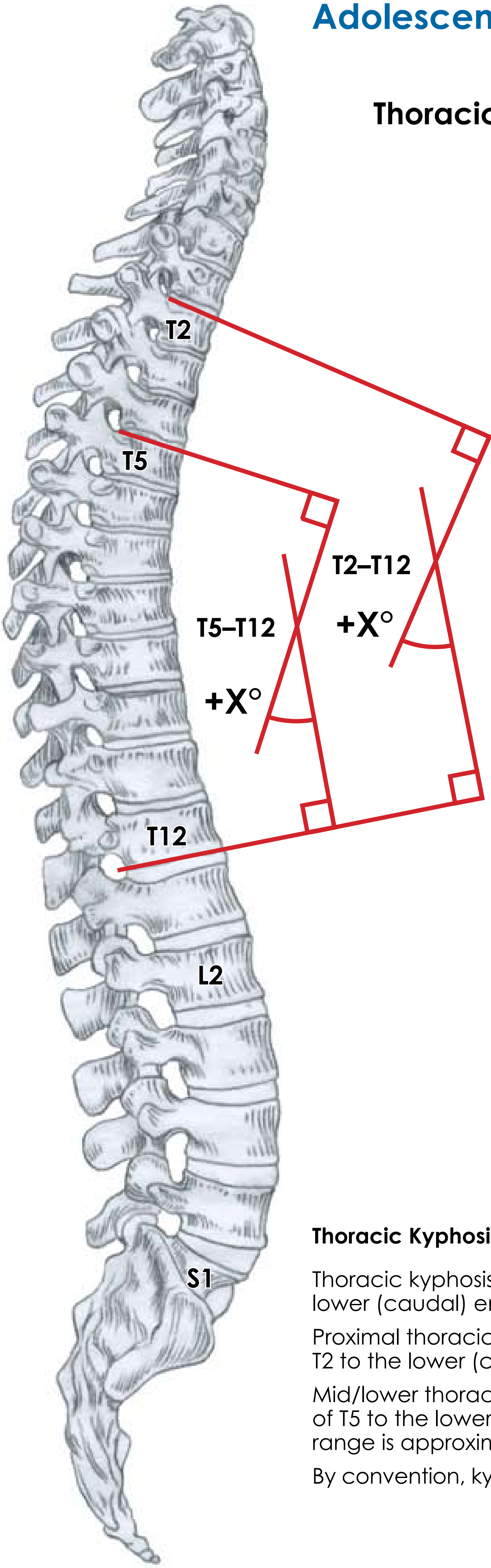


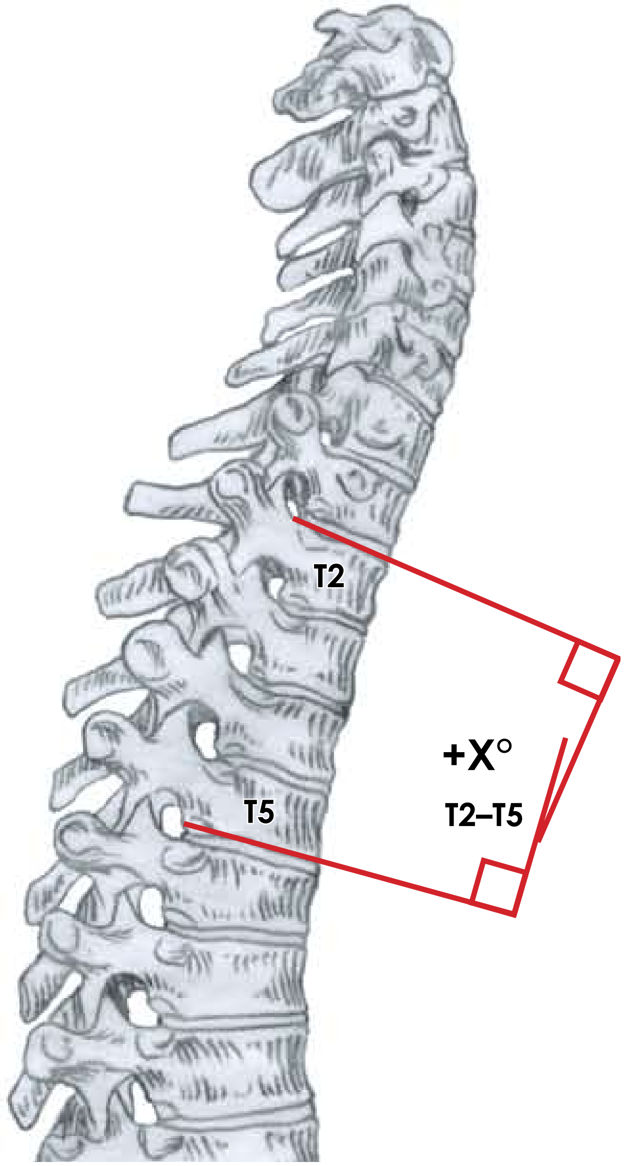




Adolescent Idiopathic Scoliosis

Thoracic Sagittal Alignment





Thoracic Kyphosis

Thoracic kyphosis is measured from the upper (cephalad) end plate of T2 to the lower (caudal) end plate of T12 using the Cobb method.

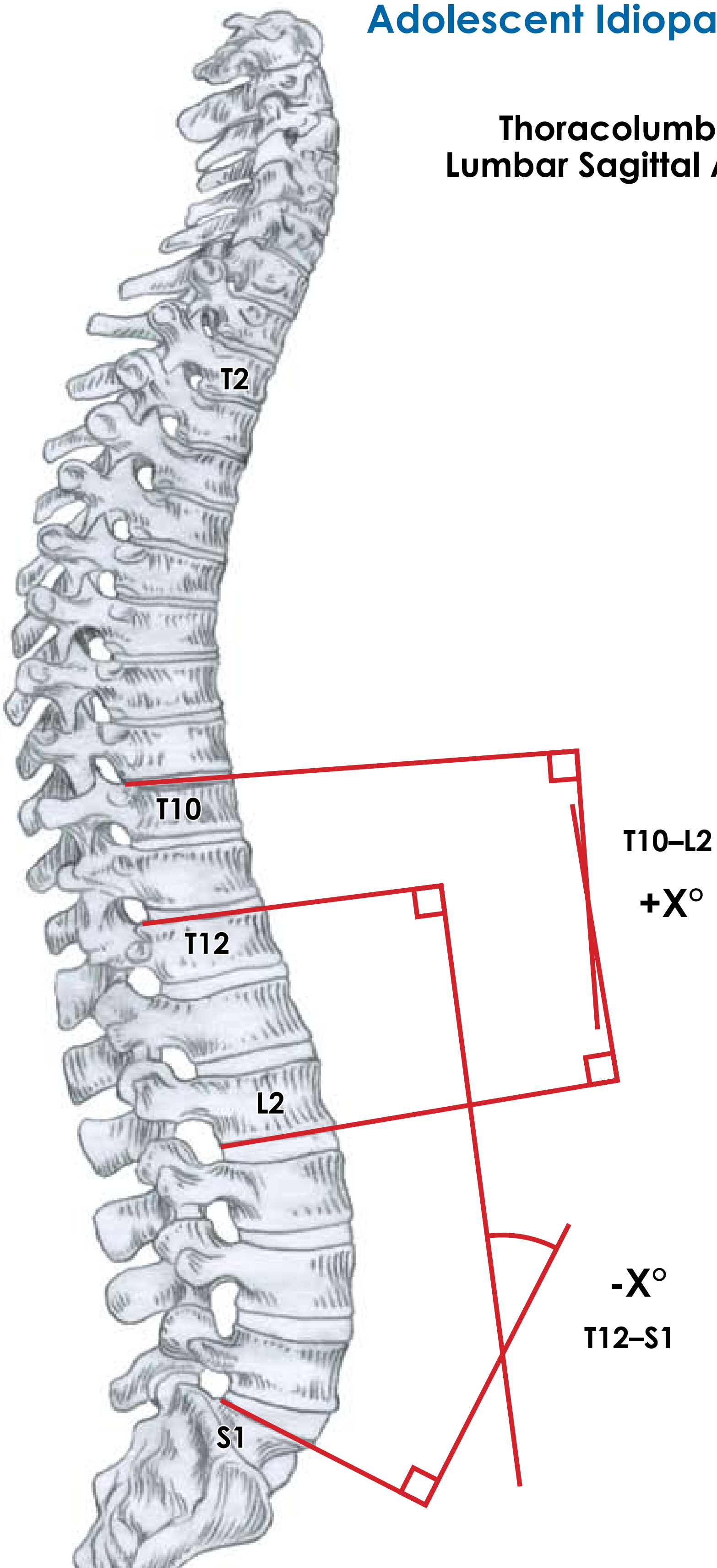
Proximal thoracic kyphosis is measured from the upper (cephalad) end plate of T2 to the lower (caudal) end plate of T5 using the Cobb method.

Mid/lower thoracic kyphosis is measured from the upper (cephalad) end plate of T5 to the lower (caudal) end plate of T12 using the Cobb method. The normal range is approximately 10 - 40° of kyphosis.

By convention, kyphosis is a (+) measurement and lordosis is a (-) measurement.

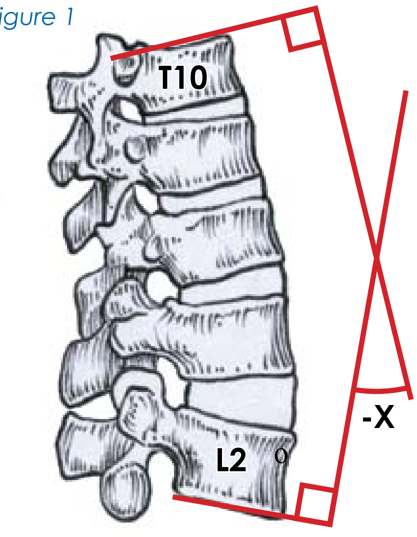
Adolescent Idiopathic Scoliosis

Thoracolumbar and Lumbar Sagittal Alignment



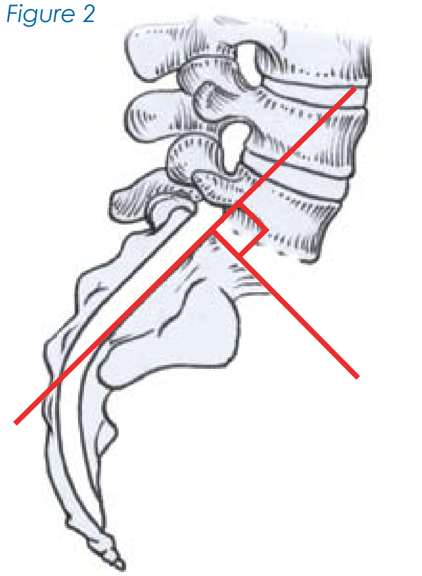
Thoracolumbar sagittal alignment is measured from the upper (cephalad) end plate of T10 to the lower (caudal) end plate of L2 using the Cobb method. By convention kyphosis is a positive angle and lordosis is a negative angle, with the patient facing to the viewer's right side (see Figure 1).

Figure 1



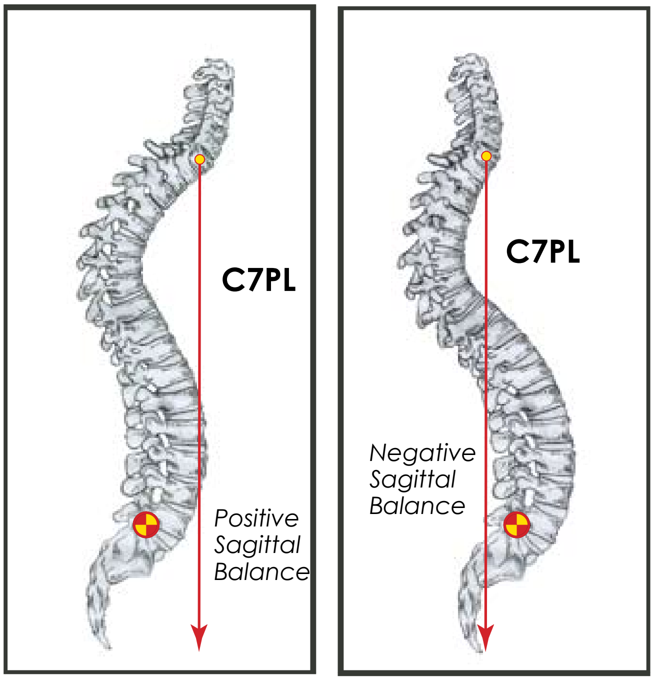
Lumbar sagittal alignment is measured from the cephalad end plate of T12 to the end plate of S1. In the event that the S1 end plate is difficult to identify, an alternative technique for drawing the sacral end plate line is to construct a perpendicular line off the posterior sacral cortical line as shown in Figure 2.

Figure 2

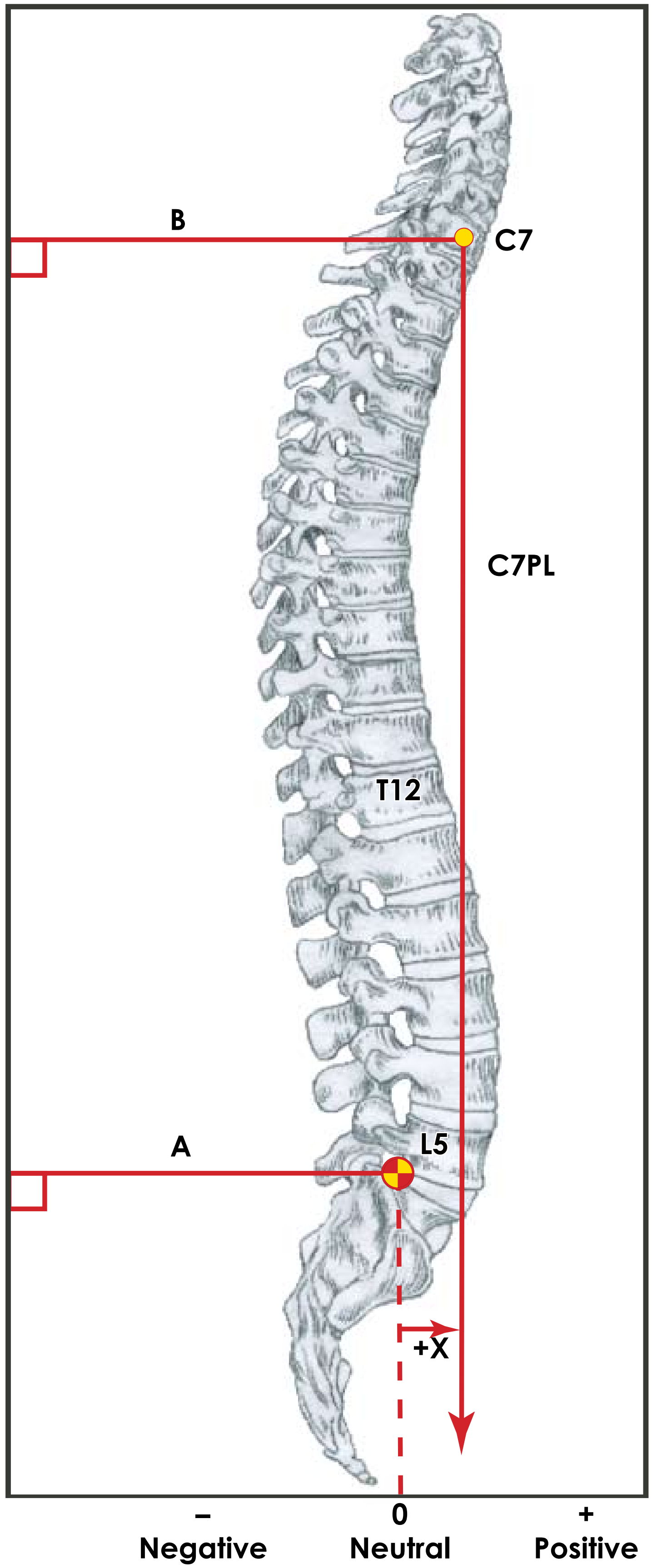


Lumbar sagittal alignment is measured from the upper (cephalad) end plate of T12 to the end plate of S1. The normal range is approximately 40 - 60° of lordosis.

Sagittal Balance



Lateral C7 to Sacrum
(Sagittal Balance = B - A)



Line A is drawn from the posterior-superior corner of S1 ( ) and is perpendicular to the vertical edge of the radiograph. Its length is measured in millimeters from the lefthand edge of the radiograph.

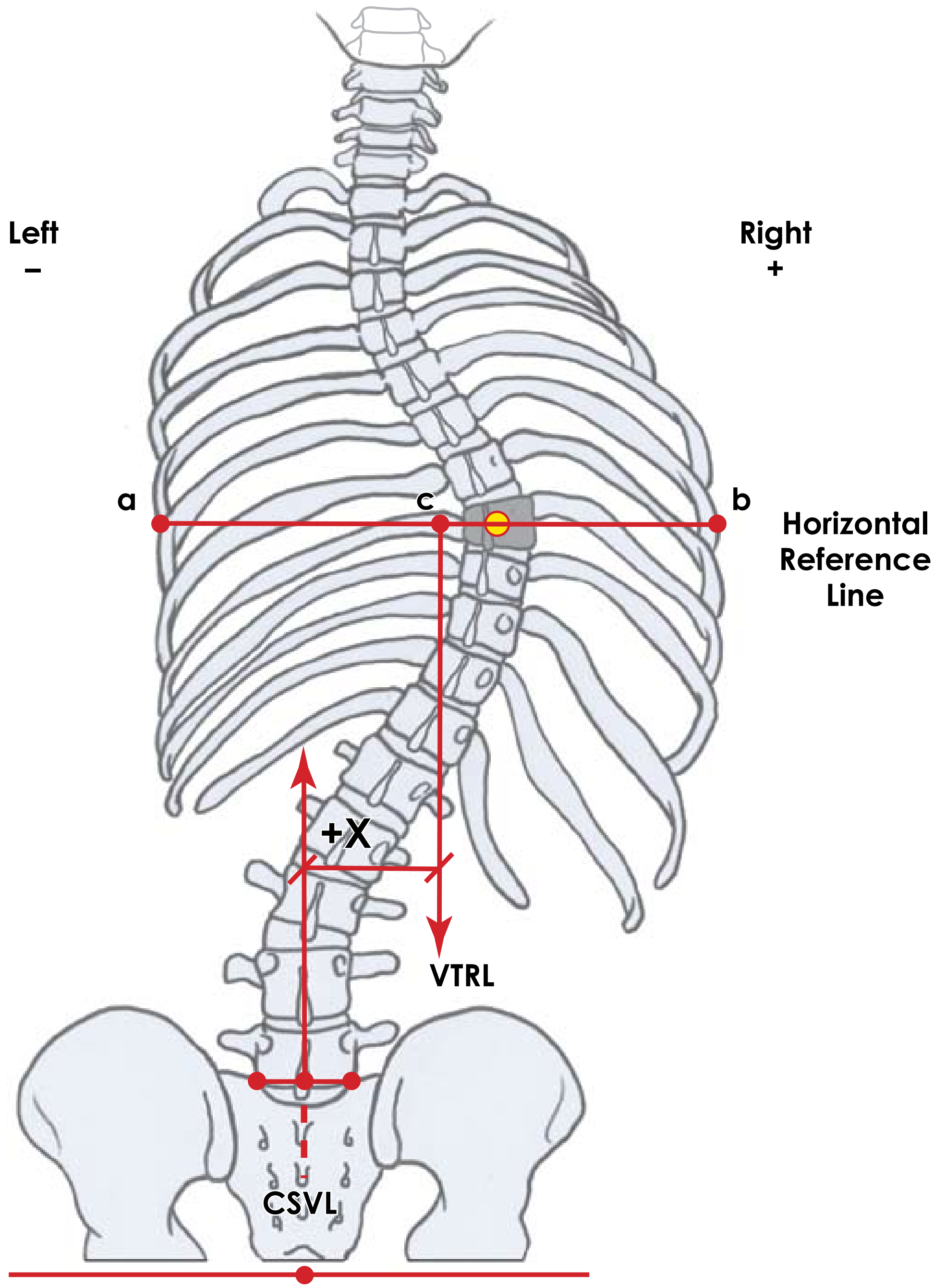
Line B is drawn from the center of C7 and is perpendicular to the vertical edge of the radiograph. Its length is measured in millimeters from the lefthand edge of the radiograph.

Neutral Balance: **B = A**

Negative Balance: **B < A**

Positive Balance: **B > A**

Thoracic Trunk Shift



Thoracic trunk shift is measured on standing PA or AP scoliosis x-rays. This measurement is performed by first identifying the apical thoracic vertebra. Through the centroid, a horizontal reference line is drawn ($\overline{ab}$). Points (a) and (b) are marked at the intersection of the horizontal reference line and the rib cage on the left (a) and the right (b). The midpoint of line segment ab, point (c) is identified, and a perpendicular line is dropped as a reference line. Trunk shift is calculated by measuring the linear distance in millimeters between the vertical trunk reference line (VTRL) and the CSVL. A trunk shift to the right of the CSVL is a positive value, and to the left of the CSVL a negative value.

Adapted from: Floman Y, Penny JN, Micheli LJ, Riseborough EJ, Hall JE. Osteotomy of the fusion mass in scoliosis. *J Bone Joint Surg Am*. 1982 Dec;64(9):1307-16.

Richards BS. Lumbar curve response in type II idiopathic scoliosis after posterior instrumentation of the thoracic curve. *Spine*. 1992;17(85):5282-6.

Pelvic Obliquity/Leg Length Discrepancy

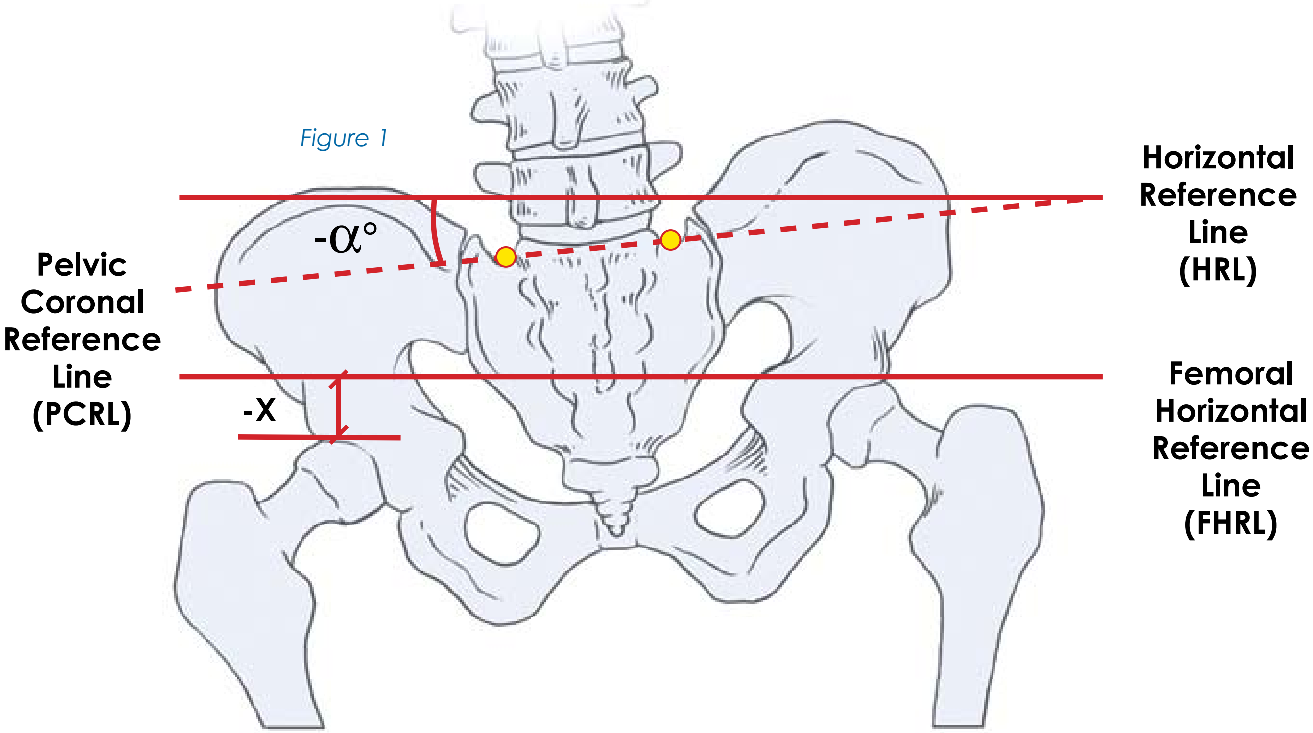


Figure 1

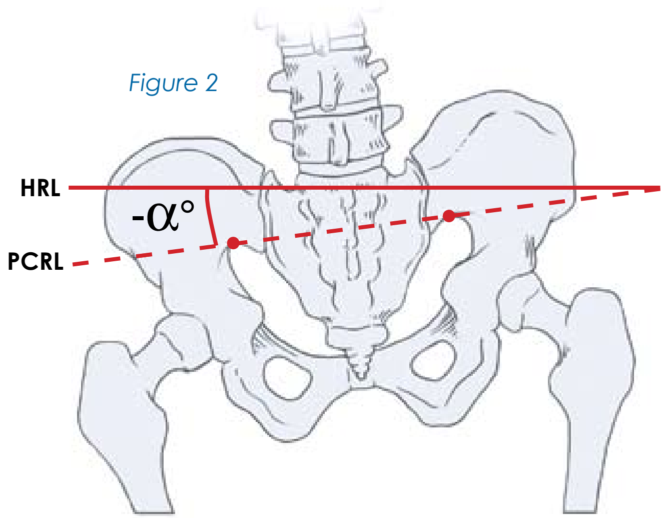


Figure 2

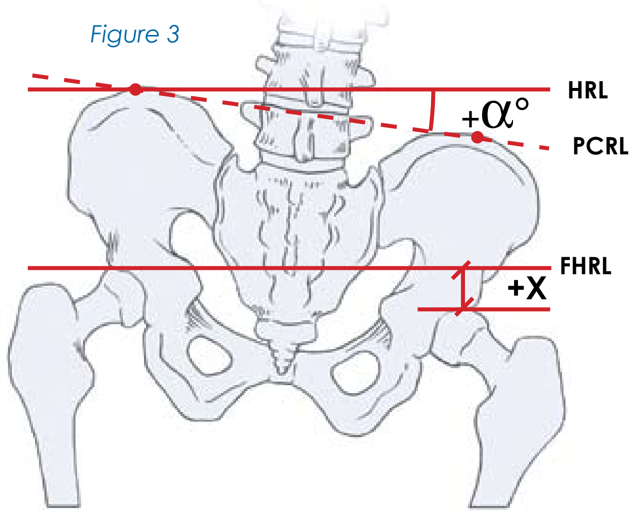
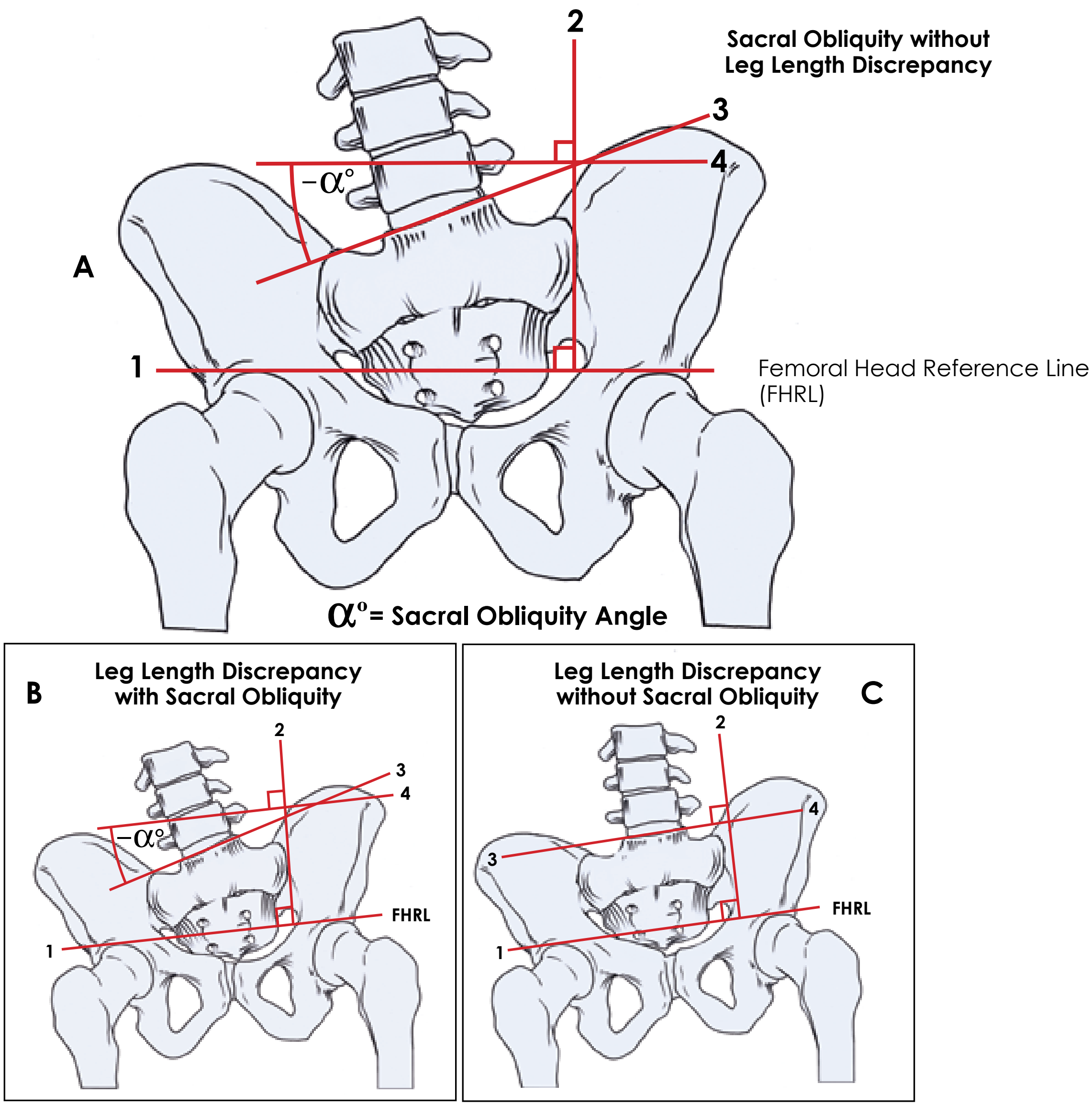


Figure 3

Because of the difficulty often encountered in identifying the anatomic landmarks of the pelvis, several options are available for defining the coronal angulation of the pelvis. The tips of the sacral ala can be used to create the pelvic coronal reference line (PCRL) for the pelvic orientation in the coronal plane. Alternative techniques for identifying the tilt of the sacrum/pelvis are identified in Figures 1, 2, and 3. If the sulcus of the S1 ala is clearly visible bilaterally, it may be used to create the PCRL. (see Figure 1 – yellow dots) The tilt will be the angle subtended by the horizontal reference line (HRL) and the PCRL. Additionally, the top of the ilium may be used to create the PCRL if no sulcus is visible (Figure 3).

Leg length discrepancy will be identified on PA standing radiographs without blocks under the patient's feet and with the knees extended. A femoral horizontal reference line (FHRL) will be created by making a horizontal line that is tangent to the top of the highest femoral head. The difference between the height of this line and the height of the lower femoral head will be defined as the leg length discrepancy. If the left hip is up the value is positive (+). If the right hip is up then the value will be negative (-).

Sacral Obliquity



Sacral obliquity is defined as a tilt in the sacral end plate secondary to an intrinsic sacral deformity. This may produce an oblique take off for the lumbar spine. Coronal plane tilting of the sacral end plate may result from 1) pelvic obliquity, 2) leg length discrepancy, 3) intrinsic sacral deformity (sacral obliquity), or a combination of these three. Either sacral or pelvic obliquity may contribute to a TL/L scoliosis. To differentiate between sacral obliquity, pelvic obliquity, and leg length discrepancy, the relationships described in Figures A, B, and C are illustrated. Sacral obliquity α° (Figure A) is measured in relation to the femoral head reference line (FHRL). The technique for measuring sacral obliquity is detailed in Figure A. First, the FHRL is drawn (1). Then a perpendicular reference line is drawn (2). Third, a line is drawn along the coronal projection of the S1 end plate on a Ferguson AP of the sacrum (3). Finally, a line is drawn (4) at the intersection of the sacral end-plate line (3) and its intersection with line 2. Line 4 is parallel to the FHRL. The angle subtended between lines 3 and 4 is the sacral obliquity angle (α°). The angle is positive if the left side of the sacrum is high and negative if the right side of the sacrum is high. If the leg lengths are equal, the FHRL is horizontal to the floor, and the sacral obliquity is identified as α° (Figure A). If the sacral end plate has an oblique orientation in the coronal plane and the FHRL is not horizontal to the floor (Figures B and C), the sacral obliquity may be secondary to both leg length discrepancy and intrinsic sacral obliquity (Figure B), or the apparent "sacral obliquity" may result from abnormal tilting of the pelvis due to a leg length discrepancy or iliac shape (Figure C).

Chapter 5

Adult Deformity

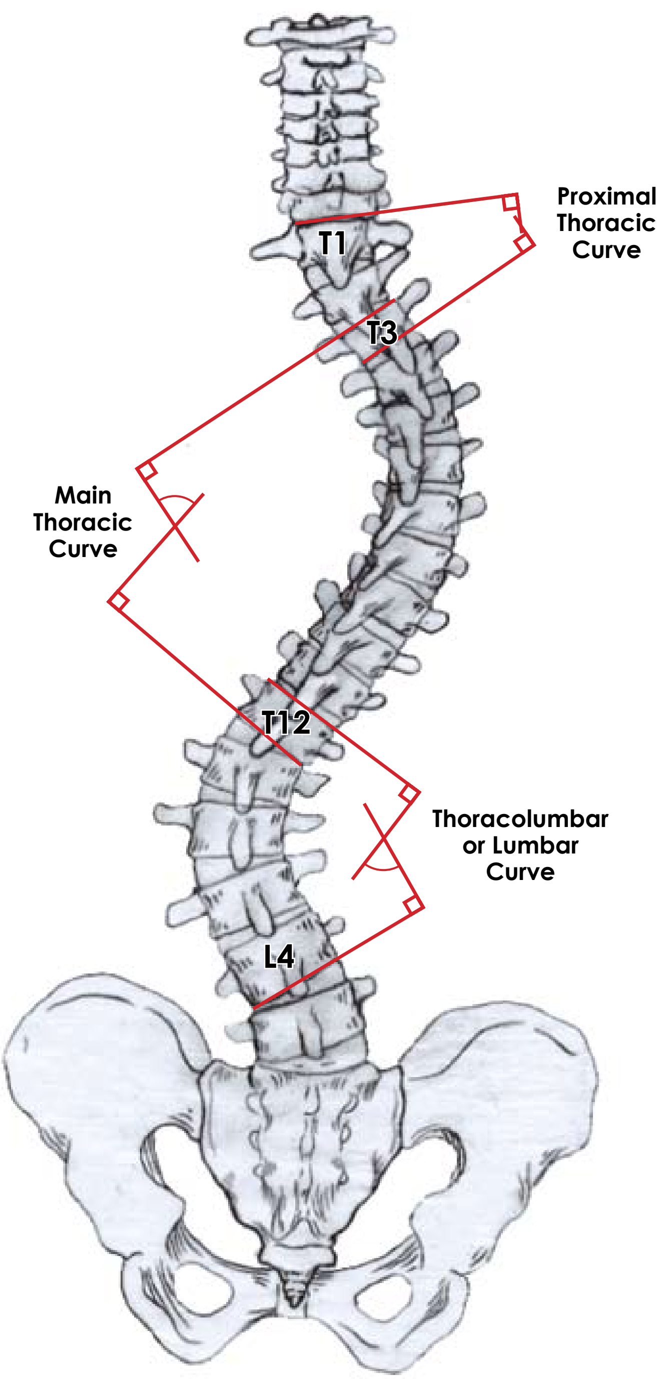


Figure 1

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SPINAL DEFORMITY STUDY GROUP™

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Adult Deformity

Coronal Cobb Measurements:
Proximal Thoracic (PT), Main Thoracic (MT), and Thoracolumbar (TL) or Lumbar (L) Curves

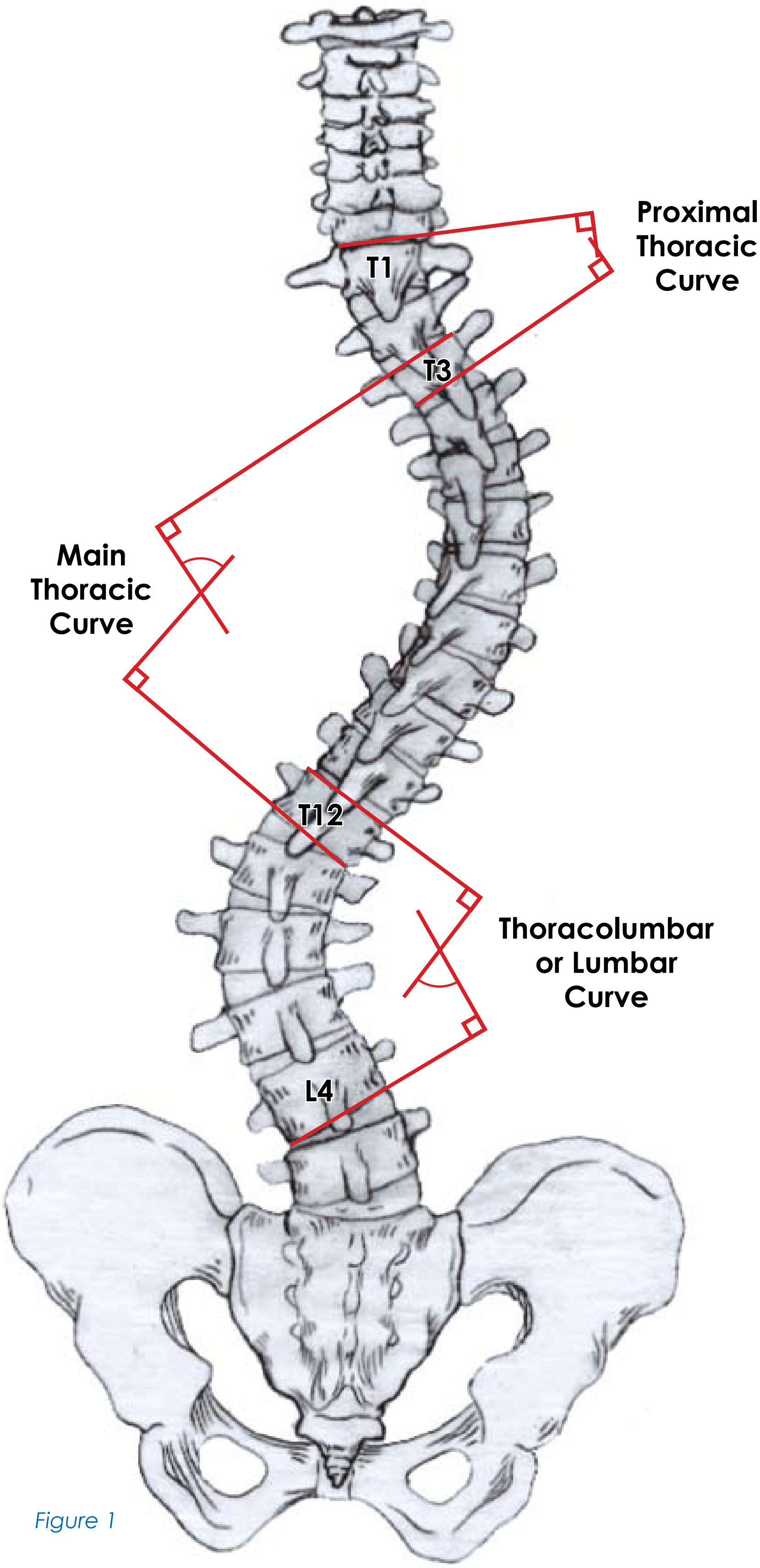


Figure 1

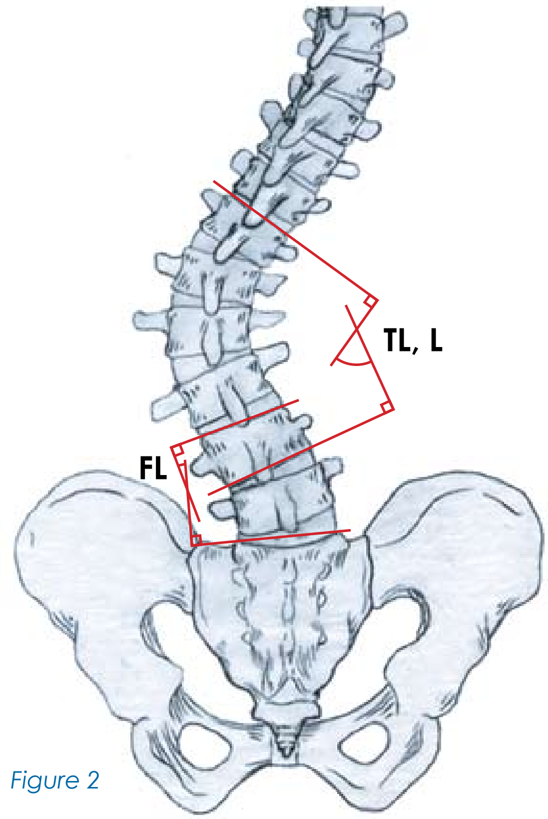


Figure 2

The technique for measuring the coronal Cobb angulation in adult deformity is the same as it is for AIS. However, because of the degenerative component found in many of these curves, the curves may transgress the usual regional boundaries of the spinal segments. For instance, "thoracic kyphosis" may include lower cervical segments, as well as upper lumbar segments. The same may be true of scoliotic deformities. All vertebral segments within the sagittal or coronal deformity, regardless of regional spinal location, should be included when calculating the coronal Cobb and sagittal measurements. Adult scoliosis in addition to having a thoracolumbar or lumbar curve (TL/L) will often have a fractional lumbosacral (FL) curve (see Figure 2).

Determination of Centroids

Several techniques for identification of the centroid of a vertebral body or disc have been described. The "x" technique has commonly been employed (Figure 1).

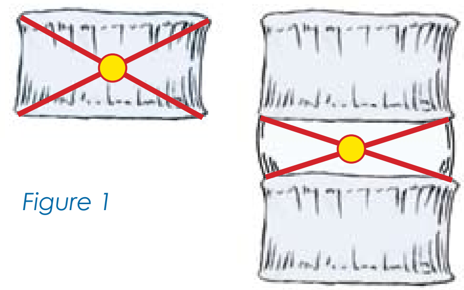


Figure 1

For a relatively rectangular structure, this works well. However, as the vertebrae or discs become increasingly trapezoidal, this technique can be inaccurate (Figure 2).

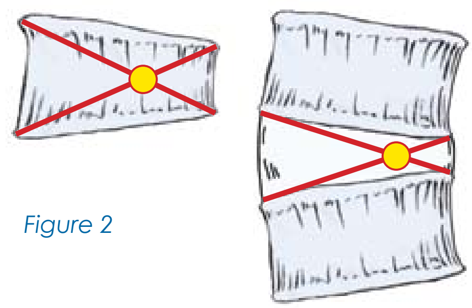


Figure 2

Therefore, the DRPro software utilizes a new technique that allows the centroids of vertebrae and discs to be identified, as a matter of course, during the radiographic measurement process. For the vertebrae, the software will utilize four points selected (Figure 3) to identify the vertebral body in space.

Figure 3

The software will automatically determine the centroid from the intersection of the midpoints of the lines derived from these selected points (Figure 4).

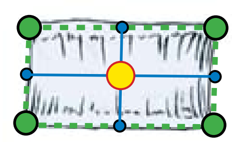


Figure 4

This technique works well for trapezoidal and rectangular shapes, whether it is a vertebra or a disc (Figure 5). Throughout this text, centroids are represented as a distinctive yellow dot.

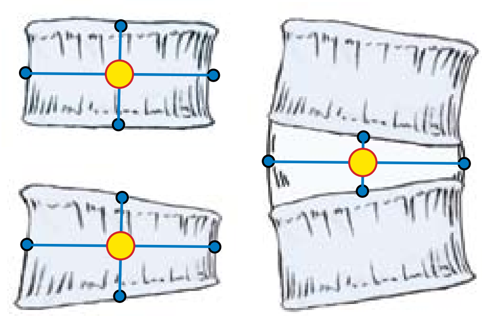


Figure 5

Identification of Apical Vertebra (or Disc) and Technique for Measuring Apical Vertebral Translation (AVT) in Proximal Thoracic, Main Thoracic, and Thoracolumbar/Lumbar Curves

The "C7 plumbline" (C7PL) is dropped from the middle of the C7 vertebral body and is drawn parallel to the vertical edge of the radiograph. The center sacral vertical line (CSVL) is drawn from the middle of S1 upwards and parallels the vertical edge of the radiograph. Identify the apex for each curve (see Chapter 3). When the C7PL and the CSVL coincide, AVT is measured as shown below (left).

Figure 1

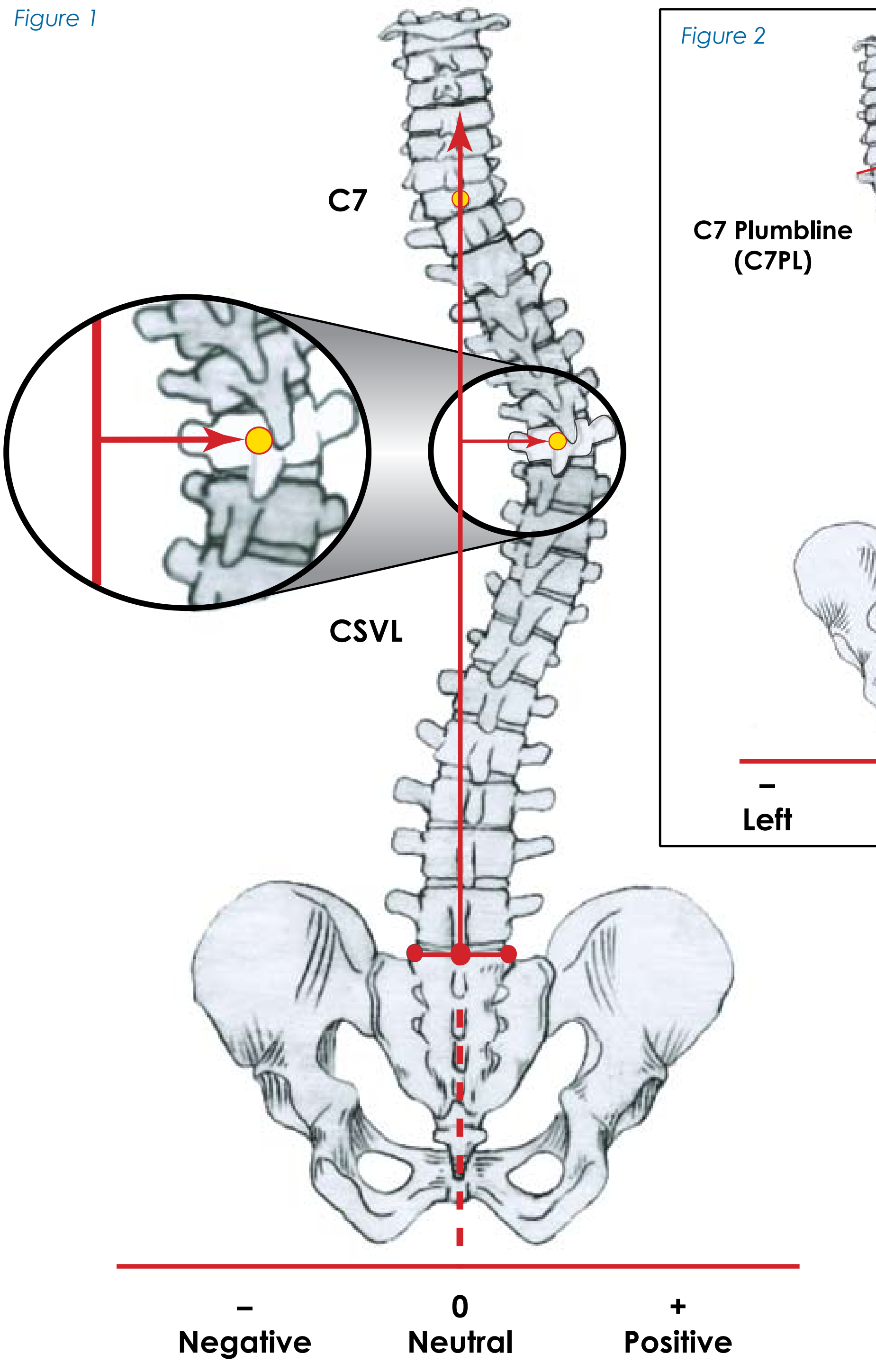
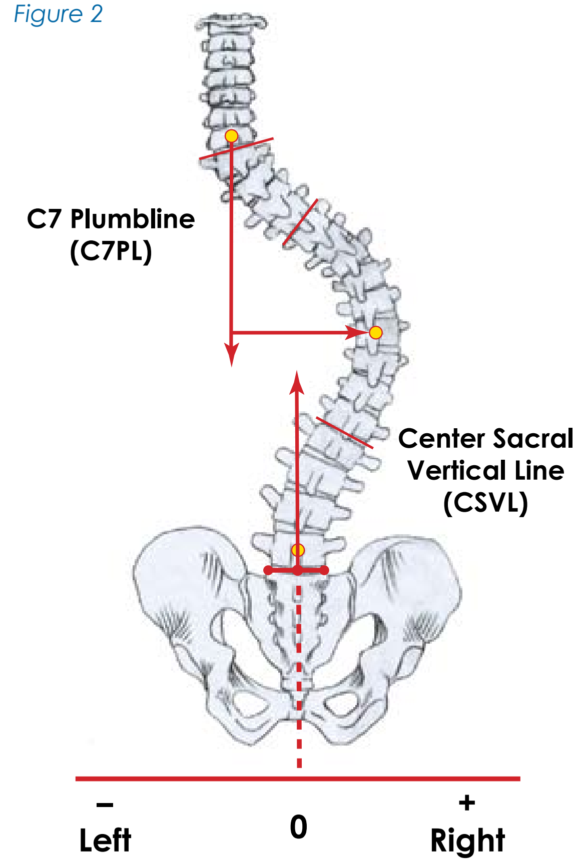


Figure 2



In the case of coronal decompensation where the C7PL and the CSVL **do not** coincide, the AVT for thoracic curves (proximal and main) are measured from the C7PL, as shown above (right). For thoracolumbar and lumbar curves, it is measured from the CSVL (see Figures 3 and 4 on page 76).

Identification of Apical Vertebra (or Disc) and Technique for Measuring Apical Vertebral Translation (AVT) in Proximal Thoracic, Main Thoracic, and Thoracolumbar/Lumbar Curves

Figure 3

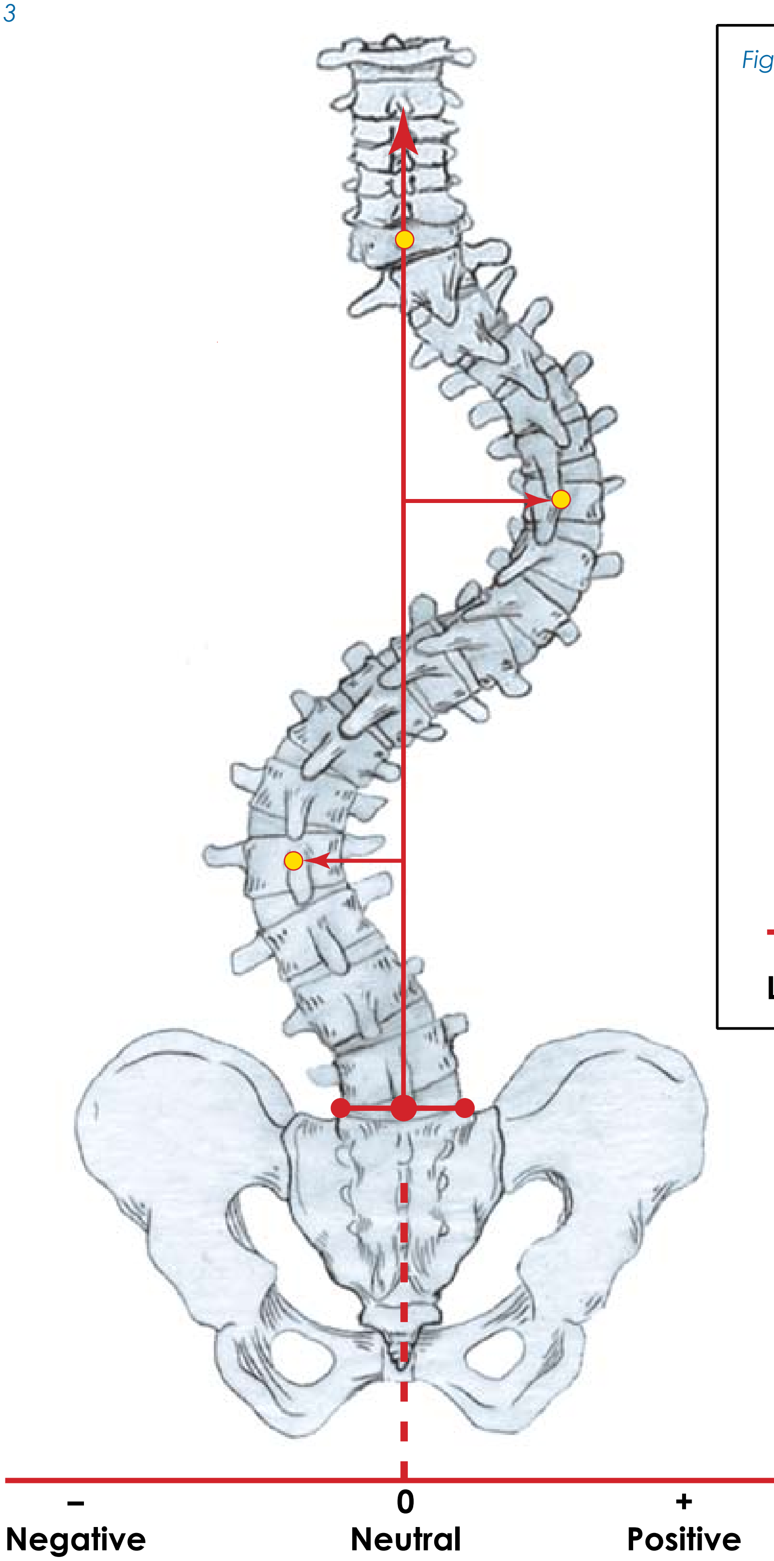
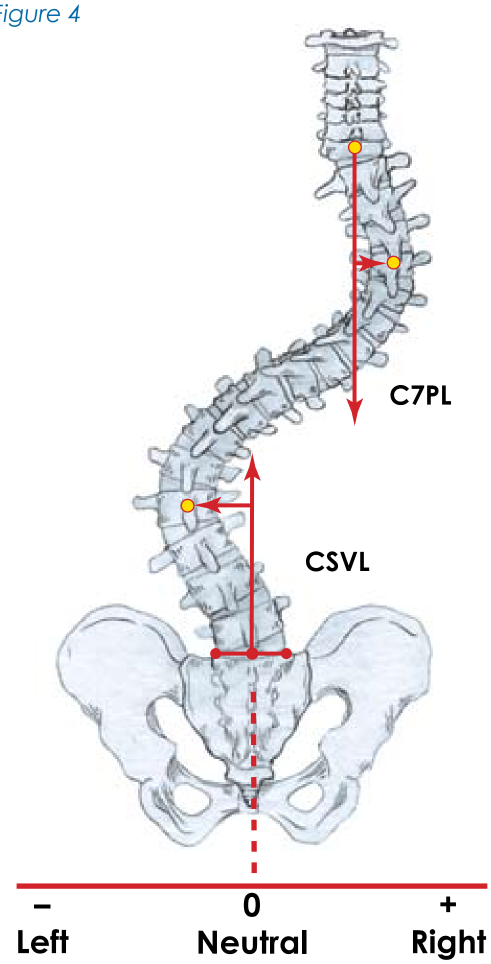


Figure 4



Identification of Apical Vertebra (or Disc) and Technique for Measuring Apical Vertebral Translation (AVT) in Thoracolumbar, Lumbar, and Lumbosacral Curves

For thoracolumbar, lumbar, and lumbosacral fractional curves, the apical vertebra is measured from the center sacral vertical line (CSVL) which is drawn parallel to the vertical edge of the x-ray originating from the center of the S1 end plate. When a vertebral body is identified as the apex of the curve, the center of the vertebral body is located using the "centroid-technique." The AVT is the linear distance from the CSVL to the centroid of the apical vertebra (see Figure 5).

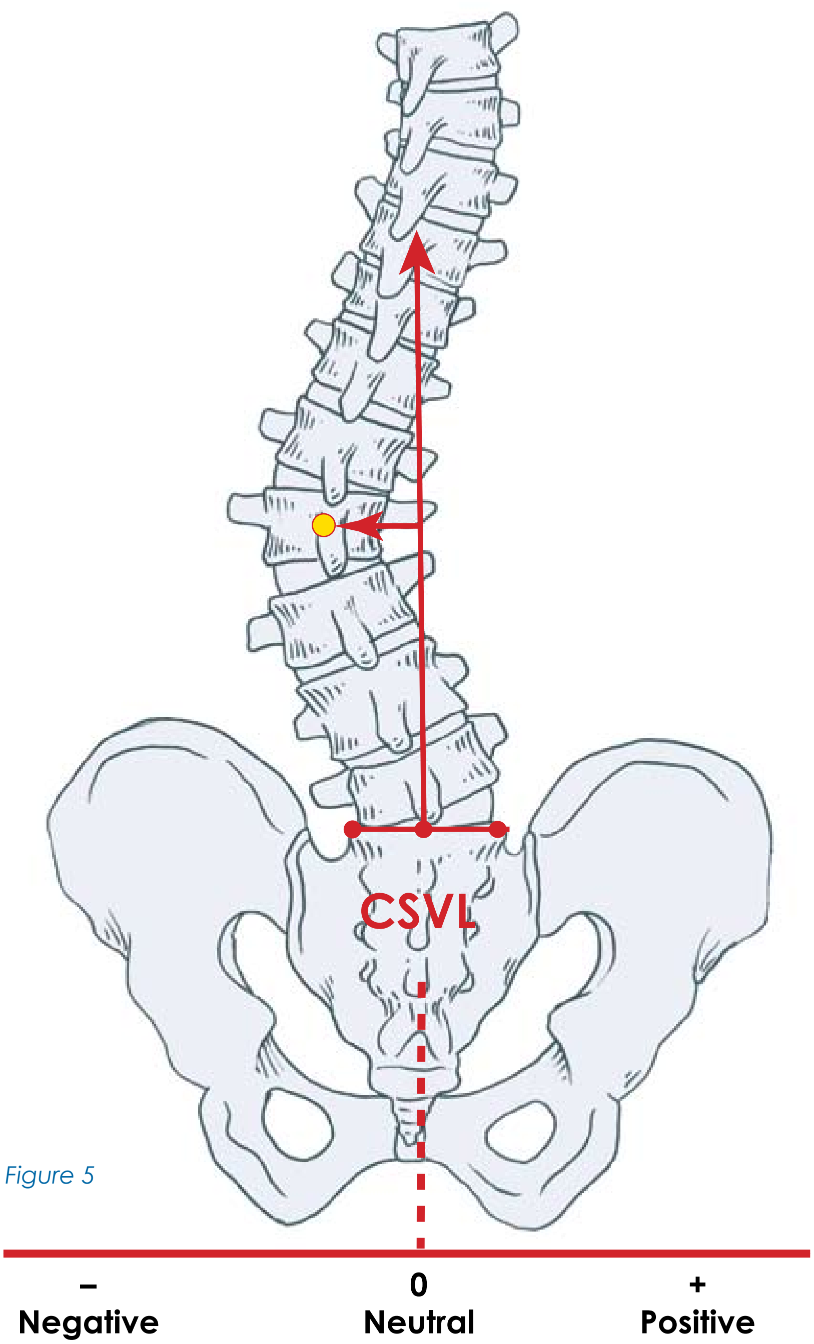


Figure 5

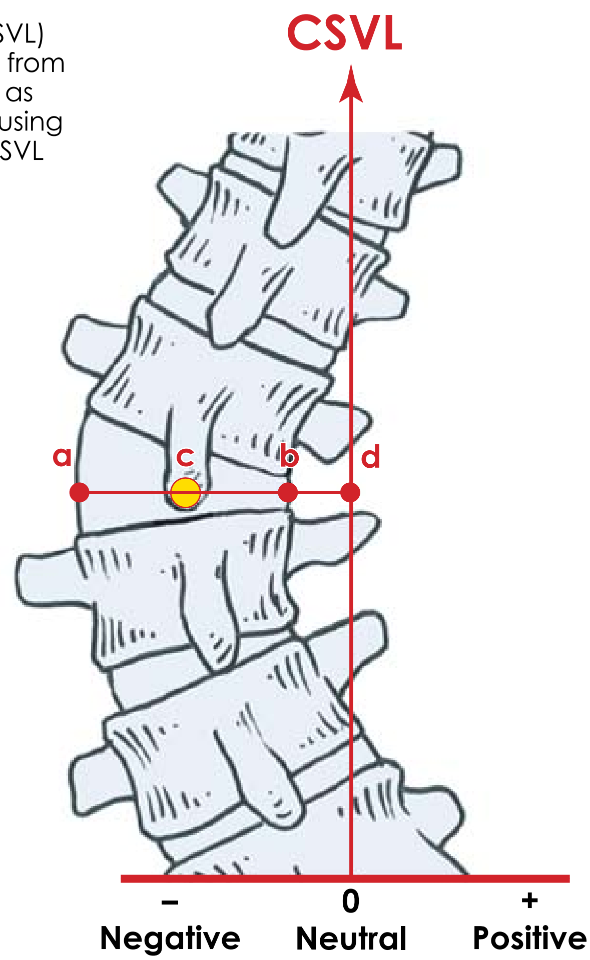


Figure 6

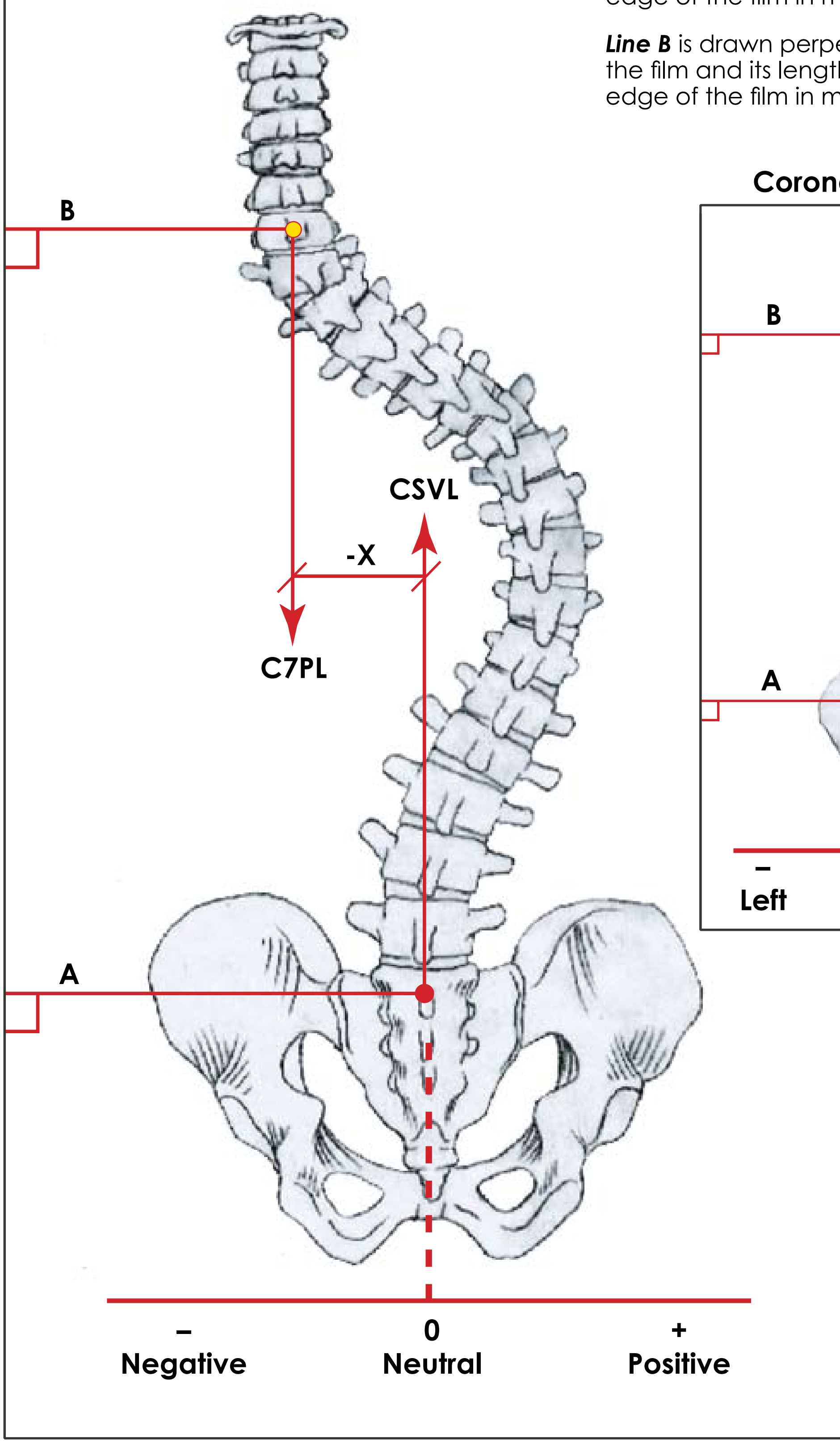
When a disc is identified as the apex of the curve the center of the disc is identified by drawing a horizontal line through the disc at its cephalad-caudal midpoint ($\overline{ab}$), and the center of that line (c) is identified as the center of the disc (see Figure 6). Apical translation of the disc is measured from the disc centroid to the CSVL ($\overline{cd}$).

Coronal Balance (Alignment of C7PL in Relation to the CSVL)

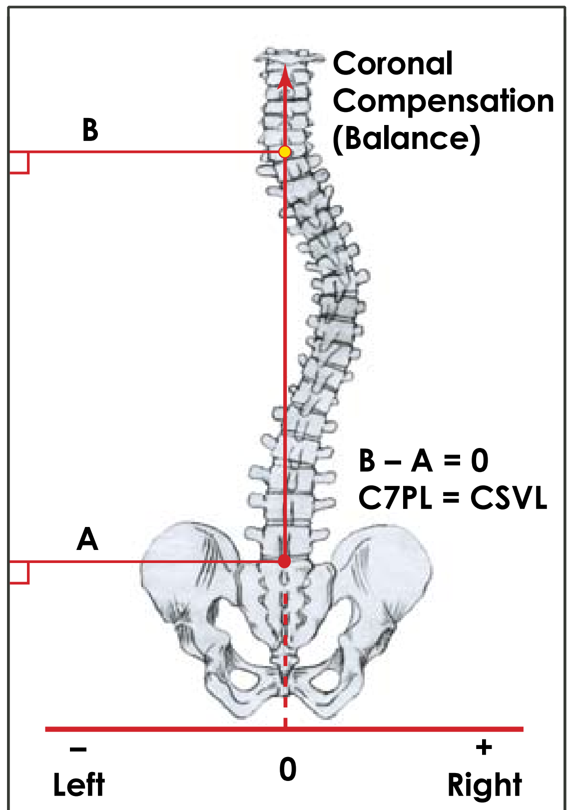
Coronal Decompression
B – A = +/–X

Line A is drawn perpendicular to the vertical edge of the film and its length is measured from the lefthand edge of the film in millimeters to the center of S1.

Line B is drawn perpendicular to the vertical edge of the film and its length is measured from the lefthand edge of the film in millimeters to the center of C7.



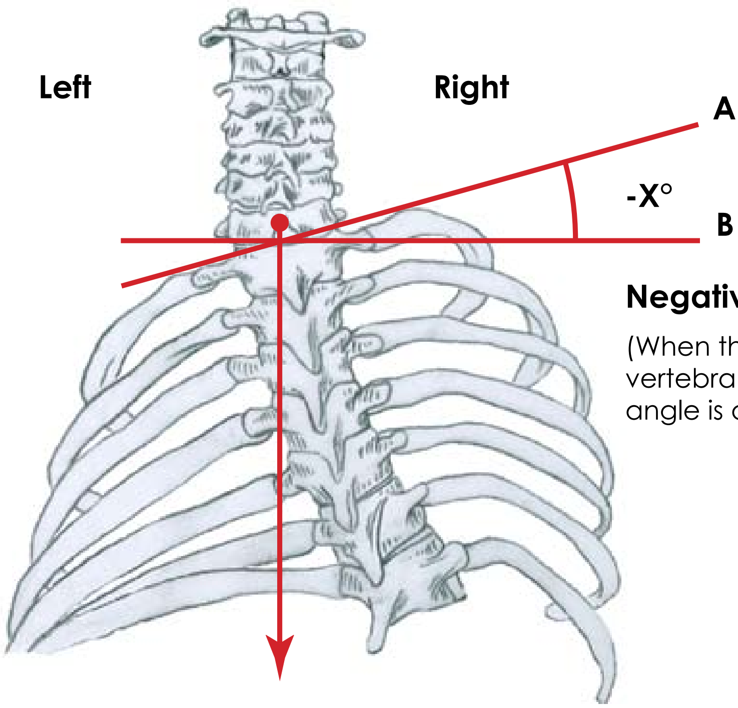
Coronal Balance = B – A = 0



T1 Tilt Angle

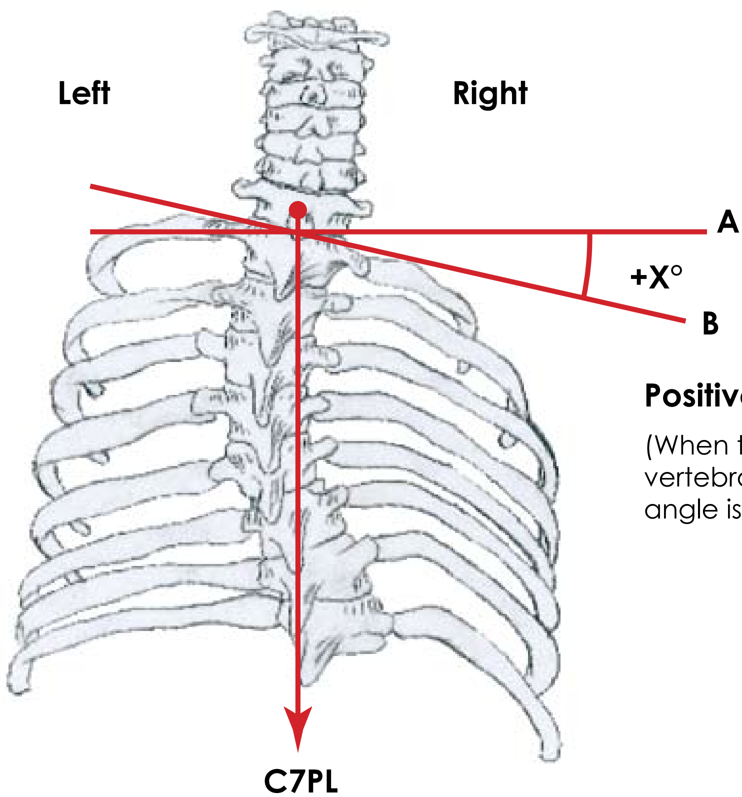
Line A is drawn along the cephalad end plate of T1 or along the zenith of both first ribs if the T1 end plate is not well visualized.

Line B is drawn perpendicular to the vertical edge of the radiograph and intersects the C7PL and line A in the midline.



Negative T1 Tilt

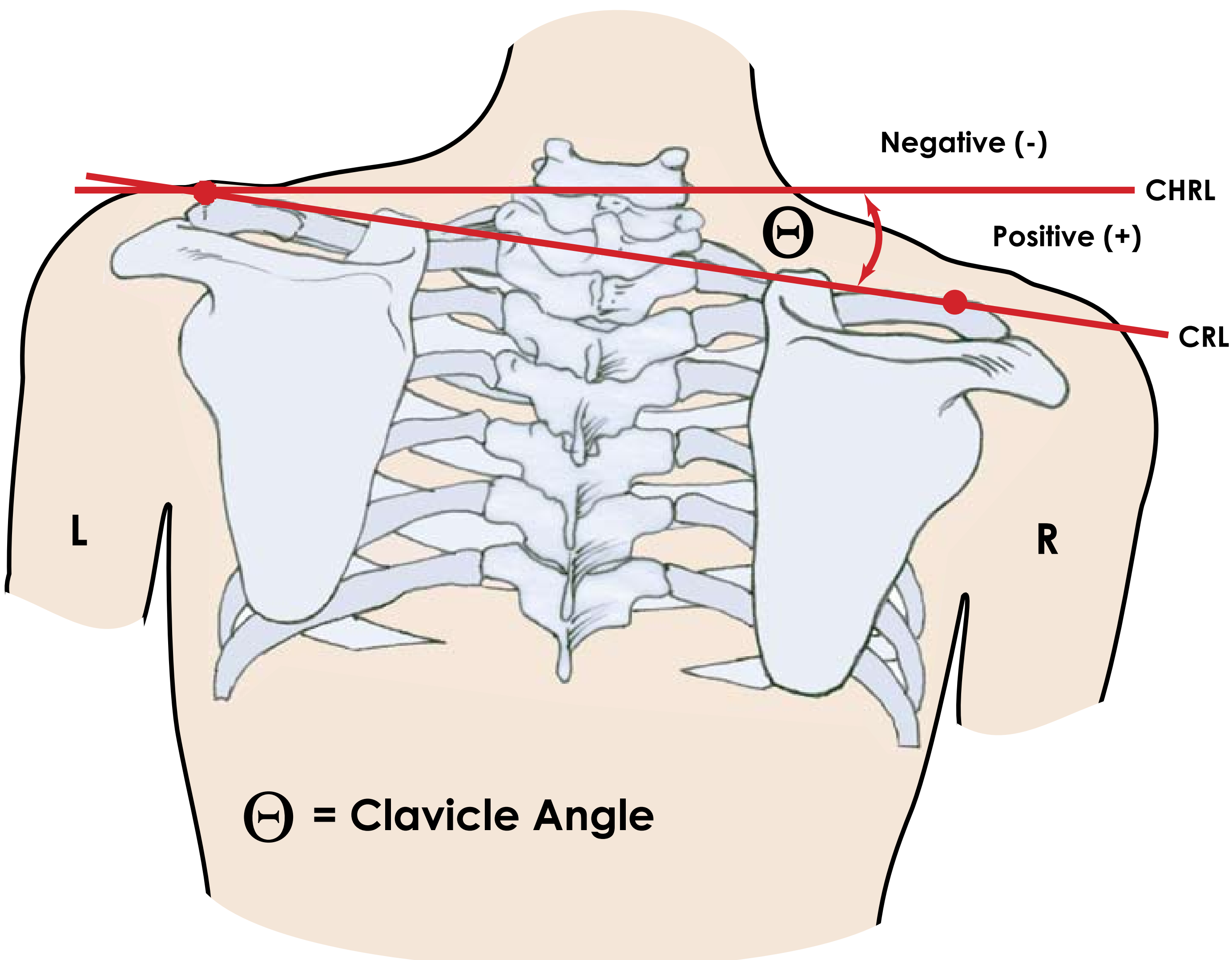
(When the right edge of the vertebral body is up, the tilt angle is defined as negative)



Positive T1 Tilt

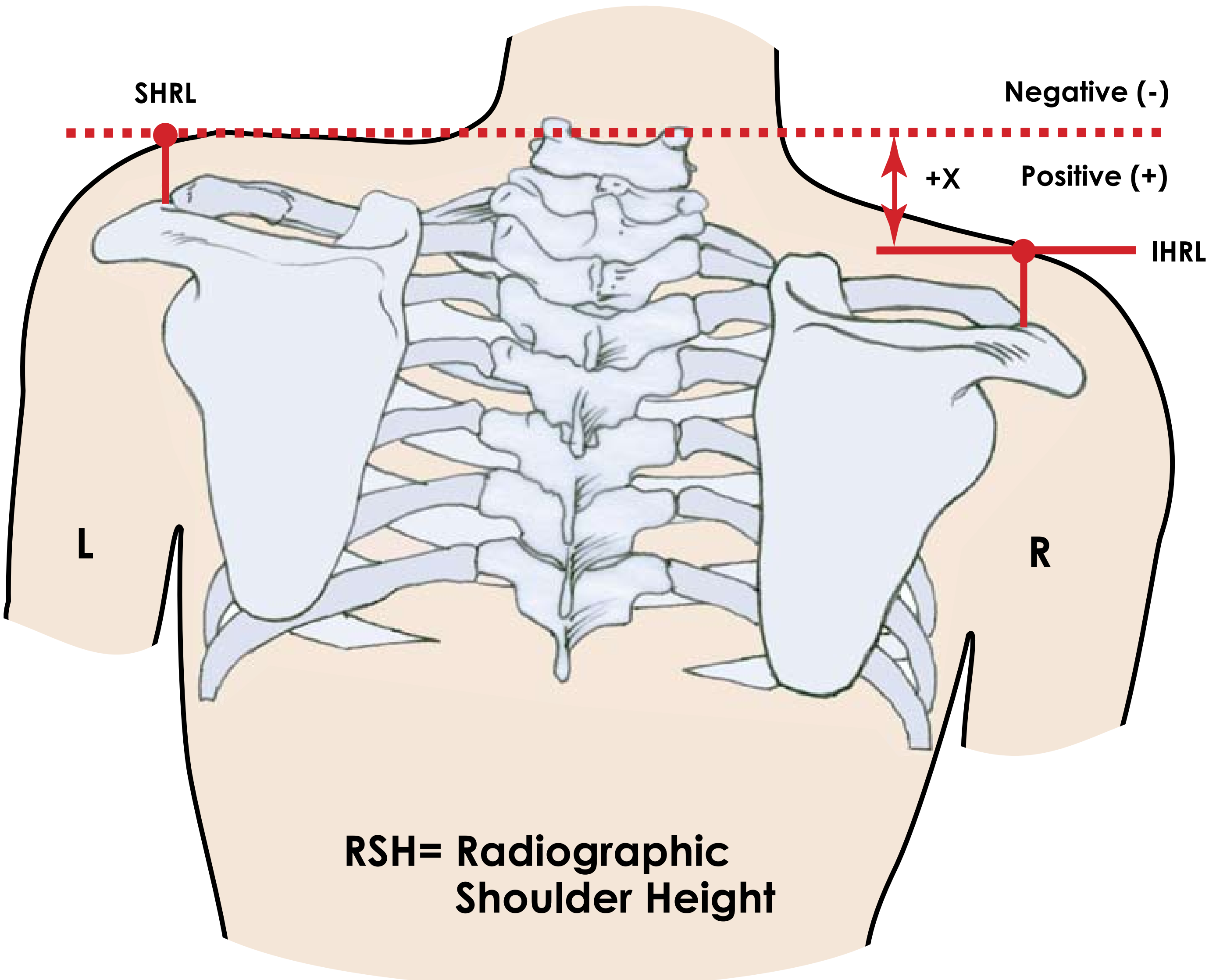
(When the left edge of the vertebral body is up, the tilt angle is defined as positive)

Clavicle Angle



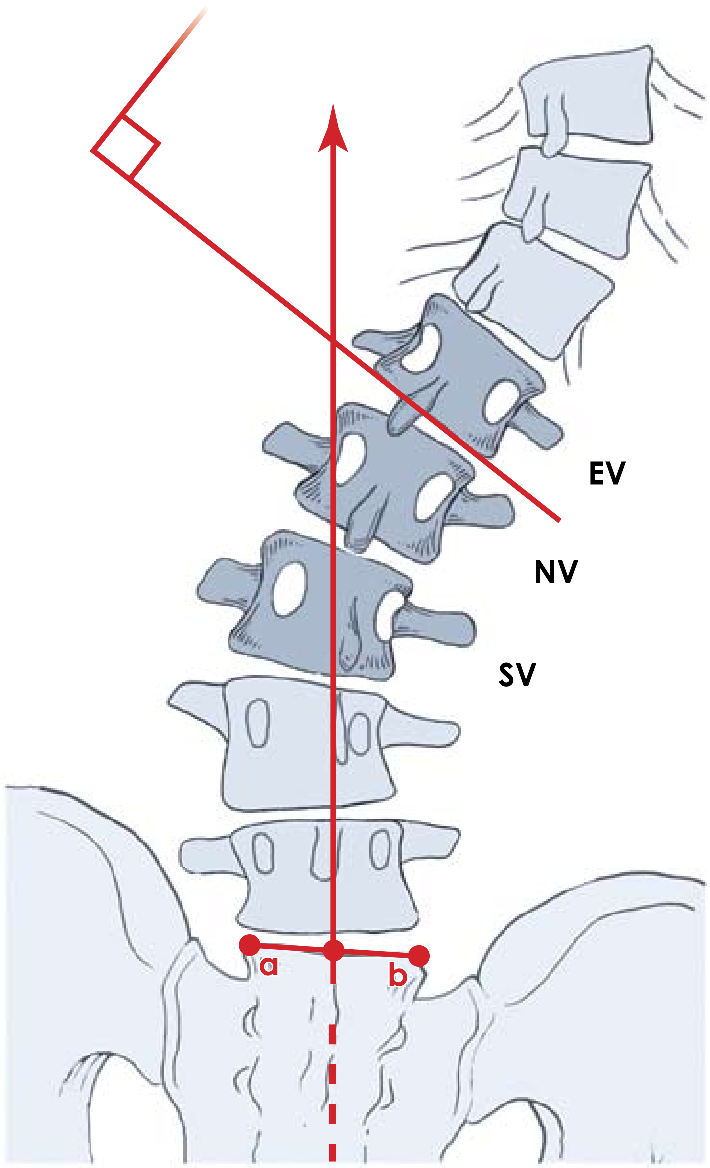
The clavicle angle is the angle which is subtended between a horizontal reference line – clavicle horizontal reference line (CHRL), which is drawn perpendicular to the lateral edge of the radiograph and touches the most cephalad portion of the elevated clavicle and a line which touches the most cephalad aspect of both the right and left clavicles (clavicle reference line [CRL]). By convention, angles subtended with the left shoulder up are positive and angles subtended with the right shoulder up are negative (consistent with directionality of the T1 tilt angle).

Radiographic Shoulder Height



Radiographic shoulder height is defined as the linear distance measured in millimeters between a superior horizontal reference line (SHRL), which passes through the intersection of the soft tissue shadow of the shoulder and a line drawn vertically up from the acromial clavicular joint of the cephalad shoulder, and the inferior horizontal reference line (IHRL) constructed in a similar fashion over the caudal acromial clavicular joint. The distance "X" is the radiographic shoulder height (RSH). The linear distance "X" is positive if the left shoulder is up and negative if the right shoulder is up.

End, Neutral, and Stable Vertebrae



The ***end*** vertebrae (EV) are the most tilted vertebrae at the cephalad and caudal ends of a curve. The ***neutral*** vertebra (NV) is the most cephalad vertebra below the apex of the major curve whose pedicles are symmetrically located within the radiographic silhouette of the vertebral body. To identify "the stable vertebra," first, a vertical reference line (CSVL) is erected from the midportion of S1. The most cephalad vertebra immediately below the end vertebra of the major curve which is most closely bisected by the CSVL is the ***stable*** vertebra (SV). Typically, the end, neutral, and stable vertebrae are different vertebral segments. However, the end, neutral, and/or stable vertebrae may occasionally overlap in the same vertebra.

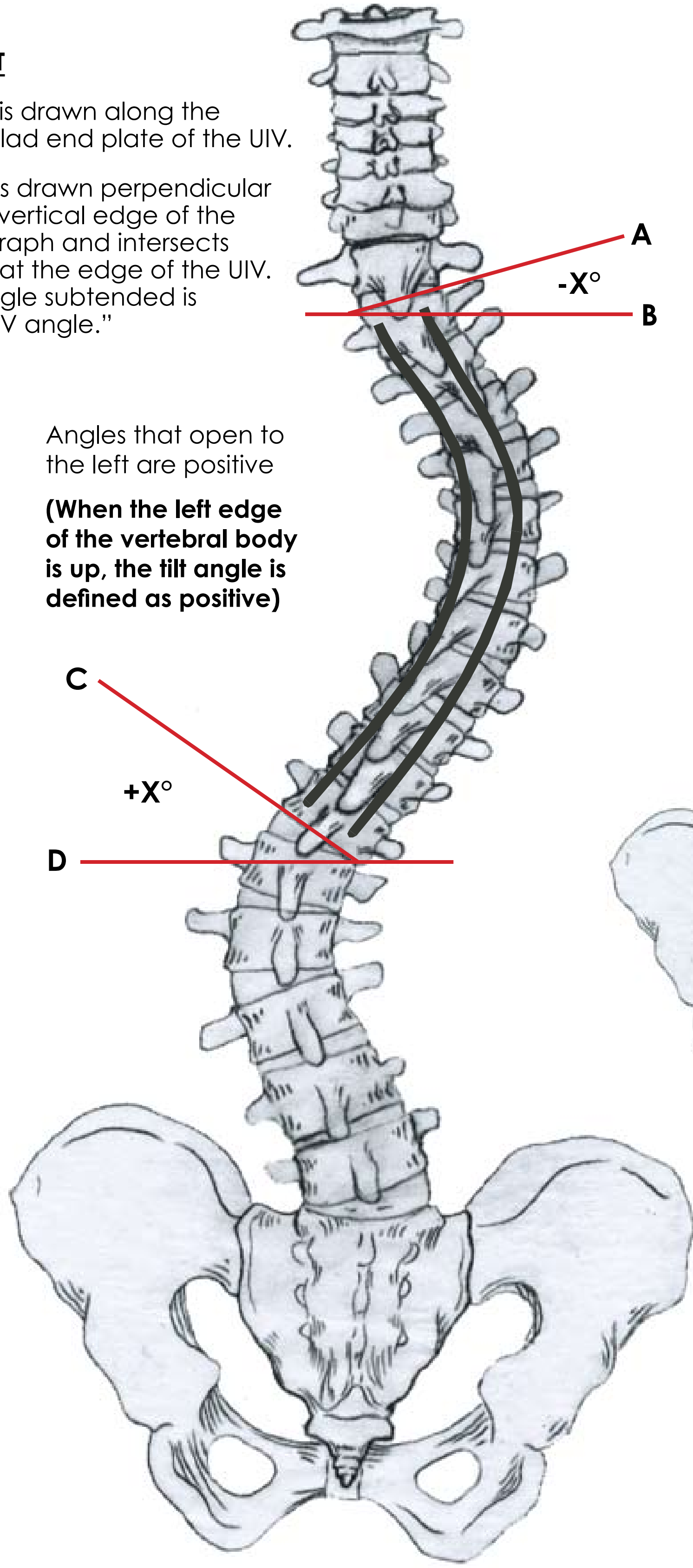
The CSVL depicts the coronal position of the spine in relation to the pelvis. The CSVL is a vertical line drawn parallel to the radiograph edge and may not be perpendicular to the sacral end plate (line $\overline{ab}$). This non-perpendicular alignment may occur when sacral or pelvic obliquity exists.

LIV and UIV Tilt Angles
Lowest Instrumented Vertebra (LIV) Tilt to the Horizontal and Upper Instrumented Vertebra (UIV) Tilt to the Horizontal

UIV TILT

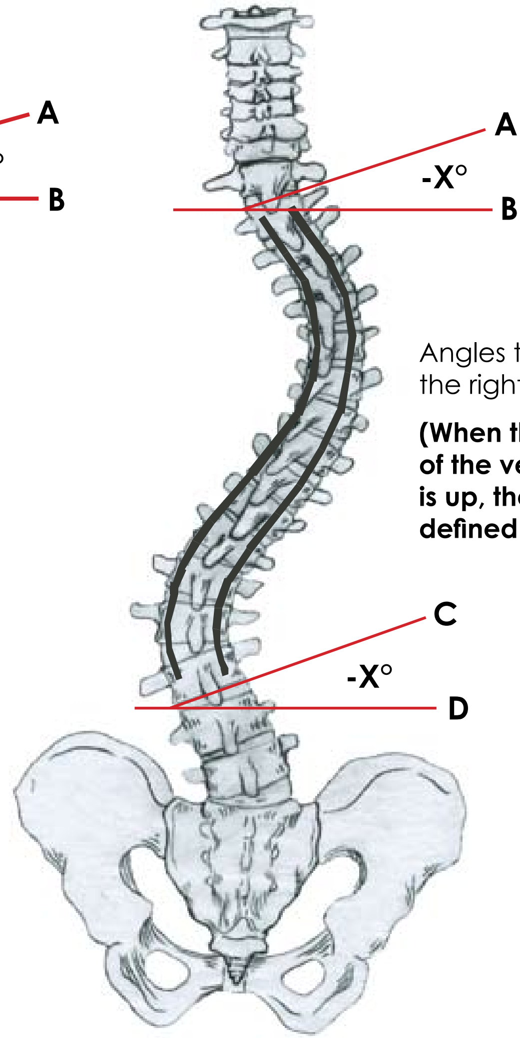
Line A is drawn along the cephalad end plate of the UIV.

Line B is drawn perpendicular to the vertical edge of the radiograph and intersects ***Line A*** at the edge of the UIV. The angle subtended is the "UIV angle."



Angles that open to the left are positive

(When the left edge of the vertebral body is up, the tilt angle is defined as positive)



Angles that open to the right are negative

(When the right edge of the vertebral body is up, the tilt angle is defined as negative)

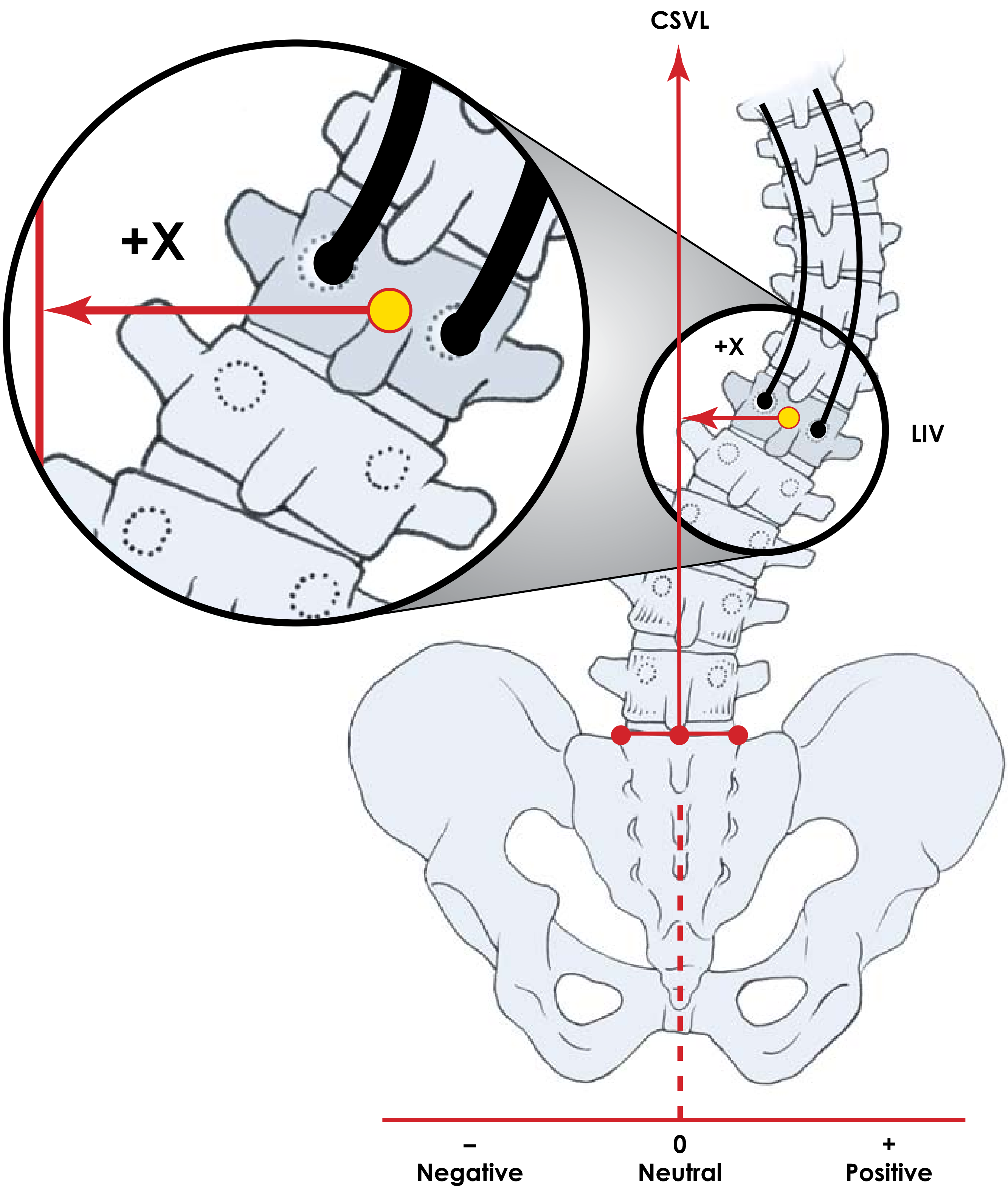
LIV TILT

Line C is drawn along the caudal end plate of the LIV.

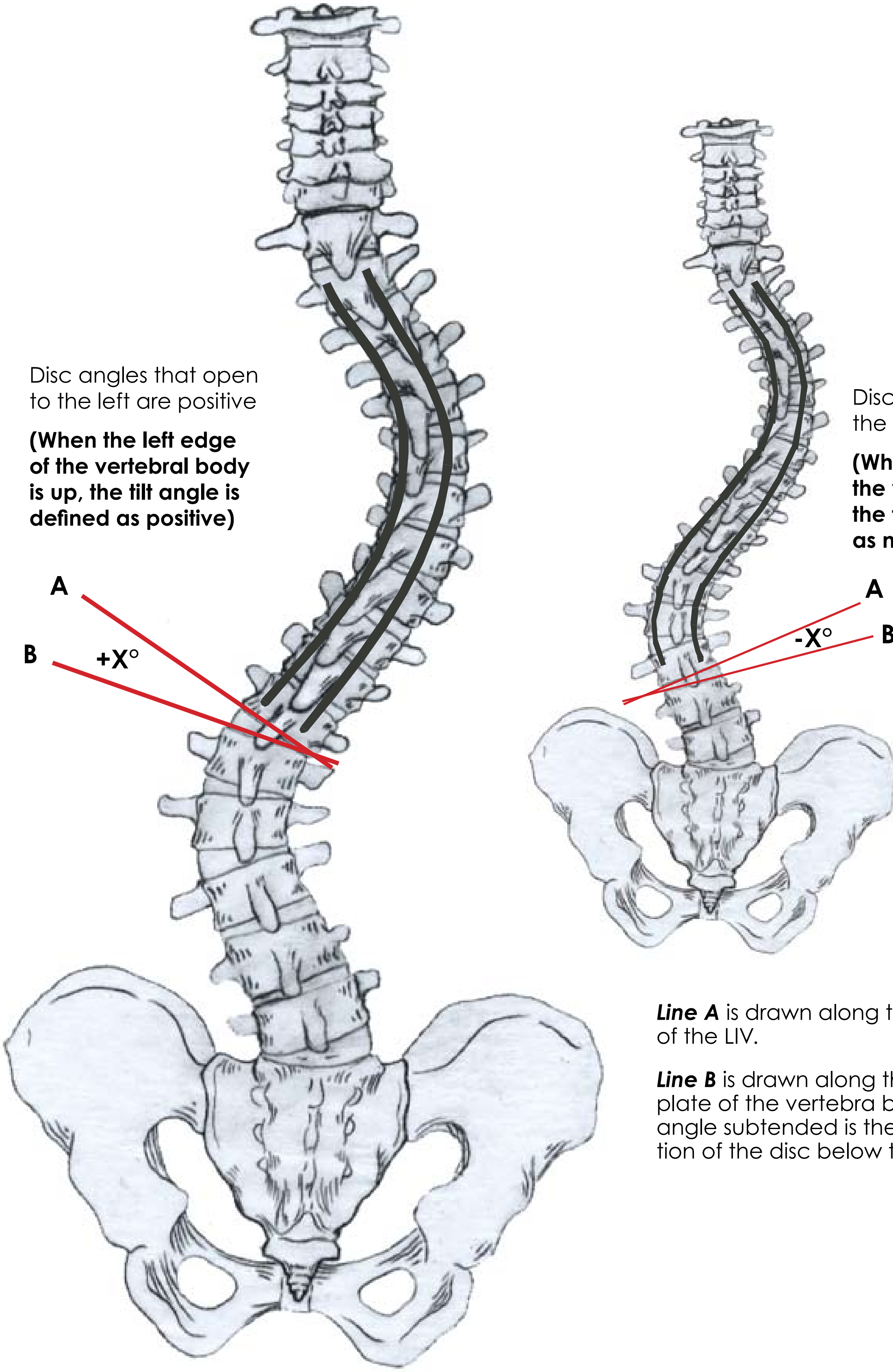
Line D is drawn perpendicular to the vertical edge of the radiograph and intersects ***Line C*** at the edge of the LIV. The angle subtended is the "LIV angle."

Coronal Position of LIV

The position of the lowest instrumented vertebra (LIV) is the measured horizontal distance in millimeters from the centroid of the vertebral body to the CSVL. Measurements to the right of the CSVL are positive, and measurements to the left are negative.



Coronal Angulation of Disc Below LIV

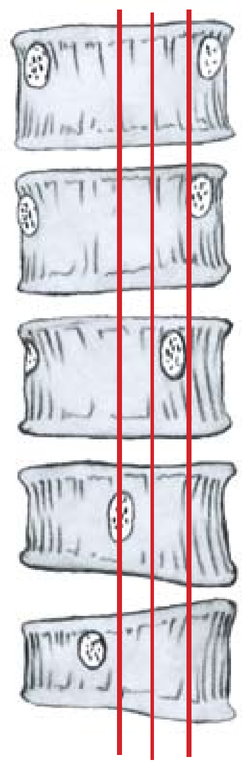


Line A is drawn along the caudal end plate of the LIV.

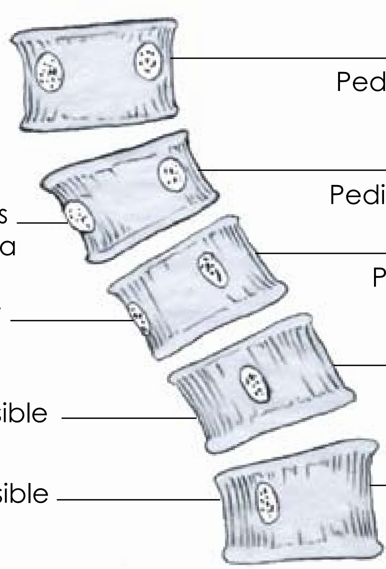
Line B is drawn along the cephalad end plate of the vertebra below the LIV. The angle subtended is the "coronal angulation of the disc below the LIV."

Nash-Moe Rotation/Apical Vertebral Rotation (Apex of All Curves)

Concave (left)	Right Thoracic Scoliosis	Convex (right)
Pedicles are symmetric		Neutral (0)
Pedicle is at the edge of the vertebral body		Grade I
Pedicle is disappearing		Grade II
Pedicle has disappeared		Grade III
		Grade IV



Left (concave) | **Right (convex)**



No rotation (0)
Pedicles in symmetric position

Grade I rotation
Pedicle slightly toward midline

Pedicle overlaps edge of vertebra

Grade II rotation
Pedicle 2/3 toward midline

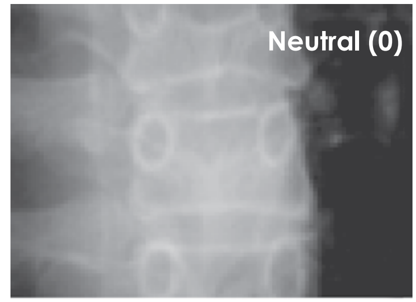
Pedicle is barely visible

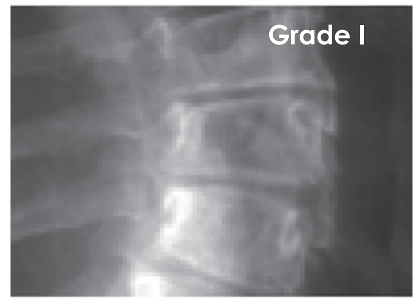
Grade III rotation
Pedicle is in midline

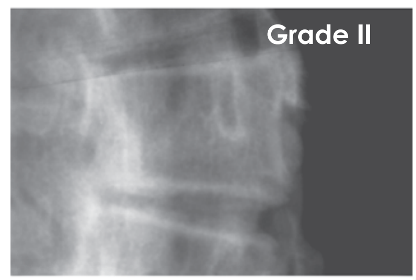
Pedicle is not visible

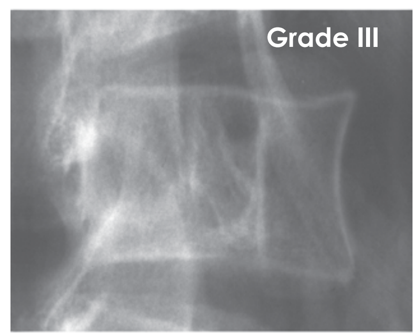
Grade IV rotation
Pedicle beyond midline

Pedicle is not visible









Thoracic Sagittal Alignment: Kyphosis

Thoracic kyphosis is measured from the upper (cephalad) end plate of T2 to the lower (caudal) end plate of T12 using the Cobb method (see Figure 1).

Mid/Lower thoracic kyphosis is measured from the upper (cephalad) end plate of T5 to the lower (caudal) end plate of T12 using the Cobb method (see Figure 1). The normal range is approximately 10 - 40° of kyphosis.

Proximal thoracic kyphosis is measured from the upper (cephalad) end plate of T2 to the lower (caudal) end plate of T5 using the Cobb method (see Figure 2).

By convention, kyphosis is a positive (+) and lordosis is a negative (-) value with the patient facing to the viewer's right.

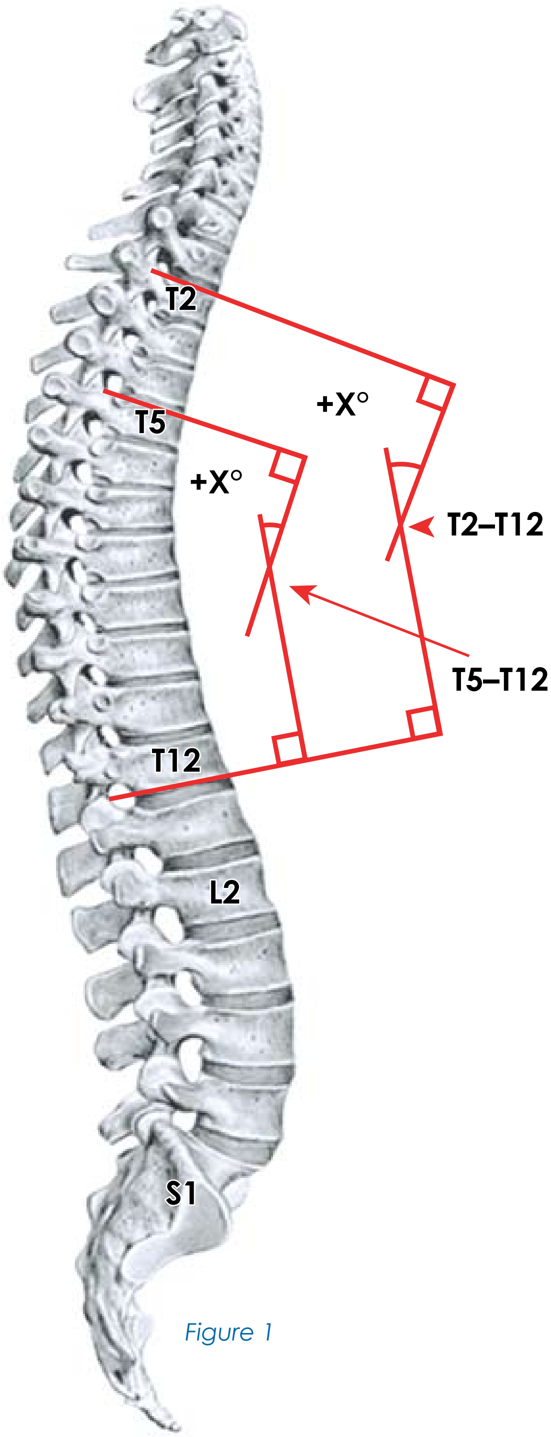


Figure 1

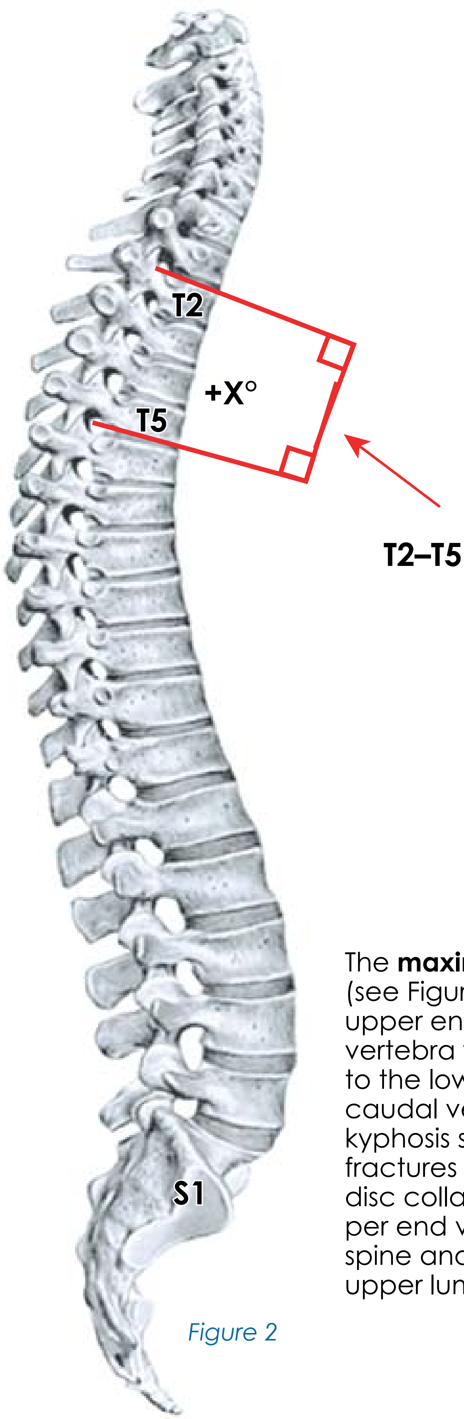


Figure 2

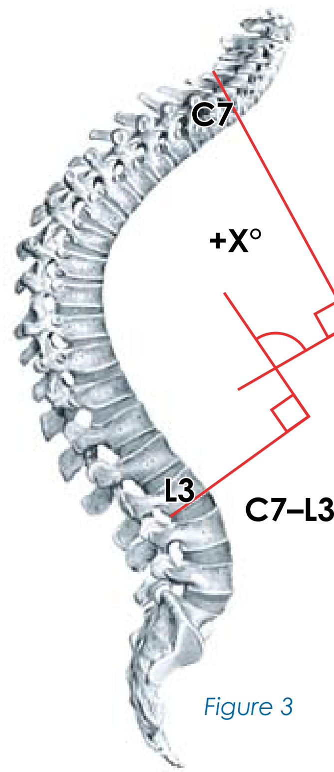


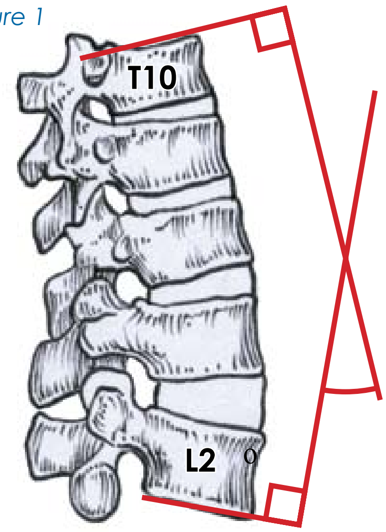
Figure 3

The **maximum measured kyphosis** (see Figure 3) is measured from the upper end plate of the most cephalad vertebra within the kyphotic curve to the lower end plate of the most caudal vertebra. In patients with senile kyphosis secondary to compression fractures or multilevel degenerative disc collapse, this may include an upper end vertebra in the lower cervical spine and a lower end vertebra in the upper lumbar spine.

Thoracolumbar and Lumbar Sagittal Alignment

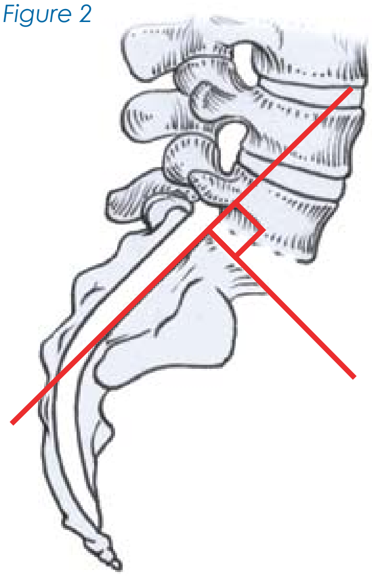
Thoracolumbar sagittal alignment is measured from the upper (cephalad) end plate of T10 to the lower (caudal) end plate of L2 using the Cobb method. By convention kyphosis is a positive angle and lordosis is a negative angle, with the patient facing to the viewer's right side (see Figure 1).

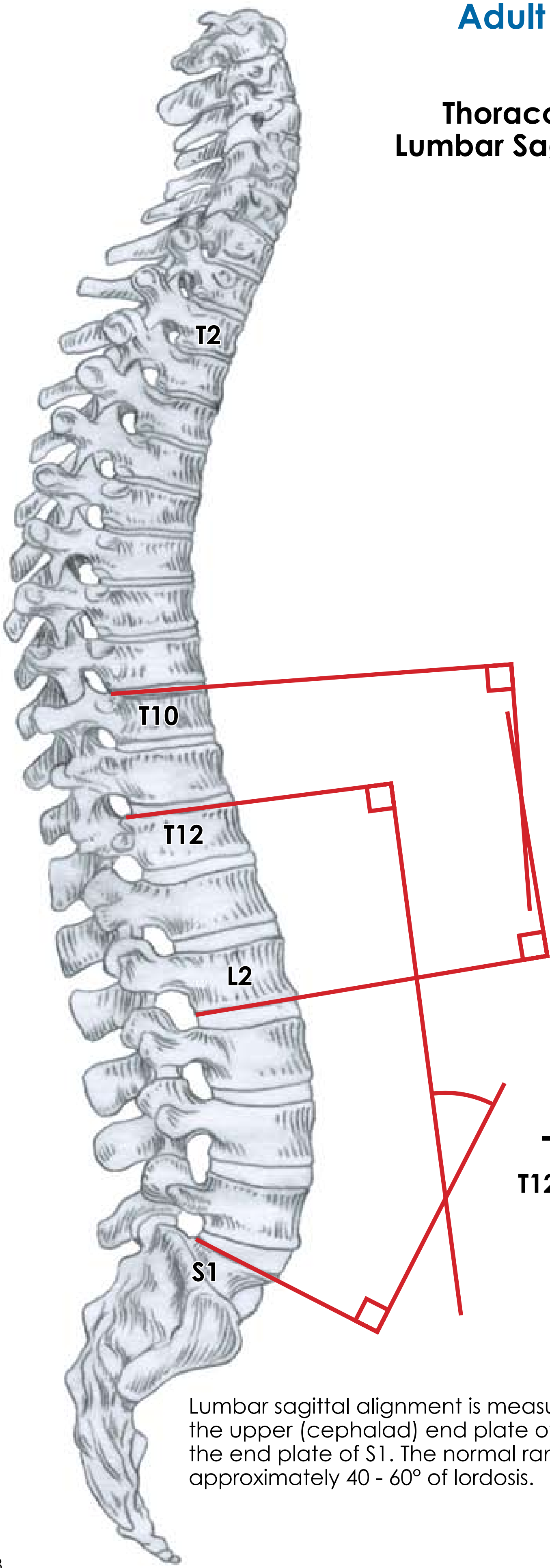
Figure 1



Lumbar sagittal alignment is measured from the cephalad end plate of T12 to the end plate of S1. In the event that the S1 end plate is difficult to identify, an alternative technique for drawing the sacral end plate line is to construct a perpendicular line off the posterior vertebral body line of the sacrum shown in Figure 2.

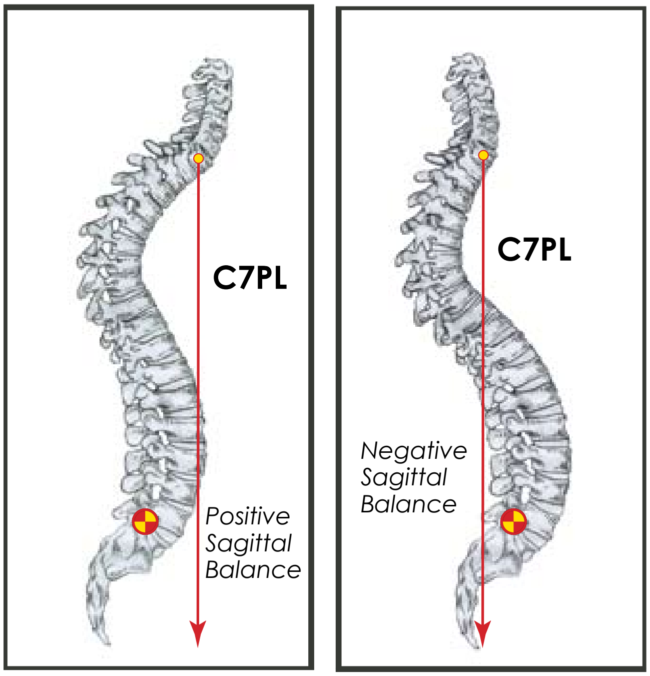
Figure 2



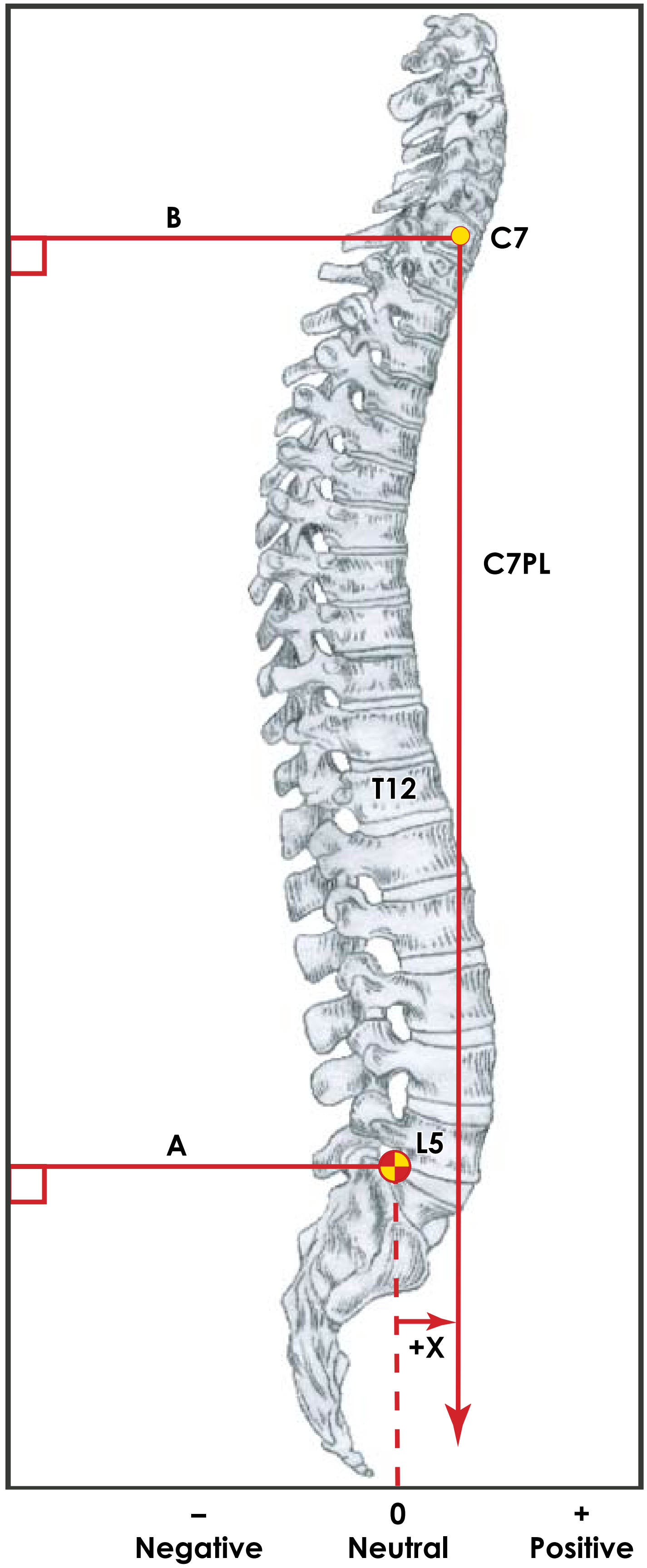


Lumbar sagittal alignment is measured from the upper (cephalad) end plate of T12 to the end plate of S1. The normal range is approximately 40 - 60° of lordosis.

Overall Sagittal Balance



Lateral C7 to Sacrum
(Sagittal Balance = B - A)



Line A is drawn from the posterior-superior corner of S1 ( ) and is perpendicular to the vertical edge of the radiograph. Its length is measured in millimeters from the lefthand edge of the radiograph.

Line B is drawn from the center of C7 and is perpendicular to the vertical edge of the radiograph. Its length is measured in millimeters from the lefthand edge of the radiograph.

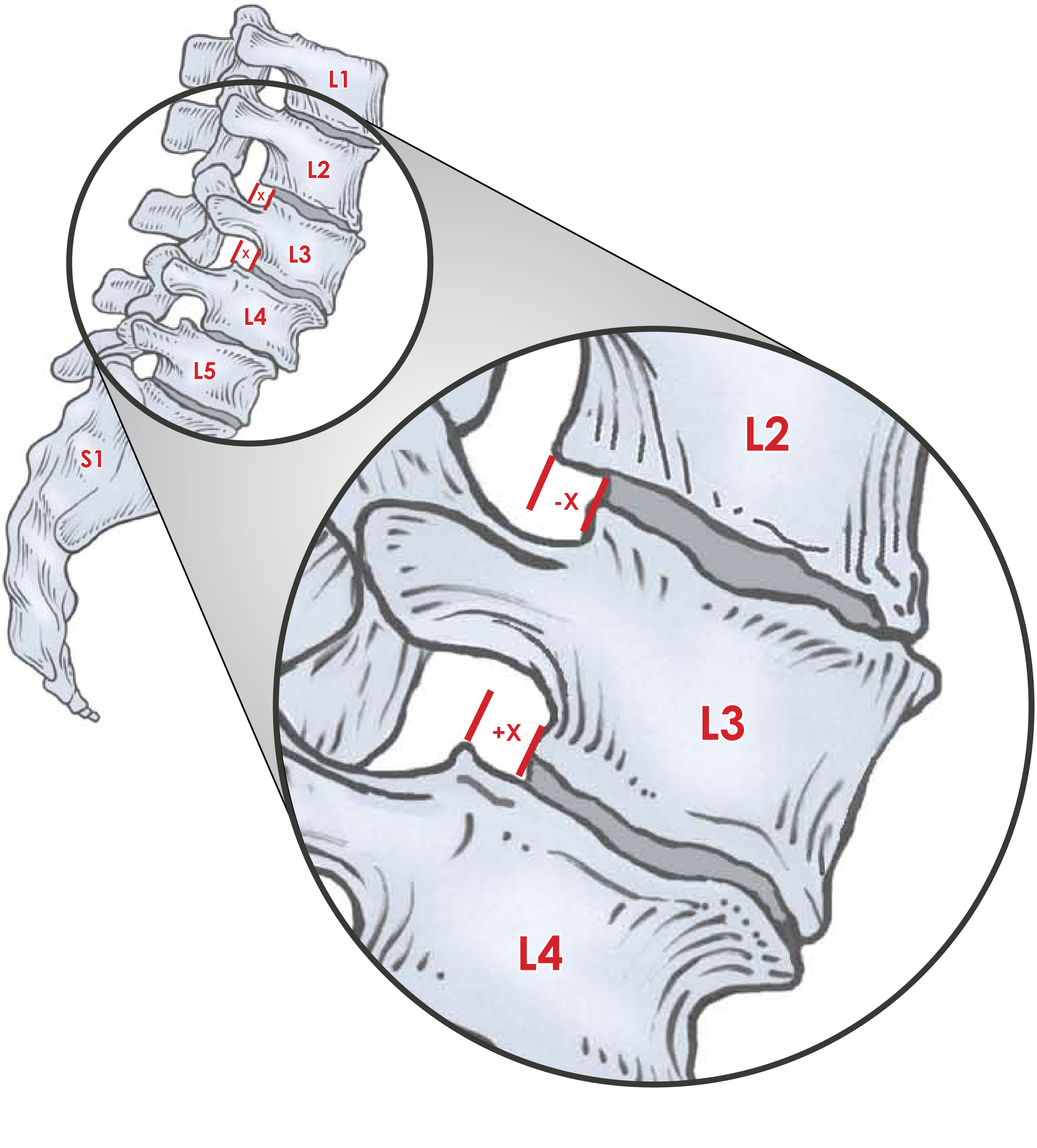
Neutral Balance: **B = A**

Negative Balance: **B < A**

Positive Balance: **B > A**

Sagittal Subluxation (Spondylolisthesis and Retrolisthesis)

Sagittal plane subluxations are often identified in degenerative adult scoliosis. These may be spondylolisthesis (anterolisthesis), as identified in the figure below, between L3 and L4 or a retrolisthesis, as shown between L2 and L3. These subluxations are measured in millimeters from the posterior inferior corner of the cephalad vertebra to the posterior superior corner of the caudal vertebra, as shown in the figure below. Anterolisthesis is recorded as a positive number and retrolisthesis is recorded as a negative number.



Degenerative Scoliosis and Rotatory Subluxation

Figure 1 Degenerative Scoliosis

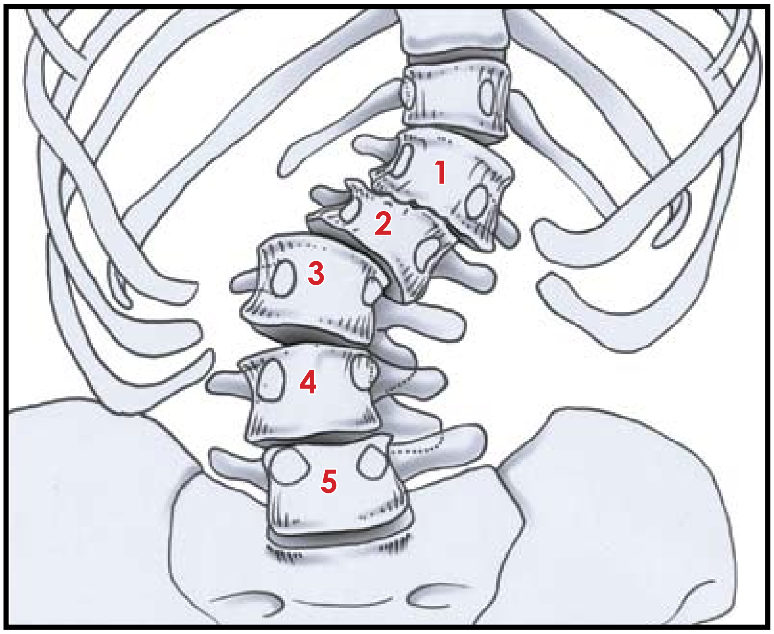


Figure 2 Lateral Olisthesis

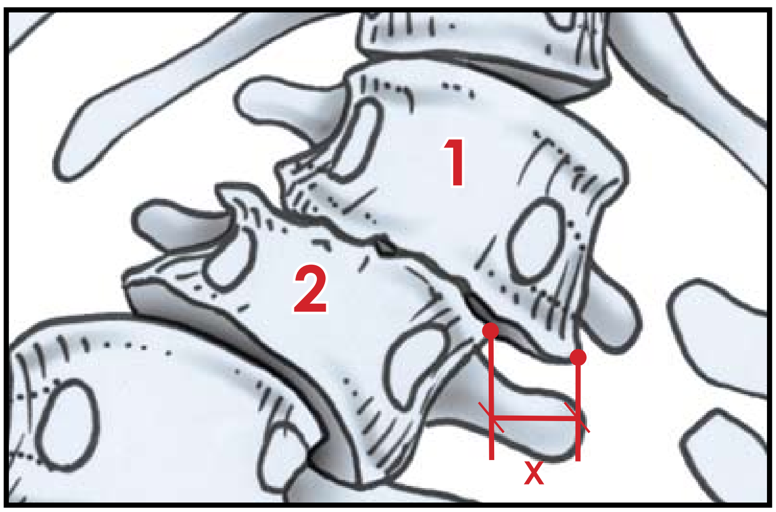
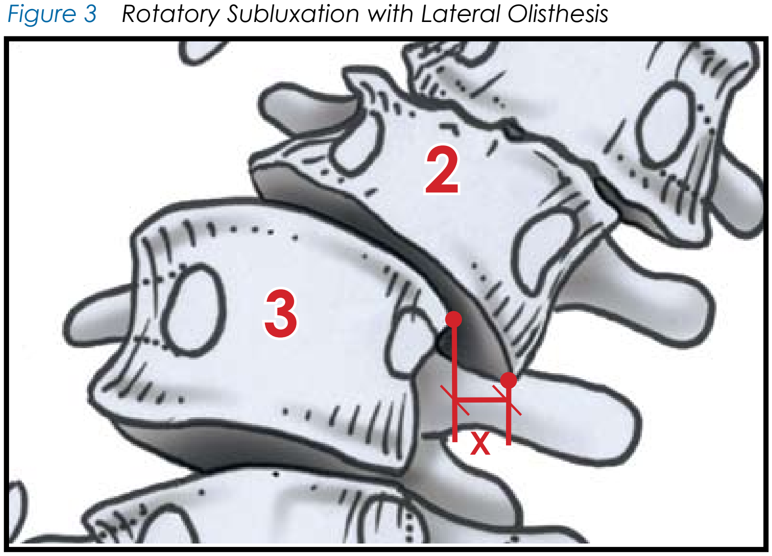


Figure 3 Rotatory Subluxation with Lateral Olisthesis



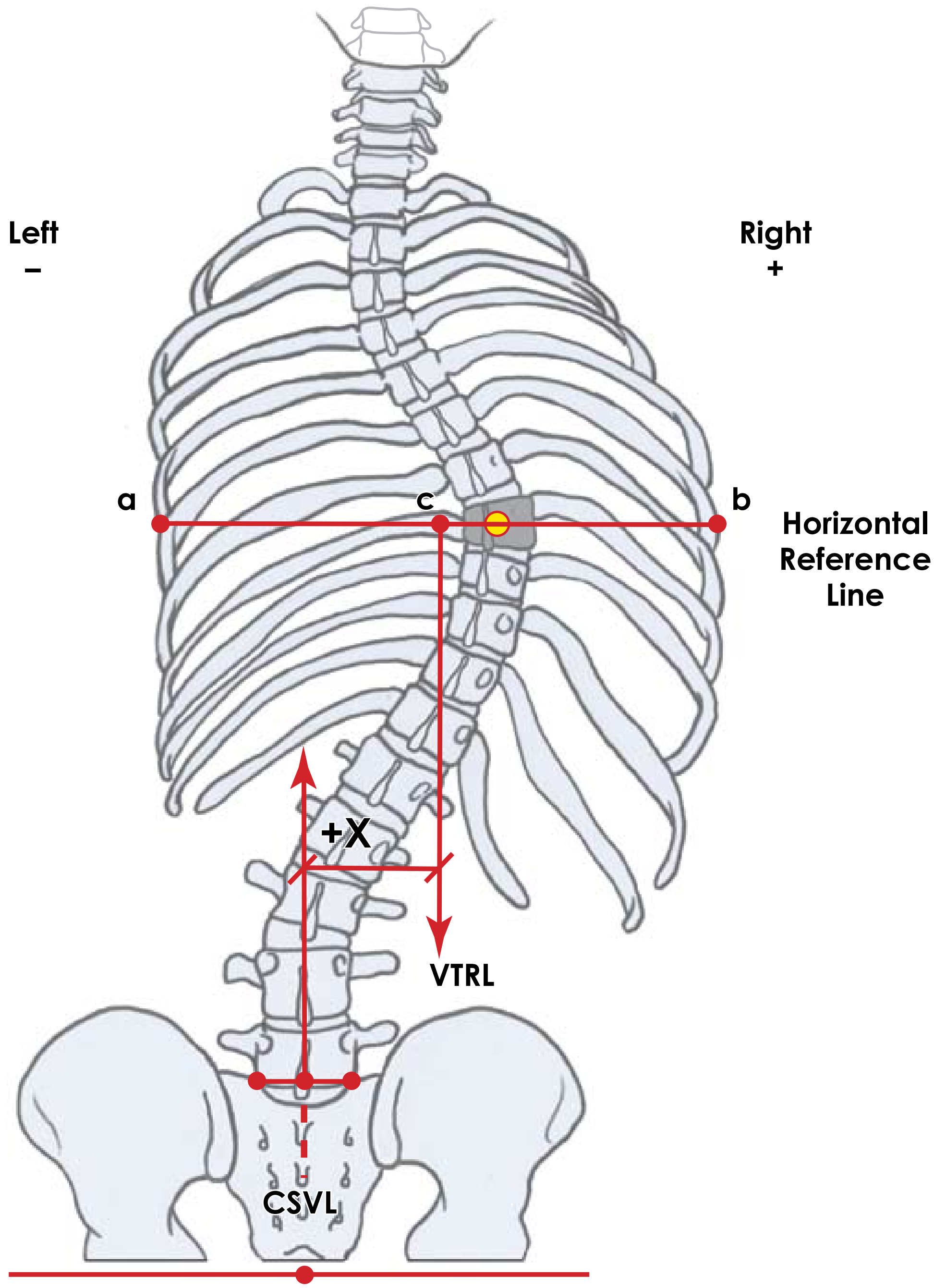
Coronal subluxations are often identified in degenerative scoliosis (Figure 1). These lateral translations may either be lateral olistheses (Figure 2) or rotatory subluxations (Figure 3). The degree of subluxation is measured in millimeters as shown in the illustration (see Figures 2 and 3). To measure the subluxation, a vertical line will be erected from the superior corner of the caudal vertebra and the inferior corner of the cephalad vertebra. The horizontal distance between these two vertical lines will define the degree of subluxation in millimeters (see Figures 2 and 3). Alternatively, if the osteophytes are too large and irregular to identify the “corner” of the two adjacent vertebra, the waist of the adjacent vertebrae can be used as reference points using the technique described above.

All olistheses (spondylo, retro, rotatory, or lateral) are described relative to the upper vertebra in relation to the lower vertebra. Therefore, the olisthesis of L1 to L2 is measured on the right side and L4 to L5 is measured on the left (Figure 1).

In lateral olisthesis, the adjacent vertebrae are relatively neutral in relation to each other.

In rotatory subluxation, the cephalad vertebra is rotated. In this case it is a Nash-Moe Grade I.

Thoracic Trunk Shift



Thoracic trunk shift is measured on standing PA or AP scoliosis x-rays. This measurement is performed by first identifying the apical thoracic vertebra. Through the centroid, a horizontal reference line is drawn ($\overline{ab}$). Points (a) and (b) are marked at the intersection of the horizontal reference line and the rib cage on the left (a) and the right (b). The midpoint of line segment ab, point (c) is identified, and a perpendicular line is dropped as a reference line. Trunk shift is calculated by measuring the linear distance in millimeters between the vertical trunk reference line (VTRL) and the CSVL. A trunk shift to the right of the CSVL is a positive value, and to the left of the CSVL a negative value.

Adapted from: Floman Y, Penny JN, Micheli LJ, Riseborough EJ, Hall JE. Osteotomy of the fusion mass in scoliosis. *J Bone Joint Surg Am*. 1982 Dec;64(9):1307-16.

Richards BS. Lumbar curve response in type II idiopathic scoliosis after posterior instrumentation of the thoracic curve. *Spine*. 1992;17(85):5282-6.

Pelvic Obliquity/Leg Length Discrepancy

Figure 1

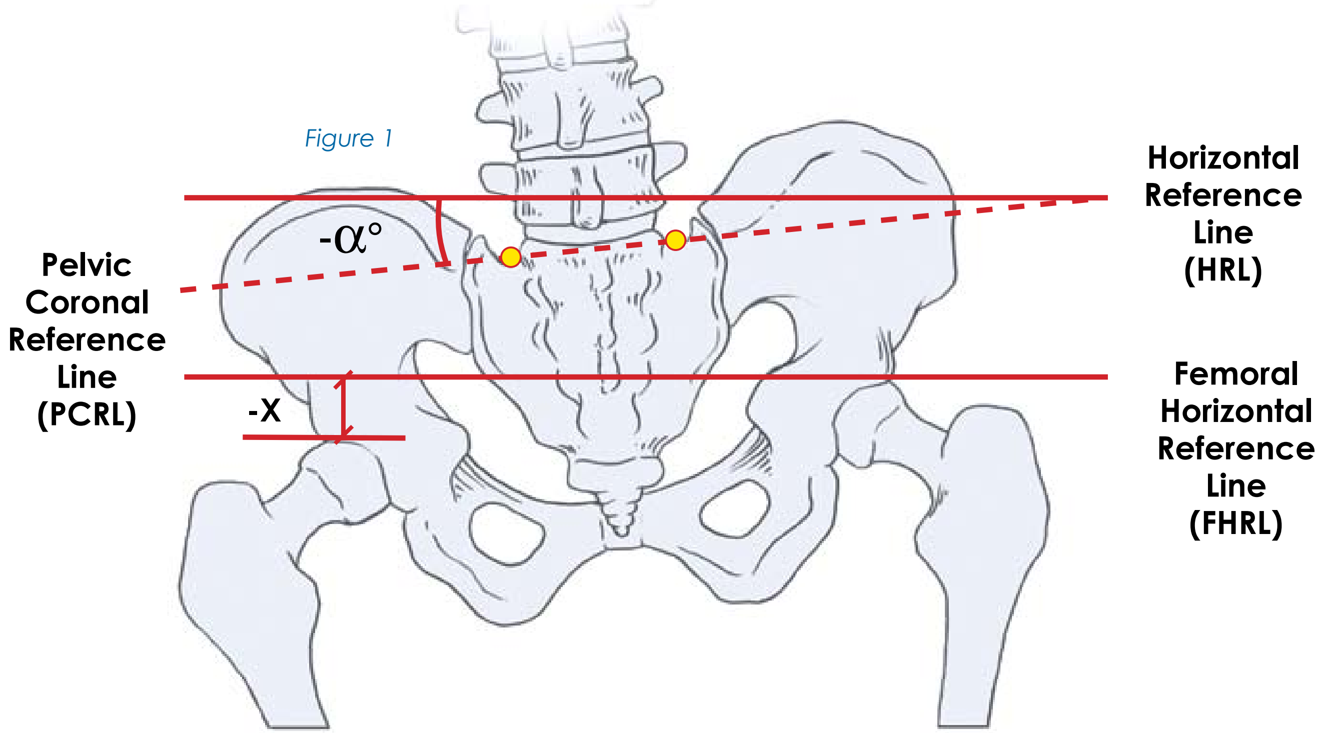


Figure 2

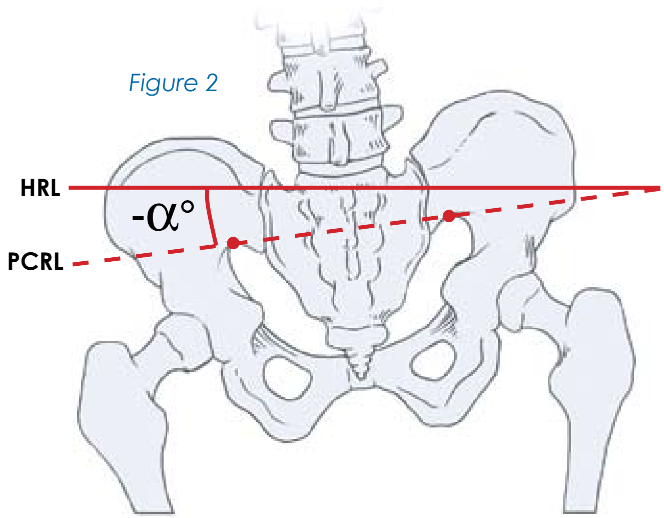
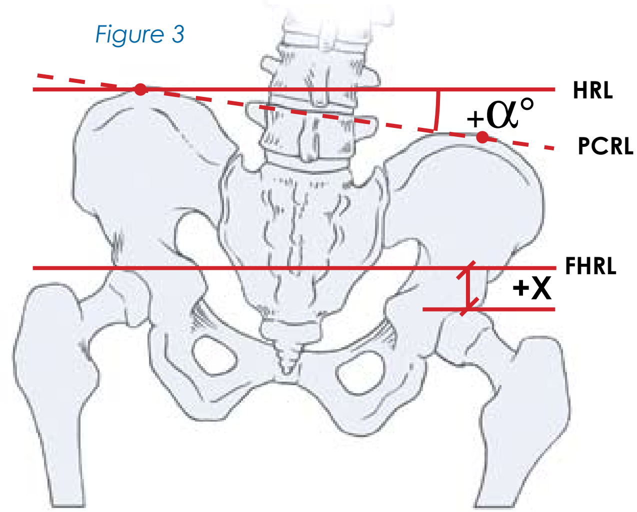


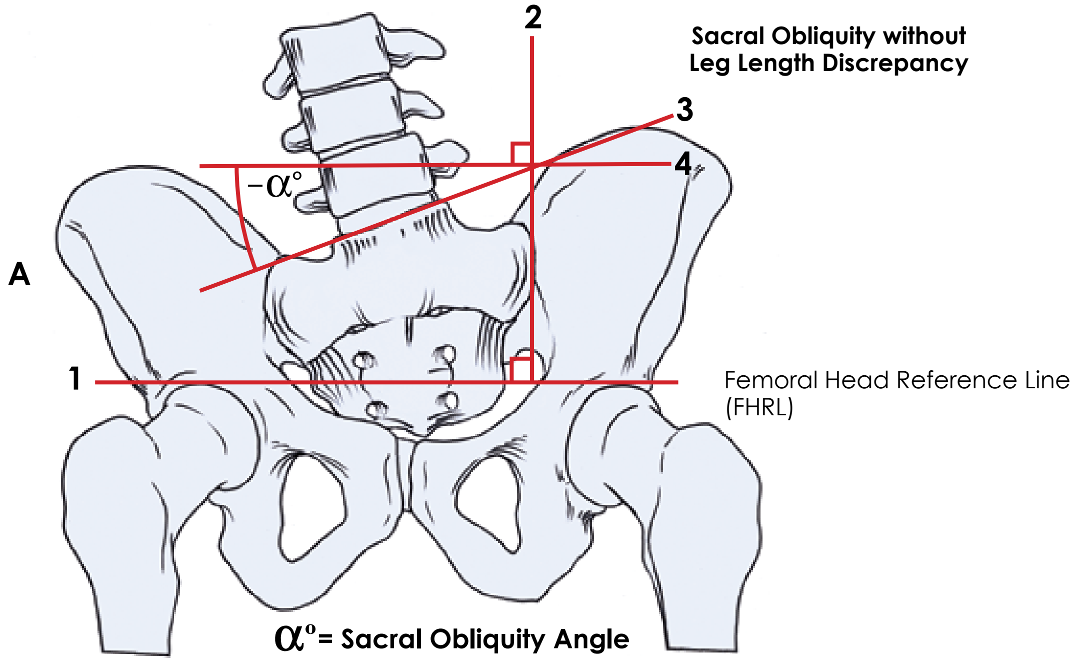
Figure 3

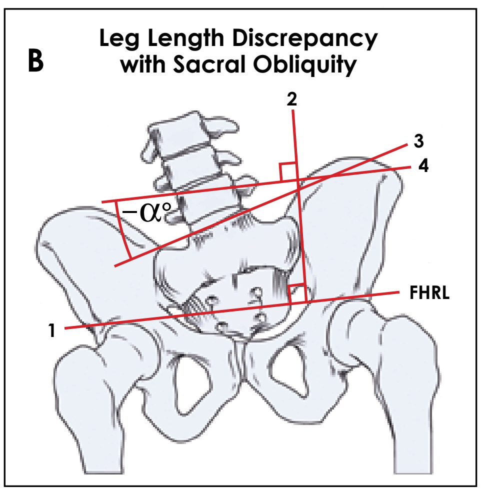


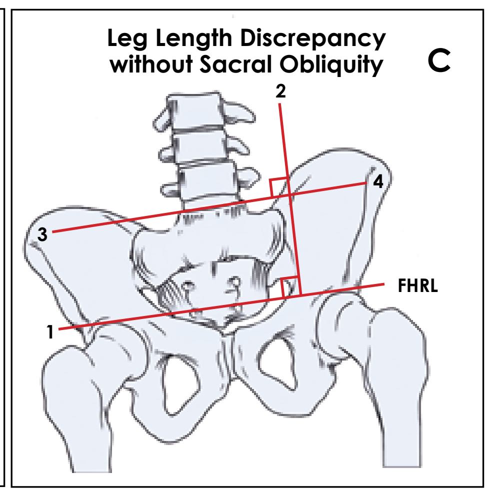
Because of the difficulty often encountered in identifying the anatomic landmarks of the pelvis, several options are available for defining the coronal angulation of the pelvis. The tips of the sacral ala can be used to create the pelvic coronal reference line (PCRL) for the pelvic orientation in the coronal plane. Alternative techniques for identifying the tilt of the sacrum/pelvis are identified in Figures 1, 2, and 3. If the sulcus of the S1 ala is clearly visible bilaterally, it may be used to create the PCRL (see Figure 1 – yellow dots). The tilt will be the angle subtended by the horizontal reference line (HRL) and the PCRL. Additionally, the top of the ilium may be used to create the PCRL if no sulcus is visible (Figure 3).

Leg length discrepancy will be identified on PA standing radiographs without blocks under the patient's feet and with the knees extended. A femoral horizontal reference line (FHRL) will be created by making a horizontal line which is tangent to the top of the highest femoral head. The difference between the height of this line and the height of the lower femoral head will be defined as the leg length discrepancy. If the left hip is up the value is positive (+). If the right hip is up then the value will be negative (-).

Sacral Obliquity

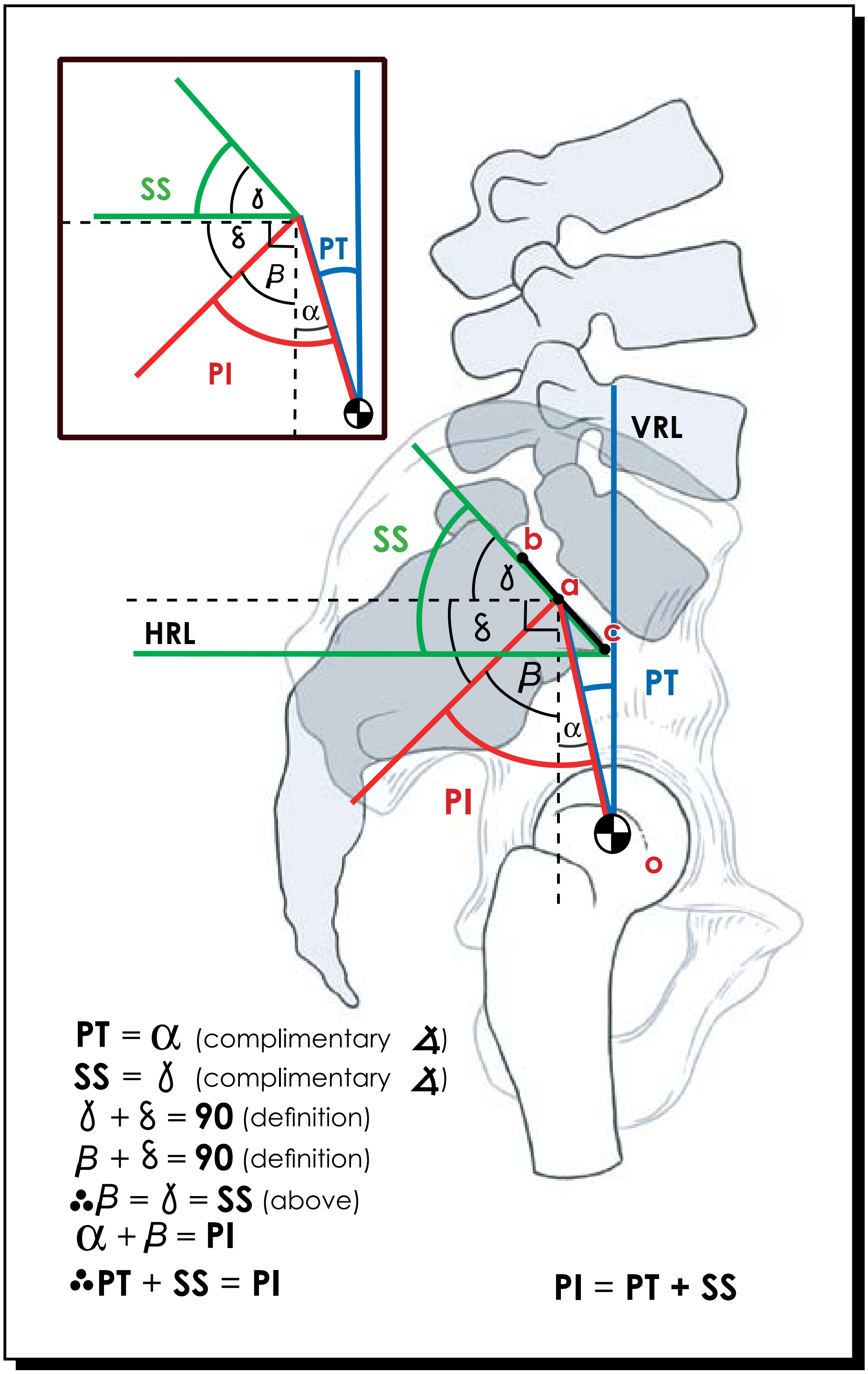






Sacral obliquity is defined as a tilt in the sacral end plate secondary to an intrinsic sacral deformity. This may produce an oblique take off for the lumbar spine. Coronal plane tilting of the sacral end plate may result from 1) pelvic obliquity, 2) leg length discrepancy, 3) intrinsic sacral deformity (sacral obliquity), or a combination of these three. Either sacral or pelvic obliquity may contribute to a TL/L scoliosis. To differentiate between sacral obliquity, pelvic obliquity, and leg length discrepancy, the relationships described in Figures A, B, and C are illustrated. Sacral obliquity $\alpha°$ (Figure A) is measured in relation to the femoral head reference line (FHRL). The technique for measuring sacral obliquity is detailed in Figure A. First, the FHRL is drawn (1). Then a perpendicular reference line is drawn (2). Third, a line is drawn along the coronal projection of the S1 end plate on a Ferguson AP of the sacrum (3). Finally, a line is drawn (4) at the intersection of the sacral end-plate line (3) and its intersection with line 2. Line 4 is parallel to the FHRL. The angle subtended between lines 3 and 4 is the sacral obliquity angle ($\alpha°$). The angle is positive if the left side of the sacrum is high and negative if the right side of the sacrum is high. If the leg lengths are equal, the FHRL is horizontal to the floor, and the sacral obliquity is identified as $\alpha°$ (Figure A). If the sacral end plate has an oblique orientation in the coronal plane and the FHRL is not horizontal to the floor (Figures B and C), the sacral obliquity may be secondary to both leg length discrepancy and intrinsic sacral obliquity (Figure B), or the apparent "sacral obliquity" may result from abnormal tilting of the pelvis due to a leg length discrepancy or iliac shape (Figure C).

Spondylolisthesis



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Spondylolisthesis

Pelvic Incidence

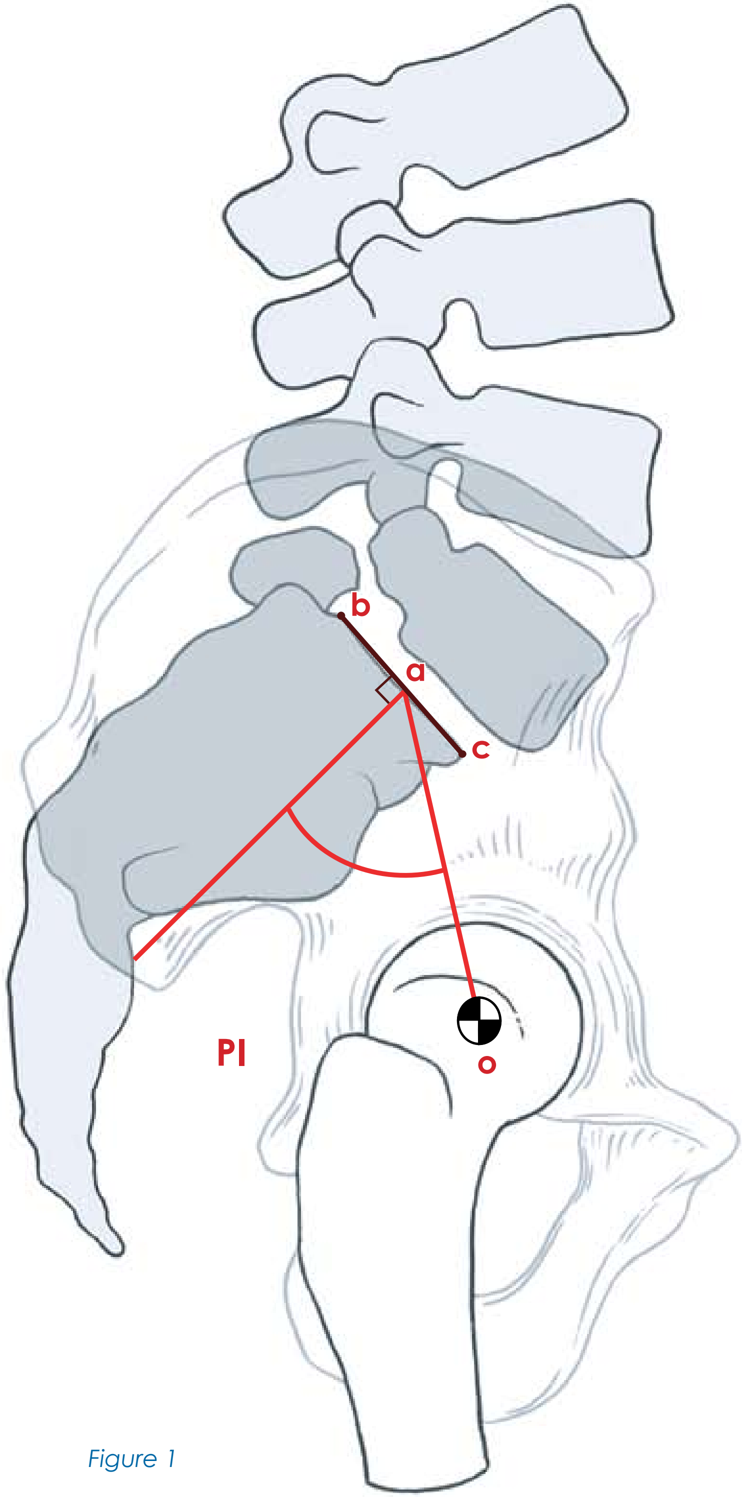


Figure 1

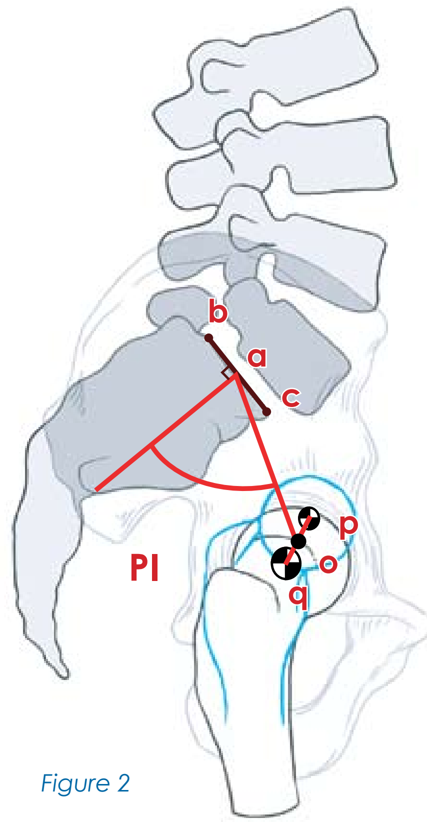


Figure 2

Pelvic Incidence (PI) is defined as an angle subtended by a line that is drawn from the center of the femoral head to the midpoint of the sacral end plate ($\overline{oa}$) and a line perpendicular to the center of the sacral end plate (a). The sacral end plate is defined by the line segment ($\overline{bc}$) constructed between the posterior superior corner of the sacrum and the anterior tip of the S1 end plate at the sacral promontory (see Figure 1).

When the femoral heads are not perfectly superimposed, the center of each femoral head is marked (crosshatched circles), and the line segment $\overline{qp}$ will connect the centers of the femoral heads. The line ($\overline{oa}$) will be drawn from the center of the line $\overline{qp}$ (o) to the center of the sacral end plate (a) (see Figure 2).

A complete loss of overlap between the femoral heads indicates an oblique view of the pelvis. Adequate sagittal radiographs of the pelvis should be obtained before making any of the proposed sagittal radiological measurements.

Legaye J, Duval-Beaupére G, Hecquet J, Marty C. Pelvic Incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J*. 1998;7:99-103.

Pelvic Tilt

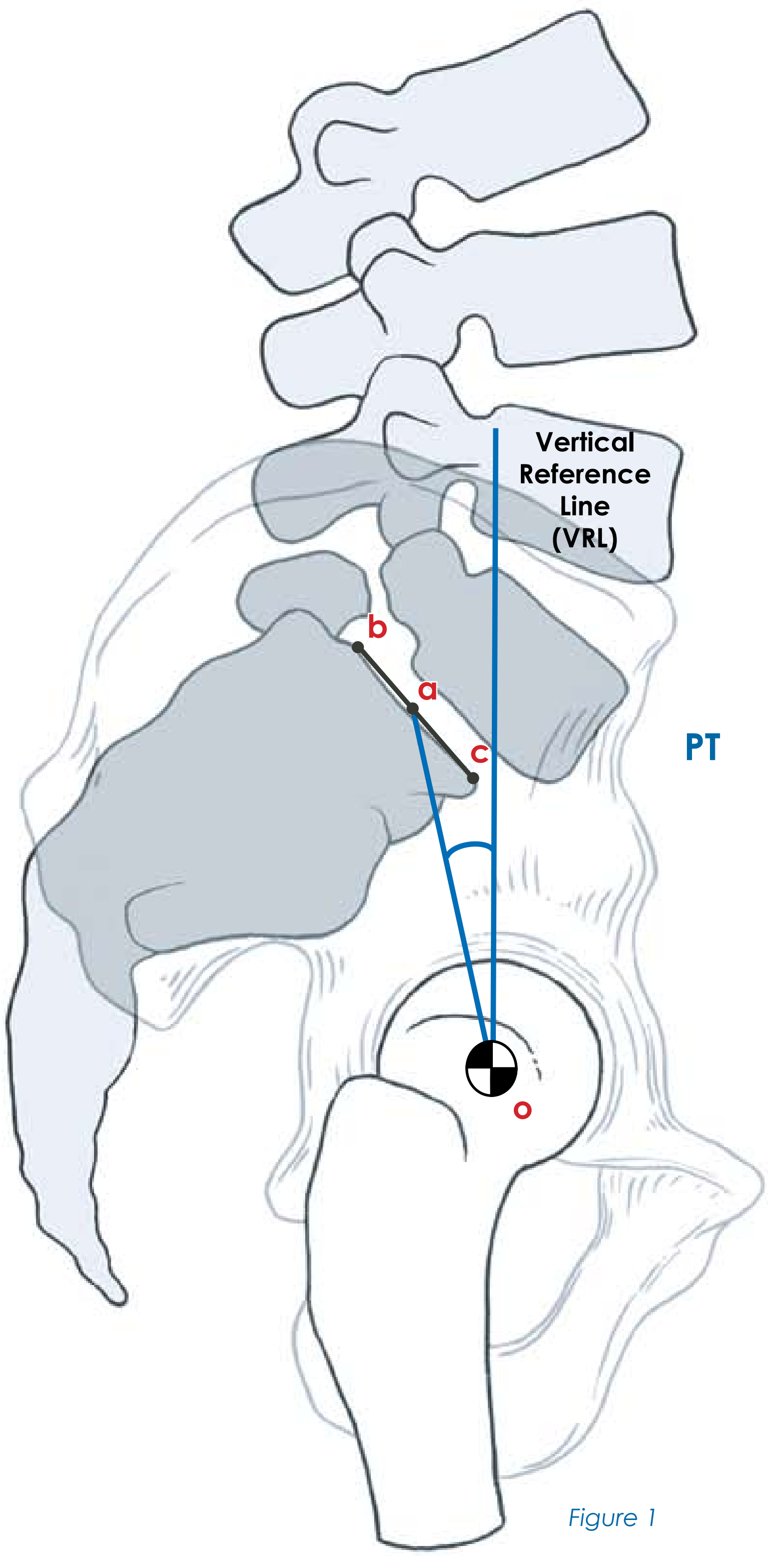


Figure 1

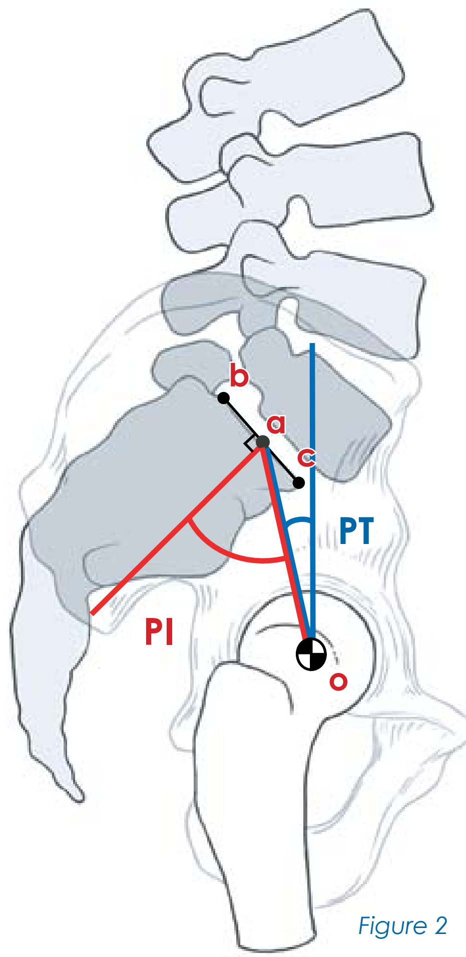


Figure 2

Pelvic Tilt (PT) is defined as the angle subtended by a vertical reference line (VRL) originating from the center of the femoral head (o) and the midpoint of the sacral end plate (a) (see Figure 1).

PT is influenced by PI since they share the line ($\overline{oa}$) and the sacral end plate as common reference lines (see Figure 2).

PT has a positive (+) value when line $\overline{oa}$ is posterior to the VRL and a negative (-) value when line $\overline{oa}$ is anterior to the VRL.

Sacral Slope

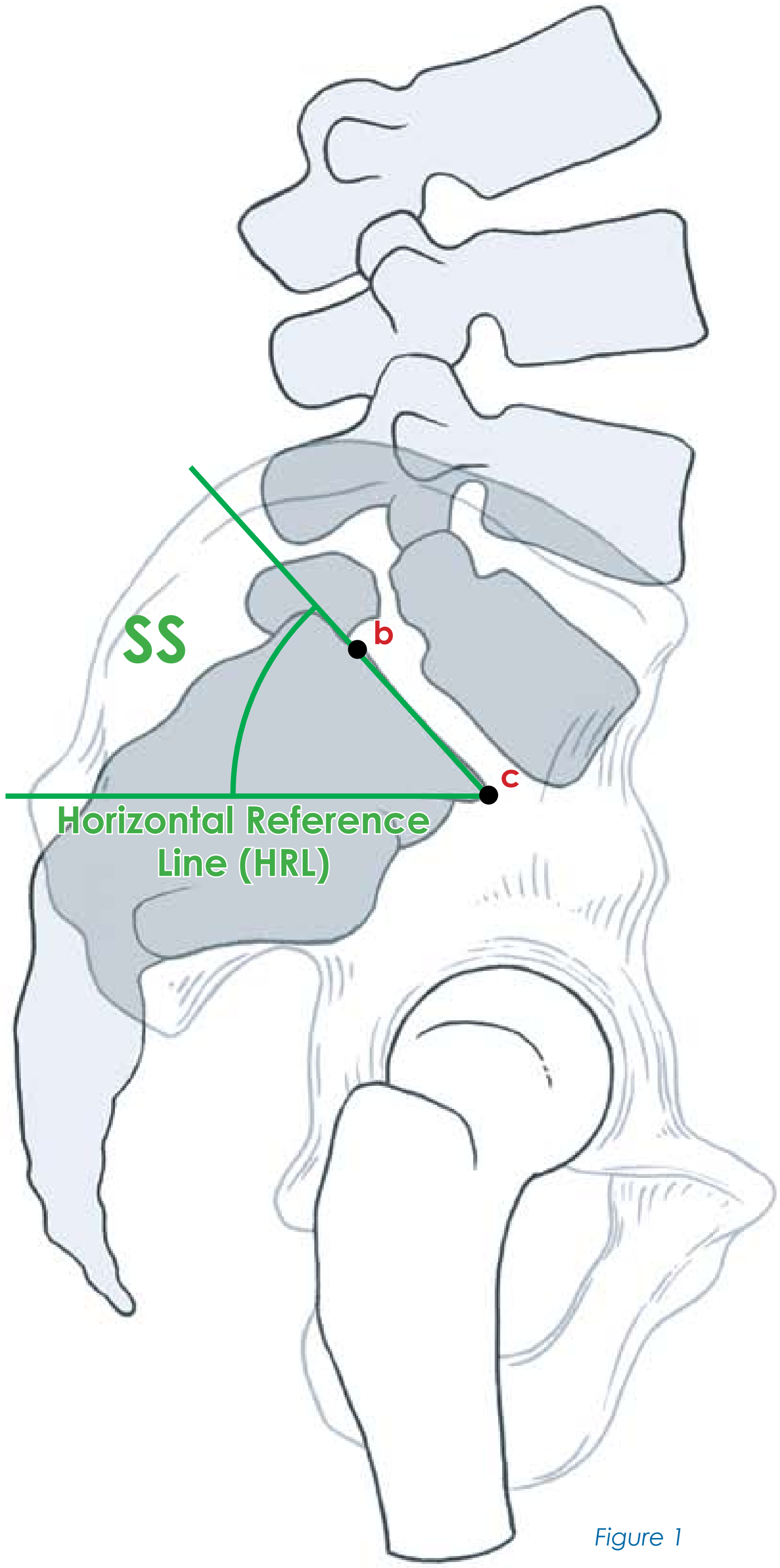


Figure 1

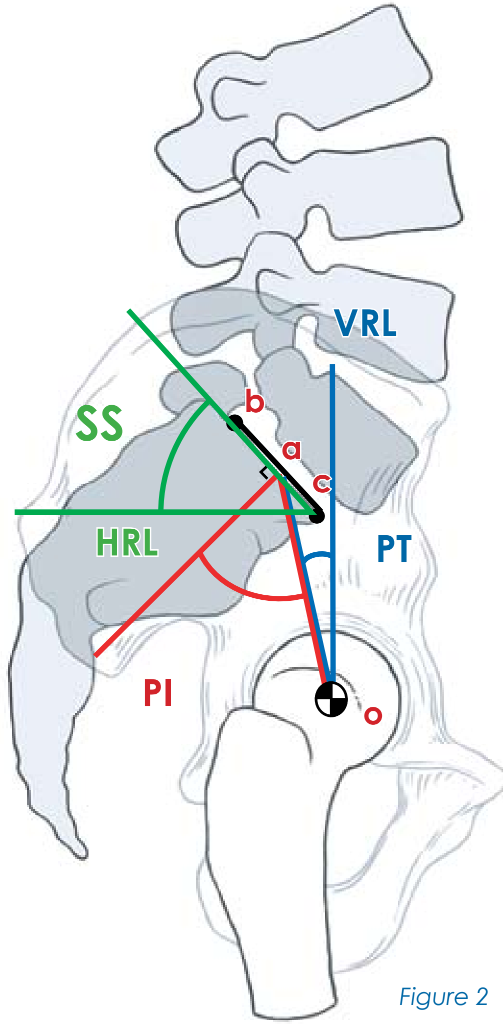


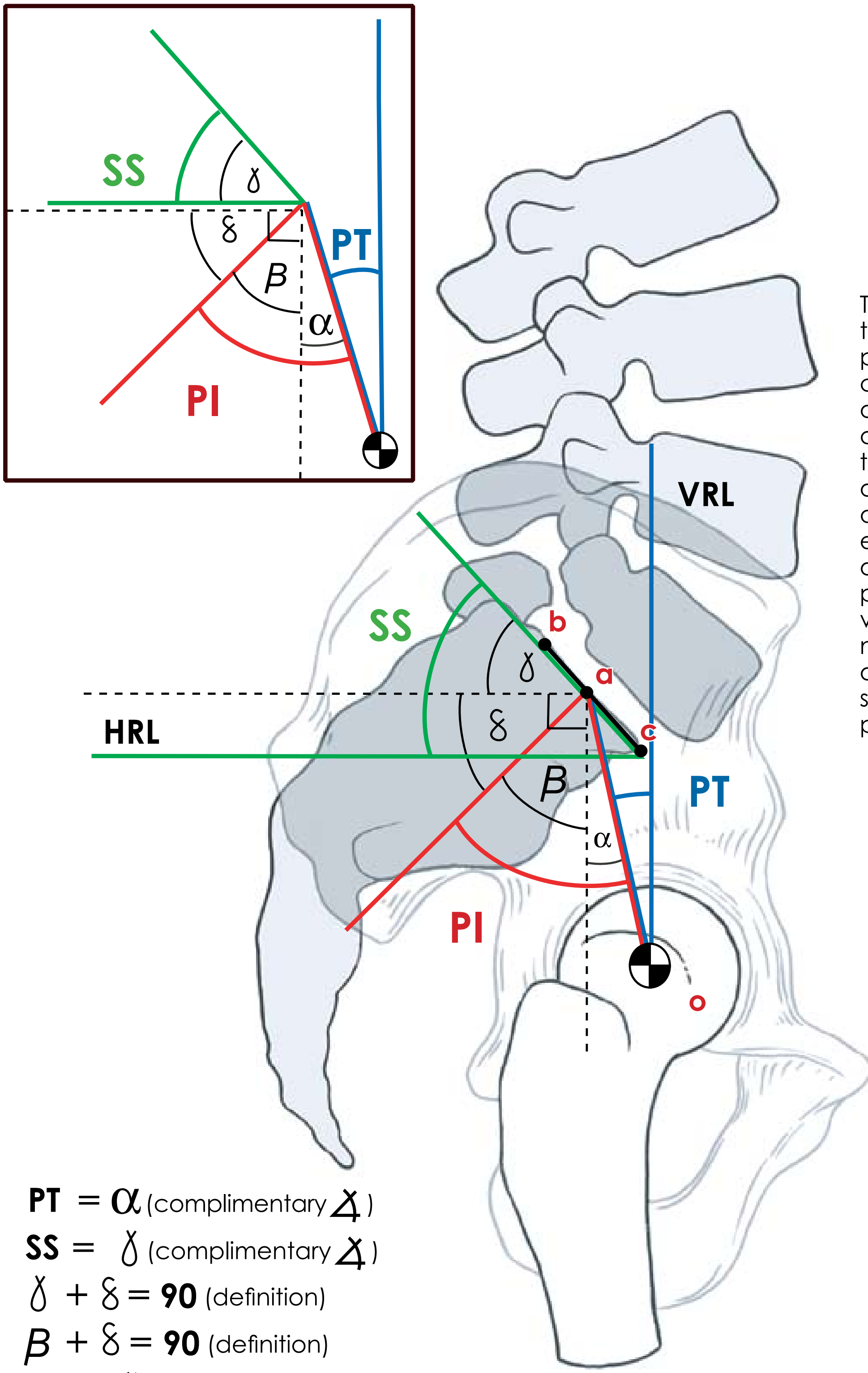
Figure 2

Sacral Slope (SS) is defined as the angle subtended by a horizontal reference line (HRL) and the sacral end-plate line ($\overline{bc}$) (see Figure 1).

Sacral Slope is related to PI and PT because it shares a common reference line ($\overline{bc}$) along the sacral end plate (see Figure 2).

It should be understood that PI is measured from static anatomic structures. PT and SS on the other hand are position dependent because they are dependent on the angular position of the sacrum/pelvis in relation to the femoral heads that changes with standing, sitting, and lying down. The relationship of PT and SS are also affected by lumbosacropelvic flexion and extension.

Geometric Proof: PI=PT+SS



The ***"Geometric Proof"*** demonstrates the relationship of pelvic incidence, pelvic tilt, and sacral slope, where a change in one parameter affects the other measurements and the overall alignment of the sacropelvic foundation. Depending on the shape and orientation of the sacropelvic foundation, the lumbosacral junction will experience a different combination of normal and shear forces. This may predispose some individuals to develop spondylolisthesis, lumbosacral nonunions after an attempted fusion of L5-S1, or traumatic spondylolisthesis of S1 after instrumentation to the proximal sacrum.

PT $= \alpha$ (complimentary ∡)

SS $= \gamma$ (complimentary ∡)

$\gamma + \delta =$ **90** (definition)

$\beta + \delta =$ **90** (definition)

$\therefore \beta = \gamma =$ **SS** (above)

$\alpha + \beta =$ **PI**

$\therefore$ **PT** + **SS** = **PI**

Pelvic Radius Angle

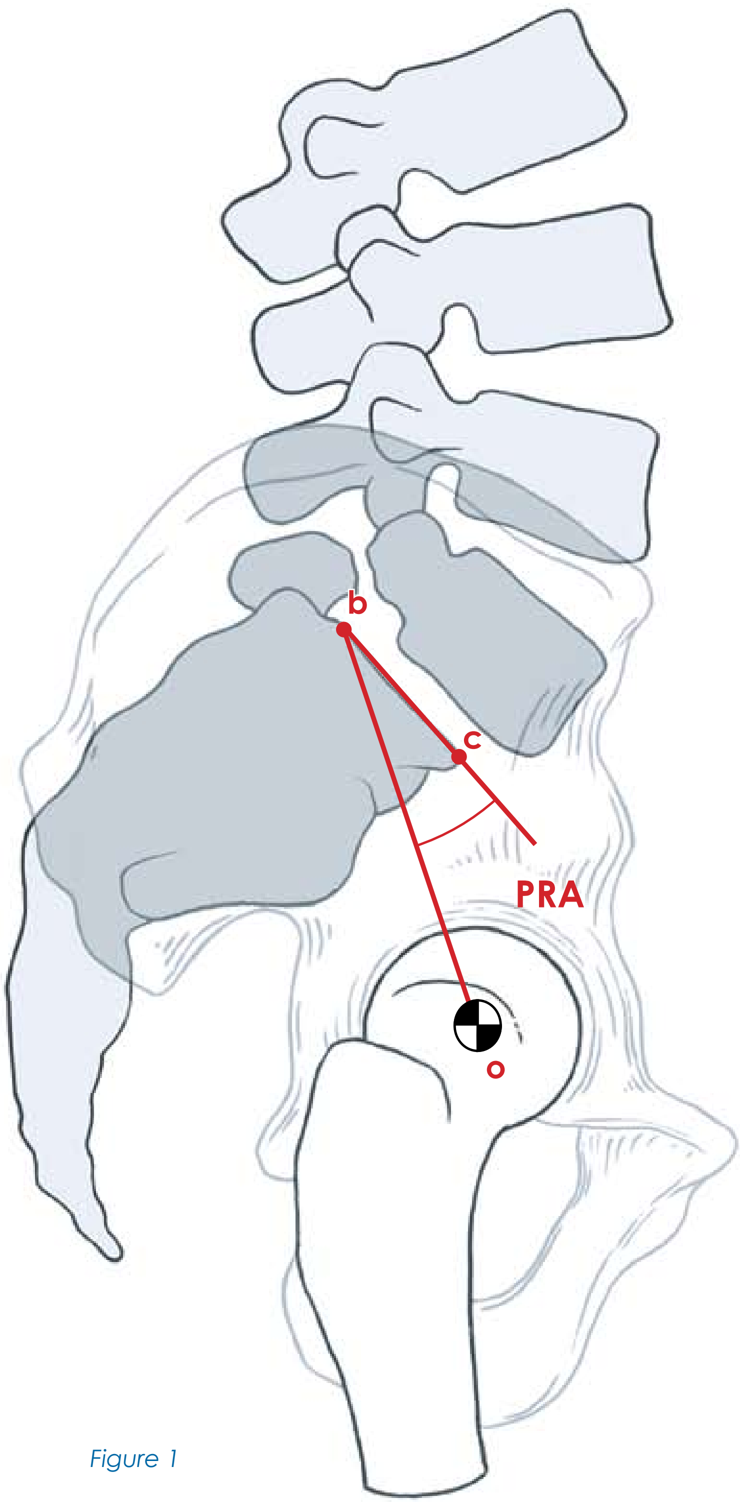


Figure 1

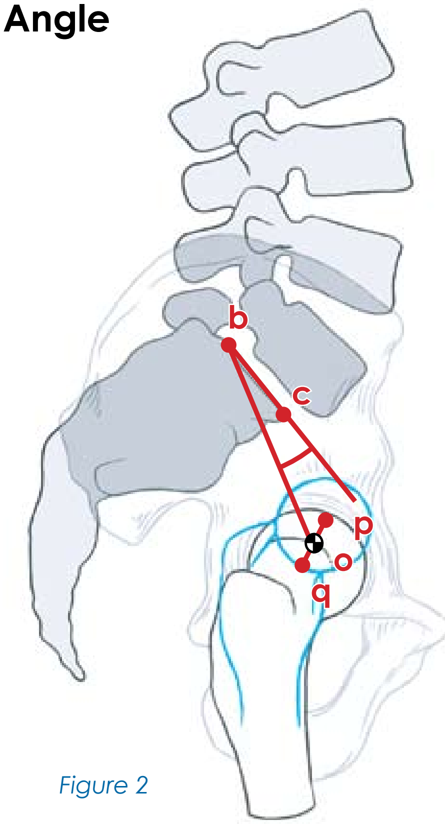
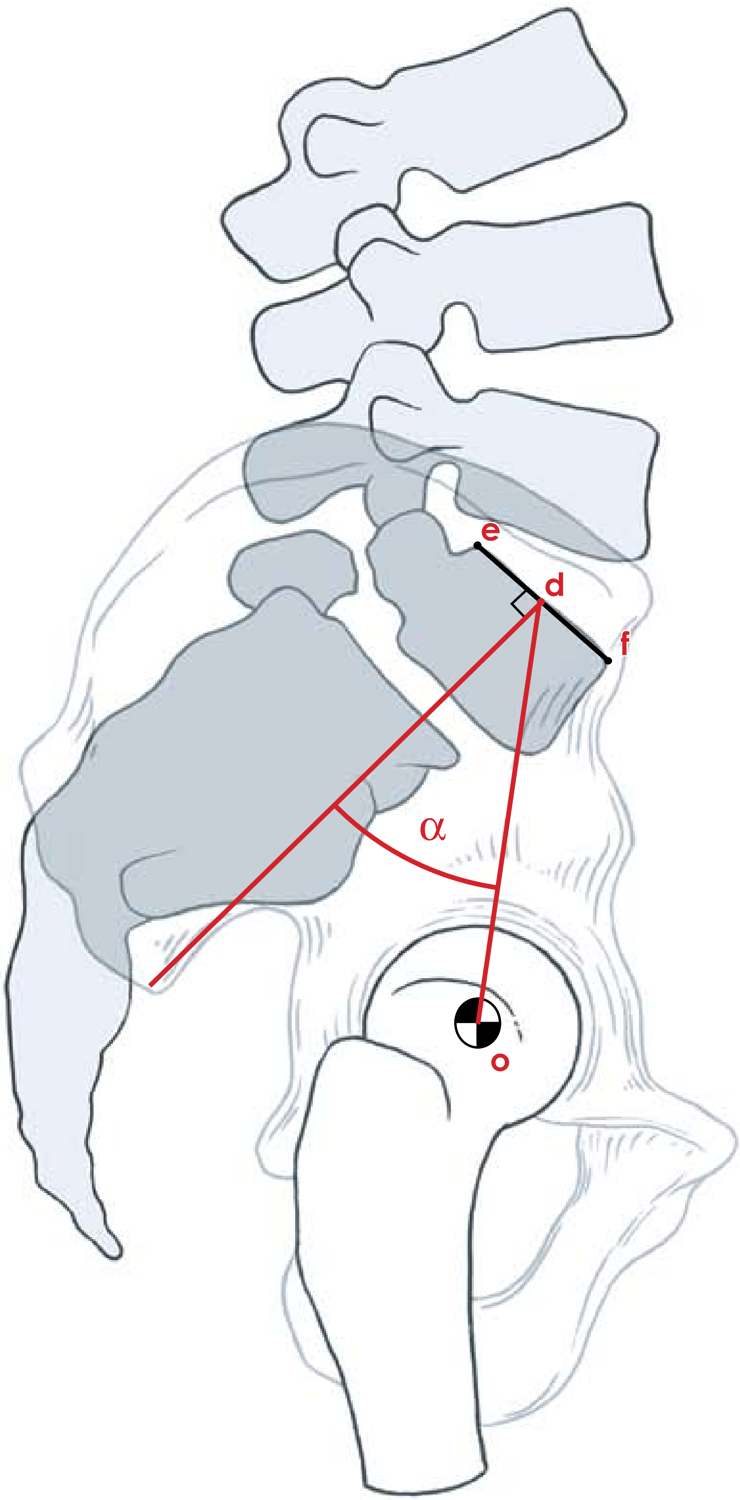


Figure 2

The ***Pelvic Radius Angle*** is defined as an angle subtended by the pelvic radius line ($\overline{ob}$), which is drawn from the center of the femoral head to the posterior superior corner of S1 (b) and a line drawn along the sacral end plate defined by the line segment ($\overline{bc}$). This measurement has been suggested by Jackson *et al*. as a supplementary measurement to pelvic incidence.

Jackson R, et al. Lumbopelvic lordosis and pelvic balance on repeated standing lateral radiographs of adult volunteers and untreated patients with constant low back pain. *Spine*. 2000;25:575-586.

L5 Incidence Angle
(L5 Coxolumbar Angle)

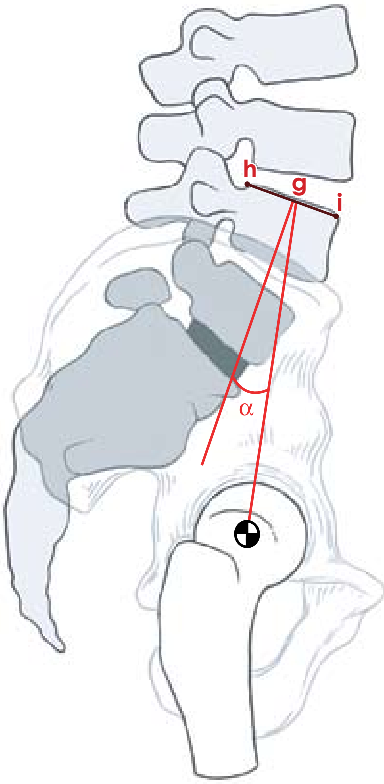


The ***L5 Incidence Angle*** (α), in concept, is similar to pelvic incidence. However, unlike pelvic incidence, which is a fixed anatomic relationship between the sacrum and the acetabulum, the L5 Incidence Angle is subject to change, being influenced by the position in space of the mobile L5 vertebra. It is defined as the angle subtended between the "L5 radius" ($\overline{oa}$) and a line drawn perpendicular to the superior L5 end plate ($\overline{ef}$) at its midpoint (d).

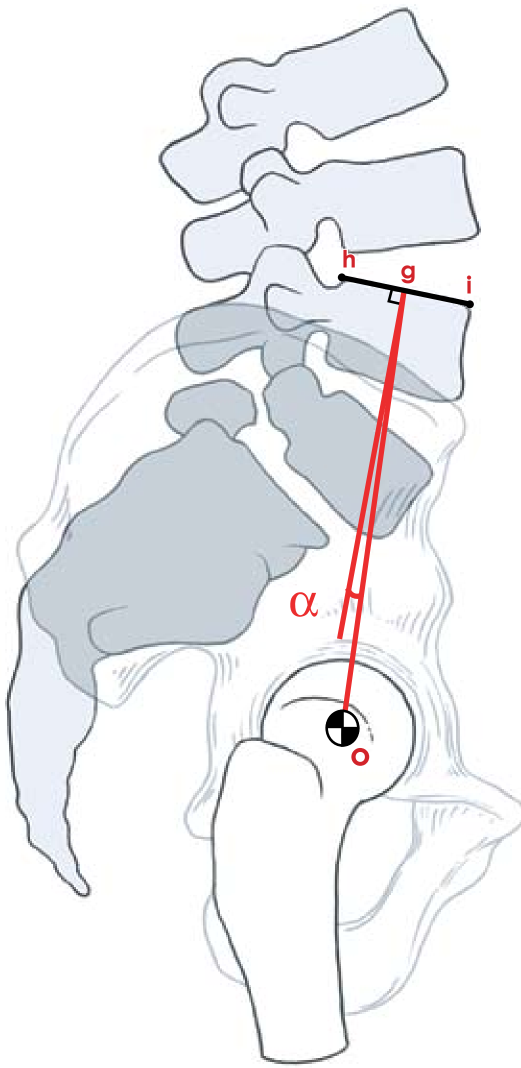
Roussouly P, et al. Changes in spinal and pelvic sagittal parameters after high-grade isthmic spondylolisthesis. *Eur Spine J*. 2001;10 s:19.

L4 Incidence Angle
(L4 Coxolumbar Angle)

The L4 Incidence Angle is constructed using the same technique as the L5 Incidence Angle

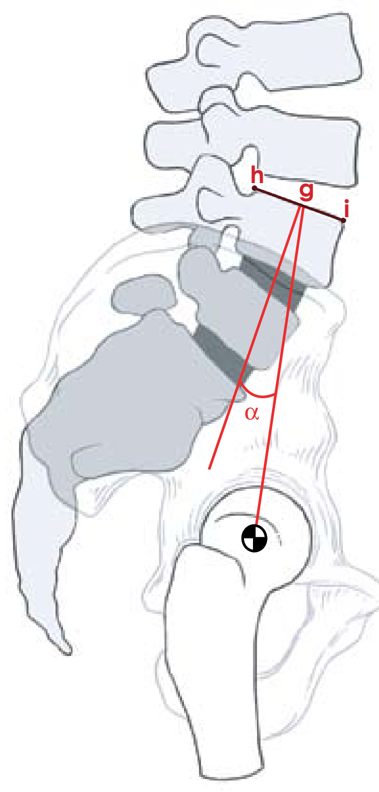


L4 Incidence Angle after L5–S1 fusion



$\overline{og}$ = L4 Radius

$\overline{hi}$ = End-plate line



L4 Incidence Angle after L4–L5–S1 fusion

Spondylolisthesis

Meyerding Classification

Grade 0 (Spondylolysis)

Figure 1

Scotty Dog (Spondylolisthesis and Spondylolysis)

Figure 2

Grade 3 Spondylolisthesis

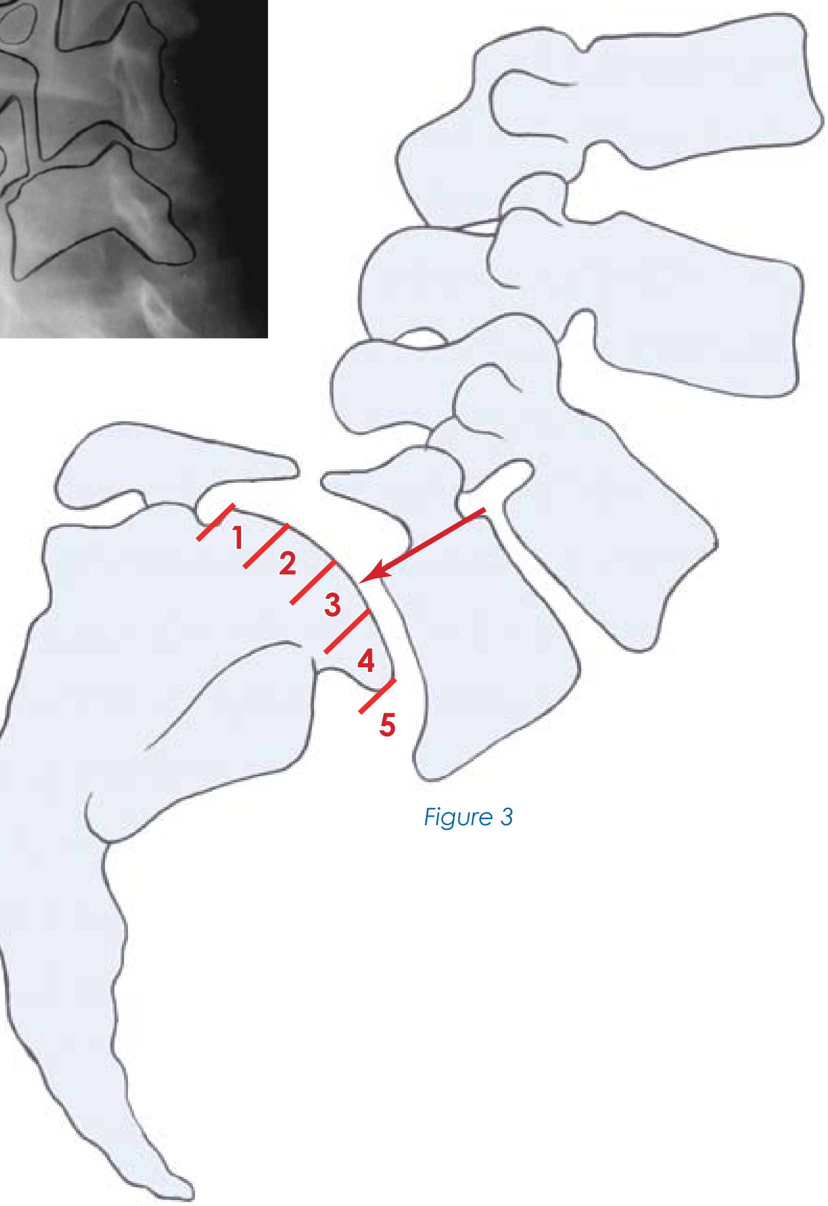


Figure 3

$$\% \text{ Slip} = \frac{\text{Length of Slip} \times 100}{\text{Length of Sacral Plate}}$$

The Meyerding classification provides a simple quantification of the degree of spondylolisthesis by describing the forward translation of L5 with respect to the sacral end plate. The system stratifies spondylolisthesis in Grades 0 through 5 (Figure 3). Grade 0 is a pars defect (spondylolysis) without any translation of L5 in relation to S1 (Figure 1). Oblique images of the lumbar spine may profile the pars defect, often termed the "Scotty Dog" image, showing a crack in the neck (collar) of the dog (Figure 2). Grade I defines a slip between 0 and 25% of the linear distance of the sacral end plate while Grades 2, 3, and 4 represent translations of L5 up to 50%, 75%, and 100%, respectively. A Grade 5 spondylolisthesis is also called a spondyloptosis. In a spondyloptosis, L5 is completely anterior and distal to the S1 end plate.

Meyerding HW. Spondylolisthesis. *J Bone Joint Surg*. 1931;13:39-48.

Spondylolisthesis

Lumbosacral Angle

Figure 1 Lumbosacral Angle

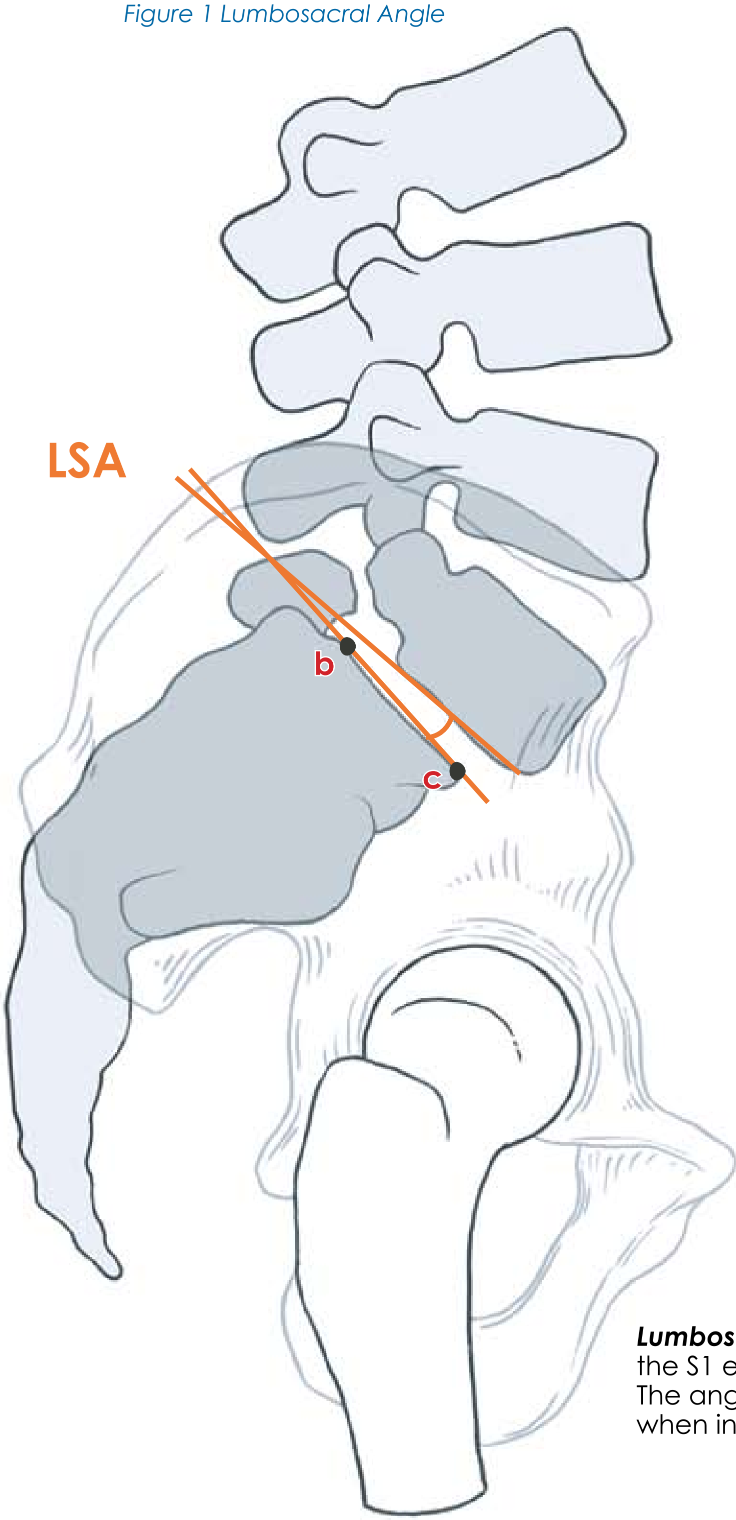
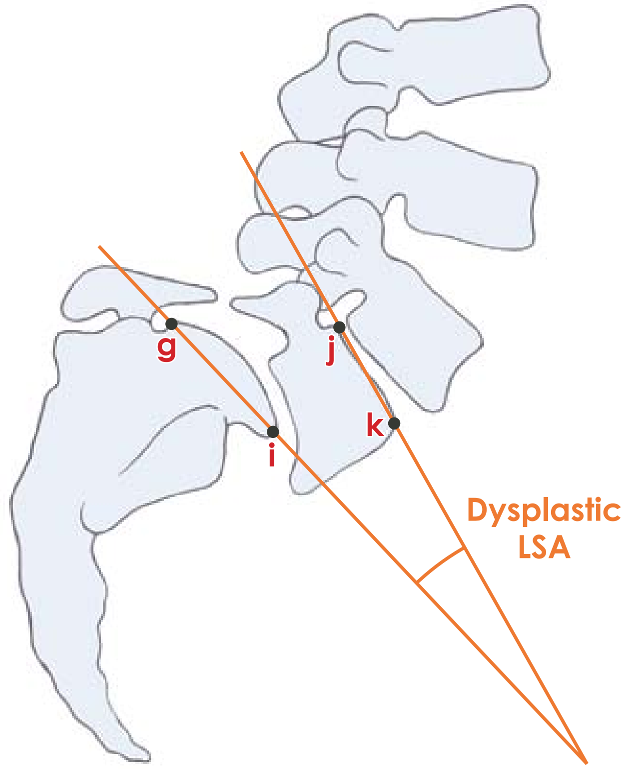


Figure 2 Dysplastic Spondylolisthesis



Dysplastic Spondylolisthesis
In high grade spondylolisthesis, remodeling and adaptive changes occur at the L5-S1 junction, resulting in doming of the sacrum and wedging of the L5 vertebral body. In this case, the lumbosacral angle is defined as the angle subtended by the S1 end-plate line ($\overline{gi}$) as illustrated for a domed sacrum, and the top of the L5 vertebral body ($\overline{jk}$).

Lumbosacral angle is defined as the angle subtended by the S1 end-plate line ($\overline{bc}$) and the inferior end plate of L5. The angle is negative (-) when in lordosis and positive (+) when in kyphosis.

Antoniades SB, Hammerberg KW, DeWald RL. Sagittal plane configuration of the sacrum in spondylolisthesis. *Spine*. 2000;25:1085-1091.

Calculation of Domed Sacrum and Sacral Remodeling in Spondylolisthesis

1. Best fit along the posterior border of the sacrum Posterior Sacral Cortical Line (PSCL)

g. Posterior point: where line 1 loses contact with the posterior border of S1

2. Best fit line along the anterior border of the sacrum Anterior Sacral Cortical Line (ASCL)

i. Anterior point: where line 2 loses contact with the anterior border of S1

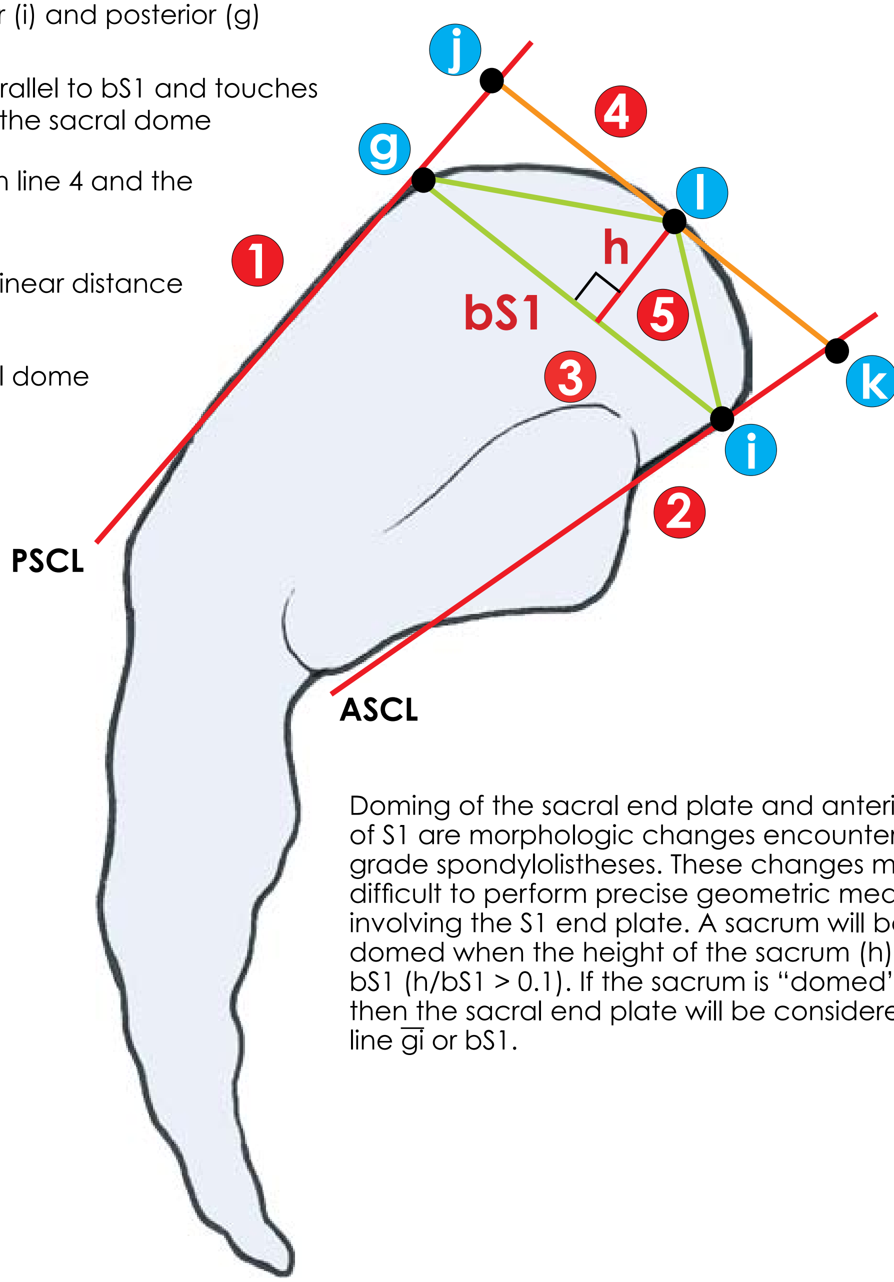
3. Line bS1 joining anterior (i) and posterior (g) tangent points

4. This line ($\overline{jk}$) is drawn parallel to bS1 and touches the most rostral part of the sacral dome

l. Contact point between line 4 and the sacral dome

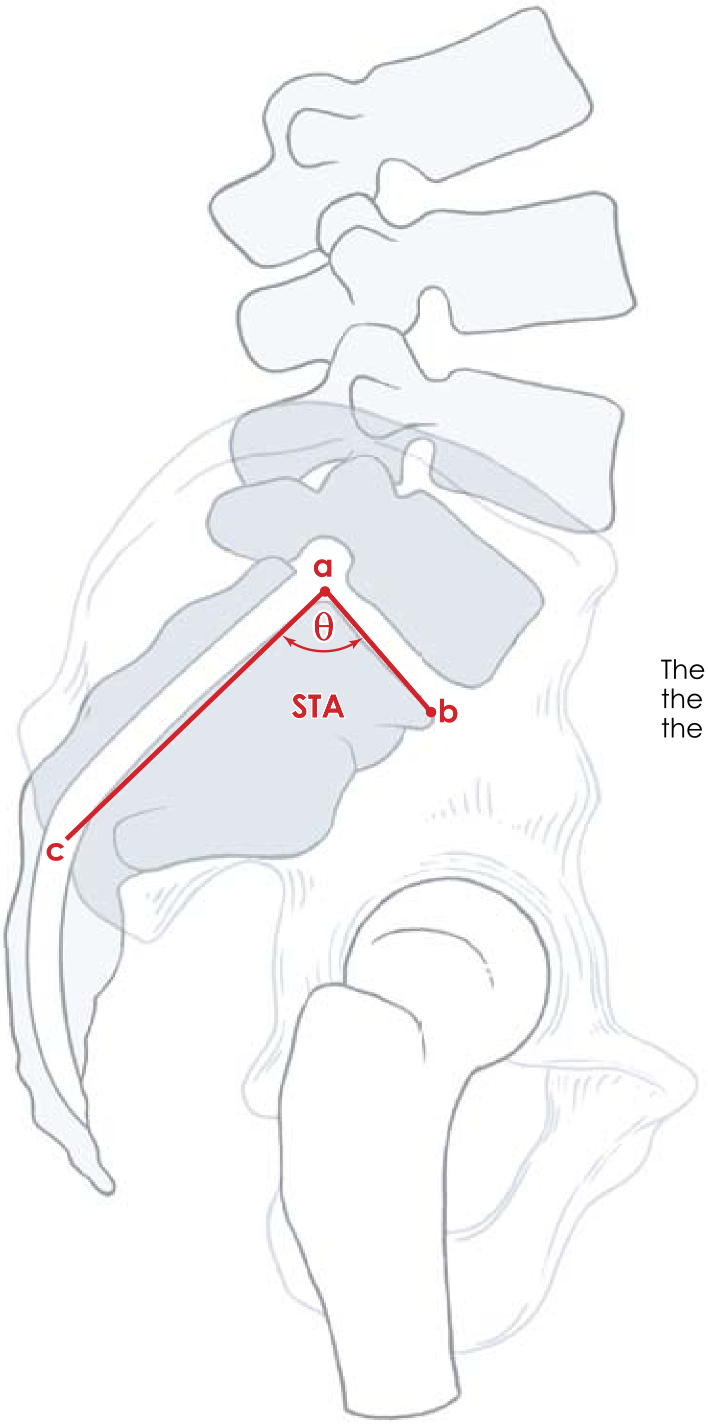
5. This line represents the linear distance from point 1 to line bS1

h. The height of the sacral dome



Doming of the sacral end plate and anterior lipping of S1 are morphologic changes encountered in high-grade spondylolistheses. These changes may make it difficult to perform precise geometric measurements involving the S1 end plate. A sacrum will be considered domed when the height of the sacrum (h) is > 10% of bS1 (h/bS1 > 0.1). If the sacrum is "domed" (h/bS1 > 0.1) then the sacral end plate will be considered to be line $\overline{gi}$ or bS1.

Sacral Table Angle

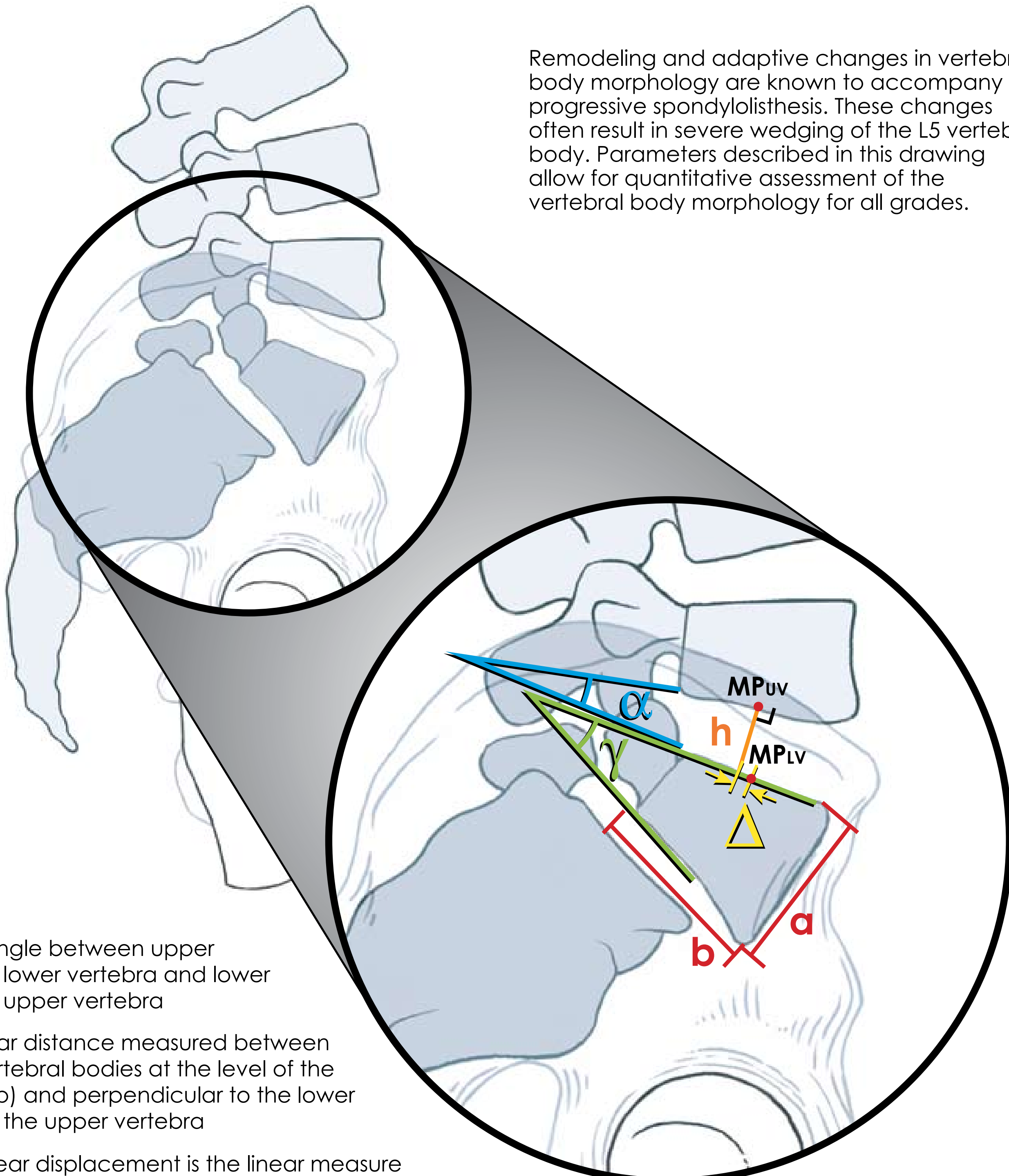


The **Sacral Table Angle** (STA) is the angle subtended by the sacral end-plate line ($\overline{ab}$) and a line drawn along the posterior aspect of the S1 vertebral body ($\overline{ac}$).

Inoue H. et al. Radiographic classification of L5 isthmic spondylolisthesis as adolescent or adult vertebral slip. *Spine*. 2002;27:831-838.

Defining Alterations in Lumbosacral Vertebral Body Morphology Accompanying Spondylolisthesis

Remodeling and adaptive changes in vertebral body morphology are known to accompany progressive spondylolisthesis. These changes often result in severe wedging of the L5 vertebral body. Parameters described in this drawing allow for quantitative assessment of the vertebral body morphology for all grades.



alpha (α): Angle between upper end plate of lower vertebra and lower end plate of upper vertebra

h: Mean linear distance measured between adjacent vertebral bodies at the level of the midpoint (mp) and perpendicular to the lower end plate of the upper vertebra

delta (Δ): Shear displacement is the linear measure along the lower vertebra upper end plate between the projected MPUV and the MPLV

a: Anterior vertebra height

b: Vertebra width

gamma (γ): Vertebra pinch or wedging

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Glossary of Terms and Guidelines for Measuring

Apex: The apex of a curve may reside within a vertebral body or within a disc.

Apical Vertebra or Disc: The most horizontal and laterally deviated vertebra or disc of a curve. This is measured from the C7 plumbline for the proximal thoracic and main thoracic curves, and from the CSVL for thoracolumbar/lumbar or lumbar curves (left is negative/right is positive by convention). The apical vertebra is also frequently the most rotated vertebra.

Apical Vertebral Translation (AVT): The lateral deviation of the apical vertebra or disc measured in millimeters from the C7 plumbline to the centroid for proximal thoracic or main thoracic curves and from the CSVL for the thoracolumbar/lumbar curve (left is negative/right is positive by convention).

C7 Plumbline (C7PL): The vertical line drawn perpendicular to the floor or drawn parallel to the radiograph edge from the C7 centroid. This depicts the carrying position of the head in space.

Center Sacral Vertical Line (CSVL): The vertical line drawn perpendicular to the floor from the geometric center of S1 that depicts the coronal position of the spine in relation to the pelvis (drawn parallel to the radiograph edge).

Centroid: The midpoint of a vertebral body or disc.

Clavicle Angle (CA): The coronal angle of the clavicle in the frontal plane. The angle formed by the intersection of a tangential clavicular line, or line connecting the highest points of the clavicles on a standing AP or PA radiograph, and the horizontal (left shoulder high is positive/right shoulder high is negative by convention).

Cobb Angle: Cobb angles (coronal or sagittal) are always measured from the superior end plate of the most cephalad end vertebra (UEV: upper end vertebra) to the inferior end plate of the most caudal end vertebra (LEV: lower end vertebra) in the curve. S1 is always measured from the superior end plate.

End Vertebra: The most cephalad or caudal vertebrae that tilt toward the concavity of a curve.

Intercrestal Line (ICL): Line used to reference the tops of the iliac crest in relation to the lowest lumbar vertebra.

Instrumentation Issues: If a point or position is obscured by instrumentation, the "best estimate" of the position should be determined from other radiographic markers.

Kyphosis/Lordosis: By convention, kyphosis in any segment or region is positive and lordosis is negative.

Lateral Olisthesis: A lateral slippage of the proximal vertebral body measured against the distal vertebral body (slip to the left is negative/right is positive by convention).

Leg Length Discrepancy: Less than 2cm will be accepted. If the leg length discrepancy is greater than 2cm the standing x-ray should be taken with the patient standing on a block to level the pelvis.

Lowest Instrumented Vertebra (LIV): The most caudal instrumented vertebra in a construct.

Lumbar (L) Curve: A curve with its apex occurring at or below the L1-L2 disc and at or above the L4 vertebra.

Main Thoracic (MT) Curve: A curve with its apex occurring at or below T2 and at or above the T11-T12 disc.

Glossary of Terms and Guidelines for Measuring (continued)

Maximum Measured Kyphosis: The largest posterior convex curve measured by the Cobb method on a standing full-length lateral radiograph.

Nash-Moe Rotation: Grading system for estimating axial rotation of a vertebra, usually applied to the apical vertebra to describe the degree of regional spinal rotation associated with a scoliosis.

Neutral Vertebra: The most cephalad vertebra below the apex of the major curve without rotation.

Pelvic Obliquity: Describes pelvic alignment in the coronal plane. It is measured by the angle formed by the pelvic coronal reference line and a horizontal reference line; an angle of ≤ 15° is considered "balanced" or neutral by convention. Pelvic obliquity is not to be confused with sacral obliquity.

Positive and Negative: By convention:

1) Displacement to the patient's left is negative and to the right is positive.
2) Angles that open to the left are positive and angles that open to the right are negative.
3) Left up is positive and right up is negative.
4) Kyphosis is denoted as a positive number regardless of segments or regions involved.
5) Lordosis is denoted as a negative number.
6) Displacement of C7 anterior to S1 is positive sagittal alignment and posterior to S1 is negative.

The patient's x-rays are viewed from posterior to anterior so that the patient's left side is on the observer's left side. For lateral projections, the patient is looking to the observer's right side.

Proximal Thoracic (PT) Curve: The curve cephalad to the main thoracic curve.

Risser Grade: A system of estimating skeletal maturity by quantifying the ossification/closure of the iliac apophysis.

Sacral Obliquity: The coronal alignment of the S1 end plate. This is normally 0°, i.e., horizontal to the floor.

Sagittal Balance: Is judged by the position of the C7 centroid in relation to the posterior superior corner of the sacrum. It is measured on a standing full-length lateral radiograph. Positive sagittal balance is present when C7 is anterior to S1 and is negative when posterior to S1. If C7 is directly over S1, the spine is considered in neutral balance.

Stable Vertebra: The most cephalad vertebra below the major curve which is most closely bisected by the CSVL.

T1 Tilt Angle: The angle formed by the intersection of a line drawn tangential to the superior end plate of T1 or the zenith of both first ribs and a horizontal reference line (left side up is positive/right side up is negative by convention).

Thoracolumbar (TL) Curve: A curve with its apex occurring at T12, L1, or the T12-L1 disc.

Triradiate Cartilage (TRC): The cartilage positioned at the intersection of the three innominate bones of the pelvis that make up the acetabulum (graded as open if not fused or closed if fused). It usually closes at approximately age 9 - 10 and its closure is associated with the patient's peak growth velocity.

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