# Scoliosis Research Society

*White Paper on Sagittal Plane Alignment*

Terminology Committee
Reginald Q. Knight, MD, Chair
Roger P. Jackson, MD
John T. Killian, MD
Earl A. Stanley, MD
Contributors
Thomas Lowe, MD
Robert B. Winter, MD

Questions pertaining to the proper assessment of the sagittal plane in normal or deformed spines remain a topic of discussion at most spine meetings today. In addition, the concept of spinal balance is not isolated to the domain of spinal surgeons. Neurologist, physiatrist, chiropractors[6], and physical therapists[4] provide extensive research regarding the subject. In the past, the validity of the method of measuring curvature in the sagittal plane via Cobb technique was in itself questioned. Voutsinas and MacEwen[15] demonstrated that while the Cobb method has its limitations, it does provide valid measurements. A survey of the Scoliosis Research Society membership prior to the 2001 annual meeting suggested that most members thought of sagittal balance as important, but many members varied in their application of the concept. The purpose of this article is an attempt to place some clarity on the subject despite the remaining questions regarding the use of a definitive number, such as 40° for thoracic kyphosis.

The spinal column is a complex structure. When viewed in the frontal plane each vertebra gives the appearance of being stacked one upon the other. The view from the sagittal plane clearly demonstrates that the vertebrae, in the different regions of the cervical, thoracic, or lumbar spine, position themselves in a posture we designate as lordosis or kyphosis. From a functional standpoint, the appropriate degree of lordosis or kyphosis in each segment of the spine creates a global posture and provides balance for our center of

gravity. While the Scoliosis Research Society has traditionally focused on the coronal plane, the collaborative efforts of biomechanical researchers and clinicians have fostered renewed interest in the sagittal plane. Ignoring the sagittal plane has produced or exacerbated a series of difficult clinical problems; junctional disc degeneration, upper thoracic bone-implant failure, and lumbar "flat-back". Furthermore, abnormal sagittal balance in the spinal column adversely effects the sacroiliac, hip, knee and ankle joints.

**What is normal sagittal balance?** According to the SRS Working Group on Spinal Classification Nomenclature, sagittal balance is the alignment of C7 to the posterior superior aspect of the sacrum on an upright long cassette radiograph. The sagittal plumb line, as drawn from center of C7, should be plus or minus 2 centimeters from the sacral promontory (Figure 1). Nowhere in that statement does it speak to the absolute number required to obtain that balance. In addition, the impact of pelvic obliquity and lower extremity joint angulation (hip or knee flexion) on this posture are negated.

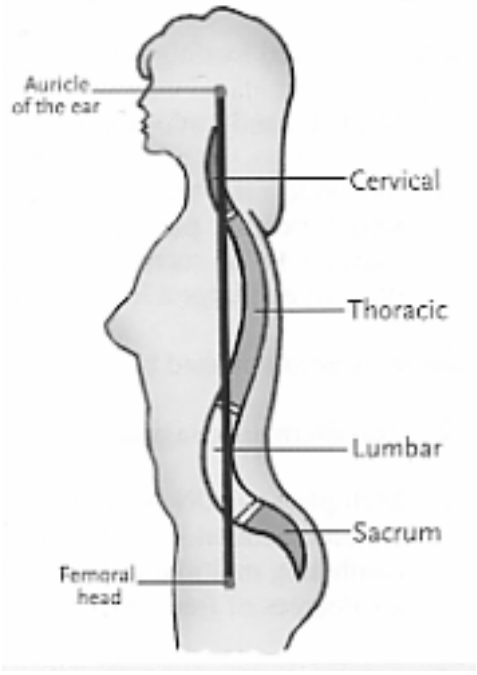


*FIGURE 1: Diagram of sagittal balance. Note that the "plumb line" depicted here passes through C7 and just anterior to the sacral promontory.* Obtained from Schnuerer AP, Gallego J, Manuel C. Core Curriculum for Basic Spinal Training, "Anatomy of the Spine and Related Structures", Medtronic Sofamor Danek, 2001, Section 2, pg. 26.

The patient's posture may or may not allow them to achieve balance in the sagittal plane. Several questions can then be posed with respect to that balance. Is sagittal balance congruent, compensated or uncompensated? The degree to which we assign balance to the sagittal plane is defined by our plumb line and its' relationship to an axis of rotation about the hips. This concept, therefore, makes assessment of both hip positions on the standing sagittal spine film very important. A critical assessment of the standard lateral radiograph of the spine can provide additional valuable information regarding the hips and pelvis.

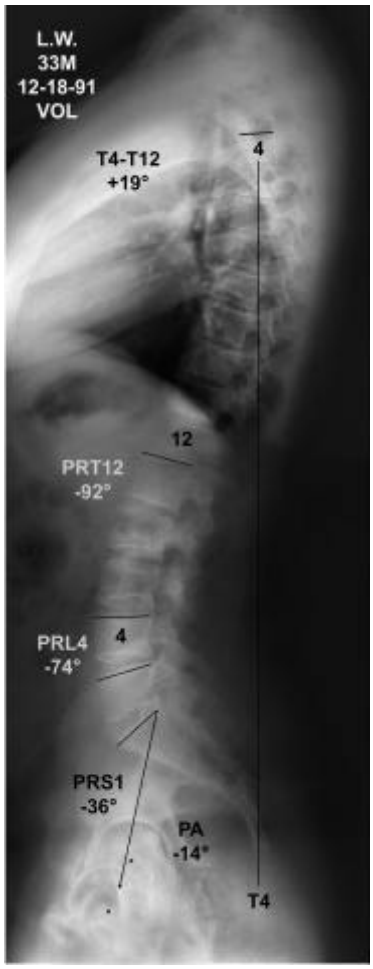


*FIGURE 2: Lateral radiograph on long cassette with selected angles of lordosis or kyphosis associated with that motion segment. Note difficulty in visualizing the upper thoracic spine.* Obtained from Jackson RP, Phipps T, Hales CH, Surber J. Pelvic Lordosis and Alignment in Spondylolisthesis, SPINE Volume 28, Number 2, pg. 151-160, 2003.

Standard lateral radiographs obtained for sagittal balance are on a three-foot long cassette. Under most circumstances the regions imaged are primarily thoracic, lumbar and sacral. The patient stands upright with his or her arms positioned on a support in front of them, their head facing forward. The x-ray tube is positioned 72" from the patient. Frequently, the shoulders obscure upper thoracic anatomy and pelvic girth limits visualization of the hips. Special grids and different film speeds are often of value in improving the image quality. Cervical and pelvic contributions to lordosis and sagittal balance are not frequently commented upon. Specific instruction to the technician can routinely produce radiographs that include this data (Figures 2 and 3).

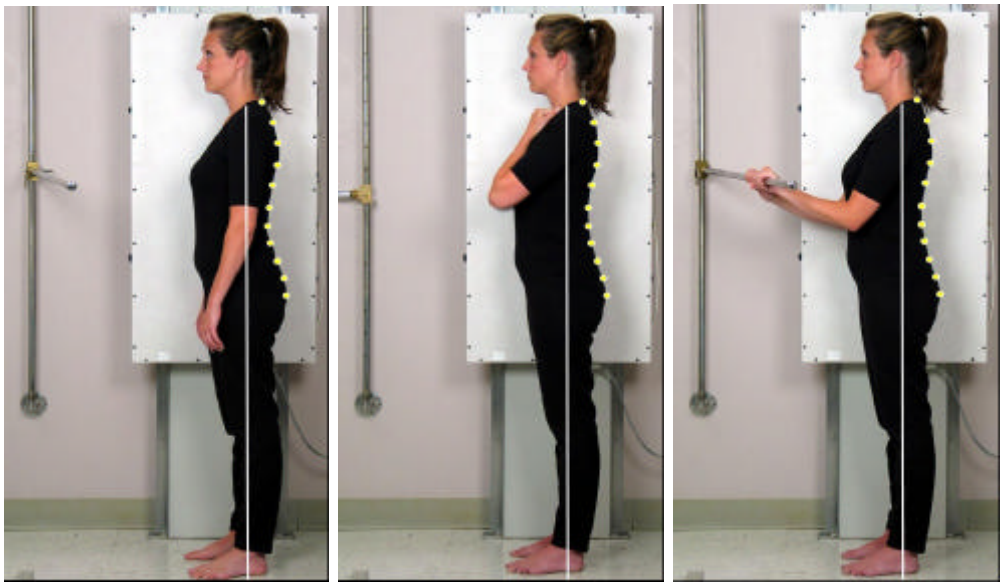

*Figure 3: Clinical examples of patient positioning for standing radiograph of the entire spine.* Obtained from Jackson, RP, et al. Sagittal Spinopelvic Alignment: Comparison between Japanese and American Volunteers, Power Point Presentation, World Spine II, Chicago, August 2003.

Reported normal value ranges for the lordosis or kyphosis of specific segments of the spine varies in the literature. Hardacker[5] suggests that the normal range of cervical lordosis is 40° (+/-) 9.7°. Data from this study implied that the occipital cervical junction is actually in kyphosis and the majority of lordosis occurs between C1-C2. Within the cervical spinal segments there are distinct regional differences. The lower cervical spine, C4-C7, is relatively flat with a average lordosis of 6°. Most presently available anterior cervical implant systems take this information into account.

Normal thoracic kyphosis is in the range of 20° to 50°[1,2,14]. There is a wide range of normal, which is made more difficult to interpret due to the variation in levels included. As mentioned previously, the upper thoracic anatomy may be obscured and difficult to measure. This has led some authors to exclude the upper thoracic levels from this measurement. As illustrated by the SRS Terminology Committee Survey, many clinicians and researchers, including SRS members, consider clinically applicable thoracic kyphosis (dependent upon quality of radiograph) from T2, T3 or T4 to T12. Bernhardt speaks to the need to clearly define the measured levels. Despite their suggestion that kyphosis uniformly include the top of T3 to T12, T1 through T3 are also most often kyphotic. Correct measurement via the Cobb method dictates that the upper and lower maximally sloped or angulated vertebrae be included. Therefore, excluding the upper thoracic spine from the measurement of kyphosis results in only a partial measurement. Clearly the designation of endverterba describing any curvature is vital information to those evaluating the data.

Lumbar lordosis ranges from 31° to 79° in normal situations depending from where you chose to measure it[12, 13, 16] .The thoracolumbar region, T10 to L2, is clearly a transition zone. Regardless of the usual 3° lordosis within the T12-L1 disc space, the overall global posture of this region is often flat. Measurements of lumbar lordosis are further complicated by the designation of its lower endvertebra, L5 or S1. The relatively large lordosis recorded at the L5-S1 disc space dramatically changes reported measurement of lordosis based on its inclusion or exclusion. Difficulty obtaining a clear image of the S1 endplate as been stated as an explanation for stopping at the inferior endplate of L5. Changes in radiographic technique may improve the clinician's ability to obtain better visualization of S1. This is yet another distinct demonstration of the regional variations within spinal segments. Clinically, the lumbosacral junction, L5-S1, presents a difficult collection of unique problems making the assessment of lordosis all the more important.

Morphologic changes in vertebral wedging (L5), sacral inclination and the pelvic anatomy itself add further complexity to the discussion of lumbosacral lordosis. It has consequently become customary to position the patient on the operative table in a manner that maintains lordosis. Maintaining lumbosacral lordosis has fueled discussion regarding the need for lordotic interbody spacers

particularly at L5-S1. The large degree of lordosis at the L5-S1 motion segment makes it particularly vulnerable to surgical manipulation. Care should be taken not to hyperextend the hips and therefore produce excessive lumbar lordosis and perhaps L5-S1 foraminal stenosis.

**How do these normal values interact?** One of the spinal column's many functions to position the head in space has been well documented. The body's computer, the central nervous system, comprises a complex network of checks and balances that maintain this posture. Overall, there is a positive correlation between thoracic kyphosis and lumbar lordosis. Voutsinas[15] states "that these curvatures tend to balance each other." This might be more clearly defined as "normal" (congruent) sagittal spinopelvic balance (Figure 4).

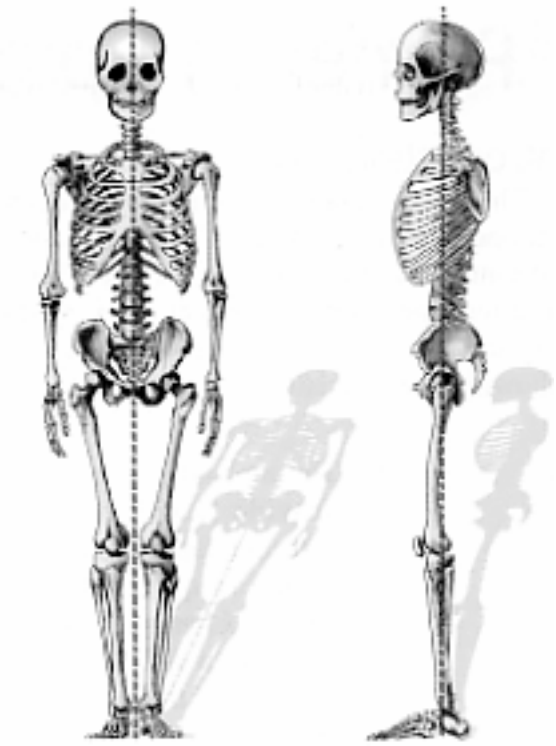

*FIGURE 4: Skeletal drawing in AP and lateral projection illustrating sagittal and coronal balance. Note the extension of these lines of gravity through the pelvis and lower extremities.* Obtained from Schnuerer AP, Gallego J, Manuel C. Core Curriculum for Basic Spinal Training, "Primers in Spinal Biomechanics", Medtronic Sofamor Danek, 2001, Section 3, pg. 34.

Naturally occurring changes associated with age and degeneration affect all components of this complex system, including muscle, tendon, ligament, nerve and bone. The result is that our posture changes with age [15]. We tend to develop more cervical lordosis, thoracic kyphosis and less lumbar lordosis as we age. If our spinal components are not capable of acquiring those postures, adaptive changes occur in the lower extremities. In this situation the body has compensated through the hips for the lack of congruence in the spine, compensated sagittal balance. The effects of iatrogenic alteration in spinal alignment, i.e. lumbar "flat back", magnify this process. Due to the rigid nature of the thoracic rib cage large changes in the thoracic profile are more difficult to accomplish. Conversely, the flexible lumbar spine is more easily altered by surgical intervention affecting most commonly a reduction in lordosis. While the actual lumbar lordosis is important, pelvic angulation due to hip flexion or extension, as noted earlier, can significantly affect each person's spinal posture. In addition, pelvic morphology can affect posture. Different measurements for pelvic morphology in the sagittal plane have been reported, including the pelvisacral angle, the pelvic incidence angle and the pelvic lordosis angle (Figure 5).

**Should routine assessment of sagittal balance include the orientation of hips and pelvis?** Authors including During[3], Jackson[7, 8,9] and Legaye[11] have commented on the effect changes in lumbar lordosis have on the pelvis, sacrum and hips. John and Fisher[10] in 1994 reported on the radiographic identification of the center of pelvic rotation. They concluded that the center of rotation was along an axis through the center of the femoral head. Hip extension, knee flexion and posterior pelvic angulation are an attempt to return the body's center of gravity to a more centered location over the hips.

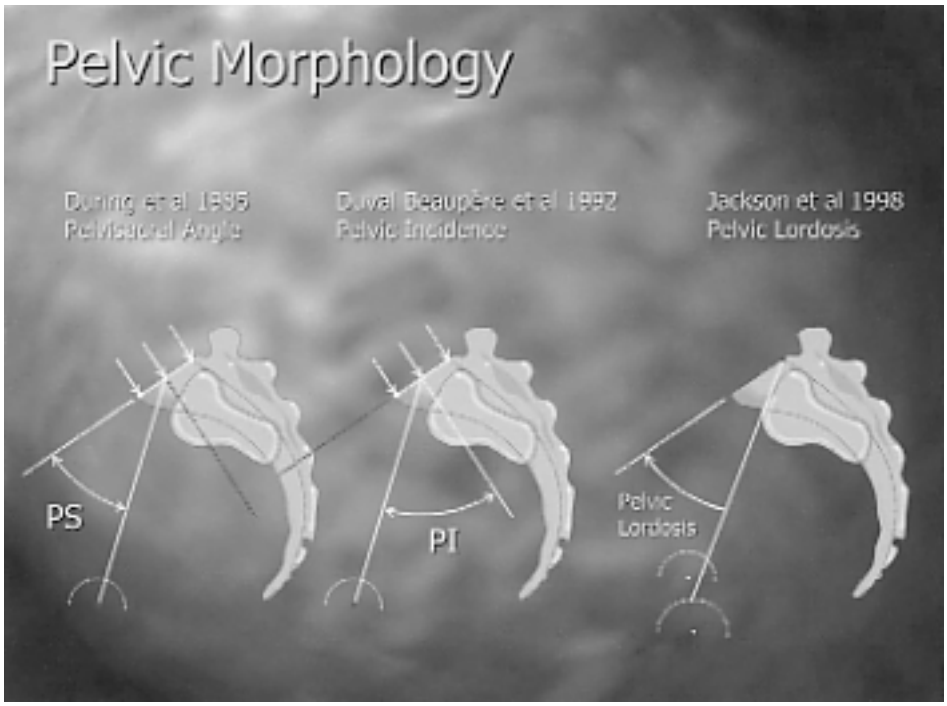


*FIGURE 5: Diagram of pelvic morphology illustrating the pelvisacral angle, pelvic incidence and pelvic lordosis (left to right).* Obtained from Jackson RP, Phipps T, Hales CH, Surber J. Pelvic Lordosis and Alignment in Spondylolisthesis, Poster Presentation, NASS, Meeting of the Americas II, New York, 2002.

In clinical situations where the loss of lumbar lordosis is not associated with a commiserate reduction in thoracic kyphosis the hips and or pelvis need to compensate where possible. Patients demonstrating this type of posture are said to be in uncompensated balance (Figure 6).

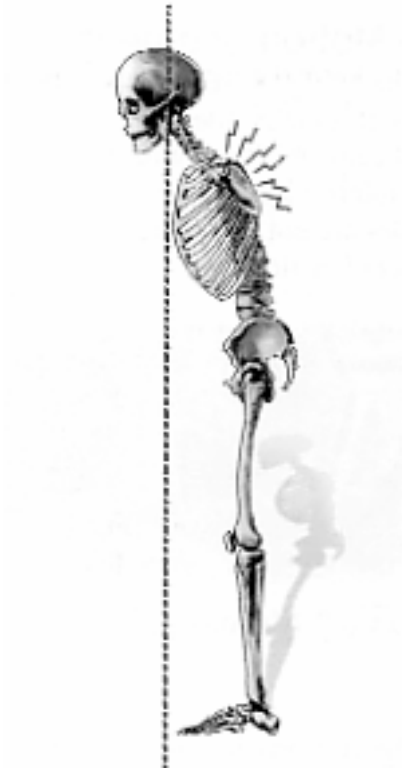

*FIGURE 6: Skeletal diagram of uncompensated balance. The skeleton is still able to maintain an erect posture, but the "plumb line" is greater than two (2) centimeters anterior to the sacral promontory.* Obtained from Schnuerer AP, Gallego J, Manuel C. Core Curriculum for Basic Spinal Training, "Primers in Spinal Biomechanics", Medtronic Sofamor Danek, 2001, Section 3, pg. 35.

Changes in position associated with activities of daily living, i.e. lifting, sitting or standing, have an effect on sacropelvic orientation. Information gathered from the Terminology Committee survey suggests that most members of the society are interested in the concept of sacropelvic angulation, spinopelvic balance and hip flexion but do not stress it clinically. While the information is deemed to be important, its' routine inclusion does not apparently affect clinical outcome. However, in the patient where sagittal imbalance becomes problematic, hip flexion and pelvic angulation with the inability to compensate becomes a key point.

In summary, sagittal balance is a combination of opposing curves; cervical lordosis, thoracic kyphosis, lumbar lordosis, sacral inclination, pelvic and hip angulation (flexion or extension). Definition of levels included in the measurement of spinal deformity is paramount to the useful transfer of information. Lumbar lordosis should include, where possible, the L5-S1 disc space. Similarly,

thoracic kyphosis should include, where possible, T1. Our use of the Cobb technique to assess degree of curvature mandates that we include the maximally angulated upper and lower endvertebra of the curve in question. If the endvertebra are not included, we are measuring only a portion of the curve, whether it lordotic or kyphotic.

Sagittal balance has as it's primary goal maintaining our center of gravity. Lumbar lordosis has the largest dampening effect on this balance. A reduction in lumbar lordosis without congruent reduction in thoracic kyphosis moves the sagittal plumb line, as drawn through the center of C7, further anterior with respect to the sacrum and the hips. When the spinal segments and the hips are incapable of adjusting to either the degenerative or iatrogenic impact on sagittal balance the lower extremities are recruited. In the example mentioned above the patient assumes the "jump" position with hip and knee flexion. The degree to which they are able to accomplish this leaves them in either compensated or uncompensated balance.

In answer to the question posed above, complete discussion of sagittal balance clearly needs to address both the axial skeleton and lower extremities, including the hips. Measurement of sagittal contours needs to be distinctly documented for useful comparison. The standing 3' radiograph with appropriate grids at a focal distance of 72" is clearly the accepted norm. Levels included in the specific regions will continue to be subjects of discussion.

# Definitions

Balance- ability to stand without the need of external supports:

-Normal sagittal balance = congruent postural alignment of cervical lordosis, thoracic kyphosis and lumbar lordosis that is proportional and produces a sagittal plumb line passing from the center of C7 through the L5-S1 disc space or within 2 centimeters of the sacral promontory and through or behind the hip axis. *(See Figures 1,2,4).*

-Compensated (incongruent) sagittal balance = disproportional change in segmental alignment, i.e. cervical, thoracic or lumbar resulting in a shift in the sagittal plumb line. The sagittal plumb line remains within the L5-S1 disc space or within 2 centimeters of the sacral promontory by changes in knee flexion or pelvic angulation (flexion or extension) around the hips in addition to the remaining flexible spinal segments.

-Uncompensated sagittal balance = changes in segmental alignment that are not successfully accounted for by changes in flexible spinal segments, knee flexion and pelvic angulation. This results in a shift of the sagittal plumb line either anterior or posterior to the L5-S1 disc space and greater than two centimeters from the sacral promontory. However, the patient is able to stand up without external support. *(See Figure 6).*

Lumbosacral angle: Accounting for the wedge shape of the L5-S1 intervertebral disc, the angle between intersecting lines drawn according to the lower endplate of L5 and the superior endplate of S1.

Nomenclature for rotational measurement of a given vertebral endplate (or sacropelvis) about a given axis to the horizontal (or vertical) in each of 3 planes:

-Coronal plane = tilt or obliquity (i.e. vertebral tilt, pelvic obliquity)

-Sagittal plane = angulation or slope or inclination

-Axial plane = rotation or torsion

Pelvisacral angle: The angle of intersection between the line from a midpoint between the center of the hip joints to the center of the superior S1 endplate and a tangent line drawn along this endplate. *(See Figure 5)*

Sacral Inclination: The angle of intersection between a line drawn along the back of the S1 vertebra and the horizontal. *(See Figure 7)*

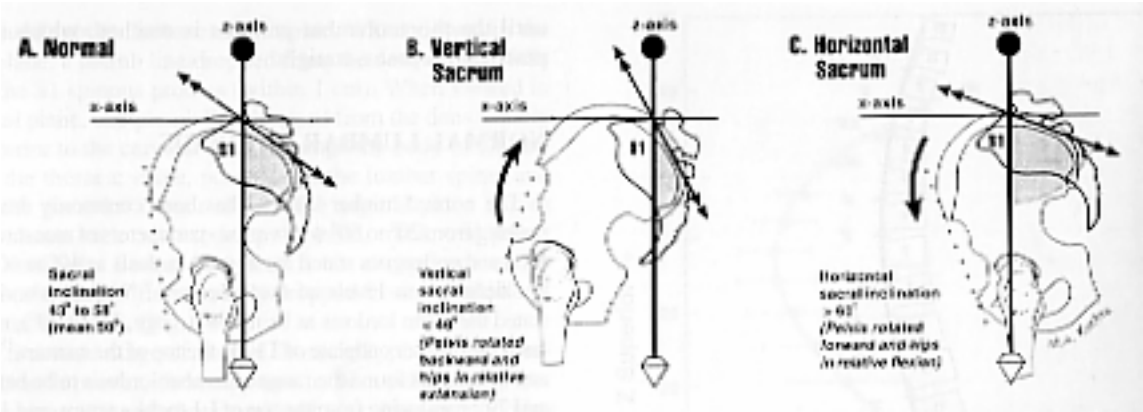


*FIGURE 7: Relation of sacral inclination, pelvic angulation, and hip joint position. (A) Sagittal profile of normal sacral inclination (the angle between the horizontal and a line drawn parallel to the back of the proximal sacrum). (B) Sagittal profile of a vertically, oriented sacrum. Note that the hip joints are in relative extension due to the backward angulation of the pelvis. Thus, while standing, hip extension and posterior pelvic angulation can reduce sacral inclination and compensate for the loss of lumbar lordosis. (C) Sagittal profile of a horizontally oriented sacrum. Patients, with flexion contractures of the hip joints have a more horizontal sacral inclination and have lost some ability to angulate their pelvis to compensate for loss of lumbar lordosis.* Obtained from - Bernhardt M. Normal Spinal Anatomy: Normal Sagittal Plane Alignment. Bridwell KH, DeWald RL. (Eds) The Textbook of Spinal Surgery, 2nd Edition, Lippincott-Raven, Philadelphia, Chapter 16, figure 8, pg. 190.

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