Clinical and Radiographic Evaluation of the Adult Spinal Deformity Patient

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KEYWORDS

• Spine • Deformity • Adult • Imaging • Radiographic • Clinical

KEY POINTS

- Adult spinal deformity encompasses a broad range of conditions. The most common are scoliosis (residual adolescent idiopathic scoliosis, also called adult idiopathic scoliosis, and degenerative or de novo scoliosis), kyphotic deformities with associated positive sagittal malalignment, and spondylolisthesis.
- Clinical evaluation of the adult with spinal deformity should include a thorough history of the condition, discussion of the presenting concerns, and a review of comorbidities. The physical examination should include assessment of the deformity and a complete neurologic examination.
- Imaging studies for adult spinal deformity evaluation should include full-length standing posteroanterior and lateral spine radiographs for assessment of regional and global alignment parameters, as well as measurement of pelvic parameters.
- Advanced imaging studies, including CT, CT myelogram, and MRI, are frequently indicated to assess for neurologic compromise and for surgical planning.

INTRODUCTION

The term adult spinal deformity (ASD) refers to a broad range of spinal conditions that have in common an abnormality of physiologic spinal alignment that may lead to pain, instability, functional disability, cosmetic concerns, neurologic compromise, and/or physiologic dysfunction. A working knowledge of the basic descriptive terminology for ASD is important for those who provide spinal care for these patients. The Scoliosis Research Society (SRS) Terminology Committee and Working Group on Spinal Classification have been proactive in developing and promoting an accurate and accepted nomenclature.[1,2] **Table 1** is a glossary of several frequently used terms, primarily derived from the efforts of the SRS.

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Table 1
Glossary of descriptive terms for ASD

Term	Definition
Scoliosis	A lateral curvature of the spine on coronal imaging
Kyphosis	A posterior convex angulation of the spine on lateral view with the patient facing rightward. The terms hyperkyphosis and hypokyphosis refer to conditions in which the kyphosis is greater or lesser than the normal range, respectively.
Lordosis	An anterior convex angulation of the spine on lateral view with the patient facing rightward. The terms hyperlordosis and hypolordosis refer to conditions in which the lordosis is greater or less than the normal range, respectively.
Kyphoscoliosis	A scoliosis accompanied by a true hyperkyphosis
Lordoscoliosis	A scoliosis accompanied by a true hyperlordosis
Major Curve	The curve with the largest Cobb angle measurement on upright long cassette radiograph of the spine
Minor Curve	Any curve that does not have the largest Cobb angle measurement on upright long cassette radiograph of the spine
Structural Curve	A measured spinal curve in the coronal plane in which the Cobb measurement fails to correct on supine maximal voluntary lateral side bending radiograph
Compensatory Curve	A minor curve above or below a major curve that may or may not be structural
End Vertebrae	The vertebrae that define the ends of a curve in a coronal or sagittal projection. The cephalad end vertebra is the first vertebra in the cephalad direction from a curve apex whose superior surface is tilted maximally toward the concavity of the curve. The caudal end vertebra is the first vertebra in the caudal direction from a curve apex whose inferior surface is tilted maximally toward the concavity of the curve.
Neutral Vertebra	A vertebra without axial rotation in reference to the most cephalad and caudal vertebrae that are not rotated in a curve
Apical Vertebra	In a curve, the vertebra most deviated laterally from the vertical axis that passes through the patient's sacrum (CSVL)
Apical Disc	In a curve, the disc most deviated laterally from the vertical axis of the patient that passes through the sacrum (CSVL)
Stable Vertebra	The thoracic or lumbar vertebra cephalad to a scoliosis that is most closely bisected by a vertically-directed CSVL, assuming the pelvis is level. Alternatively, both pedicles of this vertebra should lie between vertical reference lines drawn from the sacroiliac joints.
CSVL	The vertical line in a coronal radiograph that passes through the center of the sacrum.
C7 Plumb Line	The vertical line drawn starting from the center of the C7 vertebral body and dropped straight downward. If drawn on a coronal view, the horizontal distance from this line to the central sacral line is a measure of the CA (coronal "balance"), with rightward and leftward deviations designated as positive and negative values, respectively. If drawn on a sagittal view, the horizontal distance from this line to the posterosuperior corner of S1 reflects a measure of the sagittal alignment (SVA), with positive values assigned for C7 plumb lines anterior to the sacrum and negative values assigned for C7 plumb lines that fall behind the sacrum.

Spinal deformity may affect the axial, coronal, and sagittal planes and can involve a combination of abnormalities in multiple planes. Although scoliosis is classically defined based on a lateral curvature of the spine on coronal imaging, it is often a three-dimensional deformity that, in addition to the coronal deformity, may also include a rotational component (axial deformity) and a kyphotic or lordotic component (sagittal deformity). An abnormal sagittal spinal profile (kyphosis or lordosis) may present as a primary deformity or exist in association with other deformities. In uncompensated hyperkyphosis, the normal upright posture of the head over the pelvis and feet (physiologic sagittal alignment) is shifted forward, resulting in positive sagittal malalignment. Spondylolisthesis is a regional abnormality in the sagittal plane in which one vertebra is displaced anteriorly or posteriorly in relation to an adjacent level.

ASD has multiple causes. It may be residual from deformities that presented earlier in life, may result from degenerative conditions, or may be a combination of the two. It may result from unknown factors (eg, adolescent idiopathic scoliosis), congenital anomalies (eg, failure of segmentation), and neuromuscular conditions, including cerebral palsy, spinal cord injury, or spina bifida. ASD may also develop as a consequence of trauma, infection, malignancy, degenerative disease, or iatrogenic causes. Among younger adults, the most common cause for spinal deformity is untreated adolescent idiopathic scoliosis, whereas the most common causes for spinal deformity in middle-aged and older adults include degenerative (de novo) scoliosis, degenerative kyphosis, and iatrogenic causes.

This article focuses on clinical and radiographic evaluation of thoracic and lumbar spinal deformity in the adult population, with a focus on scoliosis and kyphosis.

CLINICAL EVALUATION

Clinical History

Clinical evaluation of the adult with spinal deformity should begin with a thorough history of the condition. For some patients, the initial visit may simply be for education and to establish judicious follow-up of a relatively asymptomatic or incidentally discovered finding. Others may present with pain and disability, neurologic symptoms, or concerns of appearance.[3,4] Establishing the presenting concerns early in the evaluation can be helpful for both the physician and the patient in ensuring that the visit is successful in addressing the needs of the patient.

In contrast to adolescents with spinal deformity, who often present with concerns of cosmesis or progression of deformity, the most common presentation for adults with spinal deformity is pain and disability.[3,5–7] It is important to document the quality, intensity, and location of the pain and whether these have changed over time. Aggravating and ameliorating factors should be elucidated as well. Both leg pain[5,7] and axial back pain[6,7] are common complaints in adults presenting for clinical evaluation of spinal deformity. It should be clarified with patients whether both are present and, if so, the relative severity of each. Aggravating and ameliorating factors should be elucidated as well. It is also helpful to assess whether nonoperative measures have been used, such as physical therapy, bracing, chiropractic care, medications, or steroid injections, and whether these have been beneficial. For leg pain, it is important to appreciate the distribution of symptoms, whether it is unilateral or bilateral, and whether the symptoms are radicular in nature or more consistent with neurogenic claudication.

Adults with spinal deformity may present with neurologic deficits and care should be taken to elicit a history that may suggest their presence.[4] A history of discrete motor weakness or altered or decreased sensation should be documented, as should symptoms of bowel or bladder dysfunction. Other symptoms of myelopathy should also be discussed, including discoordination and gait unsteadiness. Presence of upper extremity symptoms, such as weakness, numbness, or discoordination, should also be assessed because these may reflect concomitant cervical disease that could affect patient function and treatment approach for thoracolumbar deformity.

The cosmetic appearance of a spinal deformity can be a considerable factor in the psychosocial wellbeing of the patient. The importance of appearance is accepted in the pediatric population, but has yet to be thoroughly evaluated in the adult population.[8,9] Depending on the type and magnitude of the deformity, patients may also report impact on social function. For example, patients with significant positive sagittal malalignment may find it difficult to make eye contact in social interactions. Although pain and disability may dominate the presenting concerns, it is important to also recognize and discuss potential cosmetic and psychosocial issues.

In addition to the clinical history focused on the spinal deformity, it is also important to document other health conditions, previous surgical procedures, and comorbidities. Presence of osteoporosis or osteopenia should be ascertained. In patients with significant thoracic deformity, pulmonary status may need to be addressed. If corrective surgery is considered, a risk-benefit assessment should be performed because adults with deformity, especially older adults, may have significant health issues and surgeries to correct spinal deformity are typically substantial and have inherent risks of complications.[7,10,11] Although presence of comorbidities should not necessarily preclude consideration of surgical treatment, having a thorough appreciation for the patient's global health status is critical to enable effective patient counseling.

It is not uncommon for adults presenting with symptomatic spinal deformity to have had previous spinal surgery, such as limited decompressions, short-segment fusions, or previous surgery for deformity correction.[12] Documenting the previous procedures, including the dates performed and whether they were successful in addressing the symptoms, can be helpful in appreciating the presenting deformity and symptoms, as well as in optimizing subsequent operative and nonoperative management.

Physical Evaluation

Physical examination of the ASD patient should include a global assessment of the deformity. This should be achieved by observing the patient in sequential supine, sitting, and standing postures, and through observing the patient's gait. Rigid thoracic and cervical deformities are readily appreciated in the supine position. Hip flexion contractures can be evaluated by the Thomas test while supine. Sitting removes the effect of the hips and can be used to assess thoracic and lumbar curvature without leg length discrepancy and hip flexion contracture effect. Standing is the most revealing posture for sagittal and coronal deformity. Trunk shift may be assessed in the coronal plane. Patients should also be assessed with knees extended and locked. In addition, patients with scoliosis should be examined leaning forward at the waist to 90° to reveal rib hump deformities.

Depending on the magnitude, the deformity may be readily apparent on observation (**Figs. 1** and **2**); however, lesser magnitude curves, as are often seen in degenerative lumbar scoliosis, may not be apparent on observation. In both standing and walking postures, the degree to which the patient may be "pitched forward," assume a flattened buttock position, or require knee flexion (crouched posture) can provide indication of positive sagittal malalignment. Camptocormia related to neuromuscular postural disorders such as myopathy and Parkinson disease often become apparent only with gait testing. Coronal imbalance, leg length discrepancy and obliquity of the pelvis may also be apparent.

Sagittal spinal alignment has been strongly correlated with measures of health-related quality

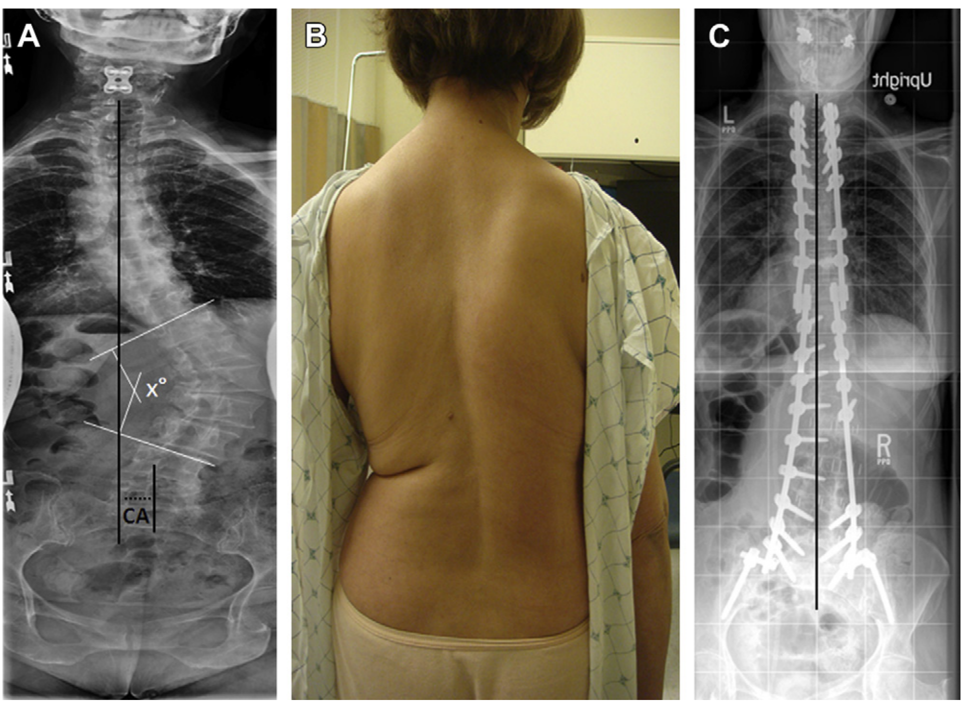

Fig. 1. Clinical photographs and radiographs of a 52-year-old woman presenting with back pain and right lower extremity radicular pain. (*A*) Preoperative posteroanterior radiograph demonstrates a dextroscoliosis with an apex at L1-2. X, coronal Cobb angle measurement. The C7 plumb line and central sacral vertical line are shown in black, and the distance between these (the coronal alignment [CA]) is depicted by the horizontal dashed line. In this case the CA is a negative value (−2.8 cm) because the C7 plumb line falls to the left of CSVL. Findings on clinical assessment are subtle. (*B*). Postoperative full-length posteroanterior radiograph following instrumented correction of the deformity (*C*). The C7 plumb line is shown in black and demonstrates restoration of CA.

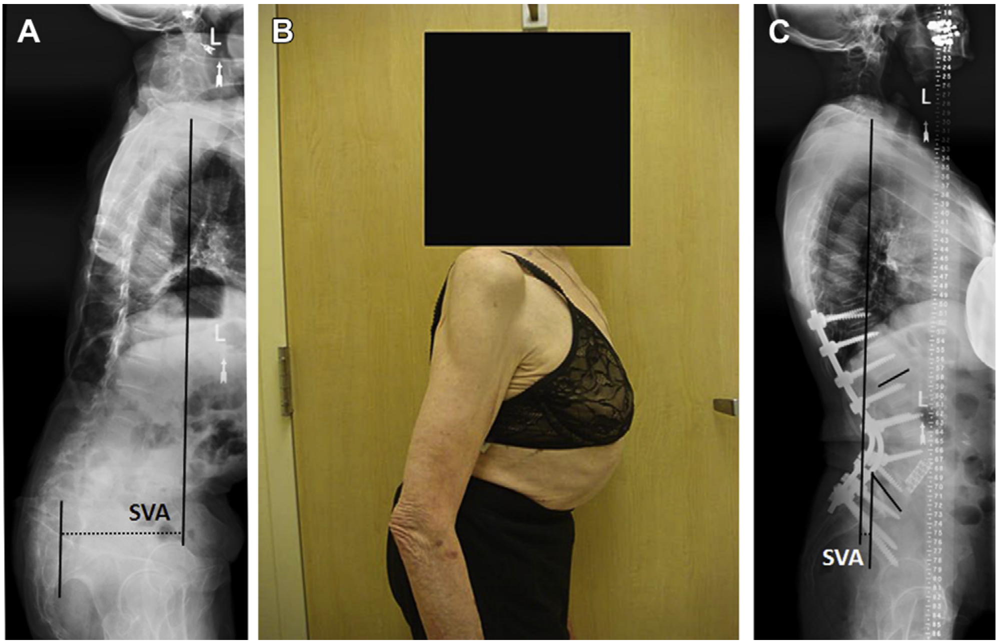

Fig. 2. Clinical photograph and radiographs of a 52-year-old woman presenting with back pain and right lower extremity radicular pain. (*A*) Preoperative full-length lateral radiograph demonstrates positive sagittal malalignment and pelvic retroversion. The C7 plumb line and a vertical line drawn at the posterosuperior aspect of the sacrum are drawn with solid black lines. The horizontal distance between these is shown as a dashed line and is the sagittal vertical axis (SVA). Findings on clinical assessment include a pronounced forward posture and pelvic retroversion on side profile (*B*). Postoperative full-length sagittal radiograph following instrumented correction of the deformity (*C*). Note that the C7 plumb line falls within 2 cm of the posterosuperior aspect of the sacrum, reflecting good restoration of sagittal spinal alignment.

of life.[13–20] Recent studies have demonstrated that the pelvis is a critical component of spinal alignment because the morphology of the pelvis sets the magnitude of lumbar lordosis necessary, which in turn, correlates with thoracic and cervical alignment, in a chain of correlation.[13,18,20–28] Evidence of compensatory mechanisms may also be evident in patients with significant positive sagittal spinopelvic malalignment (**Fig. 3**). In an effort to bring the head into alignment with the pelvis in the sagittal plane, these patients may compensate with pelvic retroversion, which results in the acetabulum assuming a more anterior position. Mild pelvic retroversion may be accompanied by hip extension, whereas more severe or fixed deformities may be accompanied by hip and knee flexion. Patients with chronic positive sagittal malalignment may develop hip flexion contracture that can prevent successful sagittal realignment surgery and should be identified and addressed with physical therapy preoperatively.

Pelvic obliquity may also be evident on clinical and radiographic evaluation and, when present, the radiographic studies should be repeated with a shoe lift (or standing blocks) that approximates the length discrepancy to assess the potential effect on the spinal curve.

A general neurologic assessment of the adult with spinal deformity should include assessment of motor strength and sensation, muscle tone, reflexes (peripheral, abdominal, and pathologic), coordination, and gait. Signs of myelopathy, such as hyperreflexia, clonus, and an impaired gait, may be present in patients with severe thoracic or concomitant cervical disease. This may prompt the need for cervical MRI before lumbar deformity correction.

RADIOGRAPHIC EVALUATION

Conventional Radiographs

Imaging studies are critical to the evaluation of ASD. Initial imaging evaluation typically begins with posteroanterior (PA) and lateral 36-in radiographs to provide assessment of global and regional spinopelvic alignment.[29] For patients able to stand, these radiographs should be obtained in a free-standing posture, with elbows flexed at approximately 45° and fingertips on the clavicles. This position ensures capturing the true degree of deformity

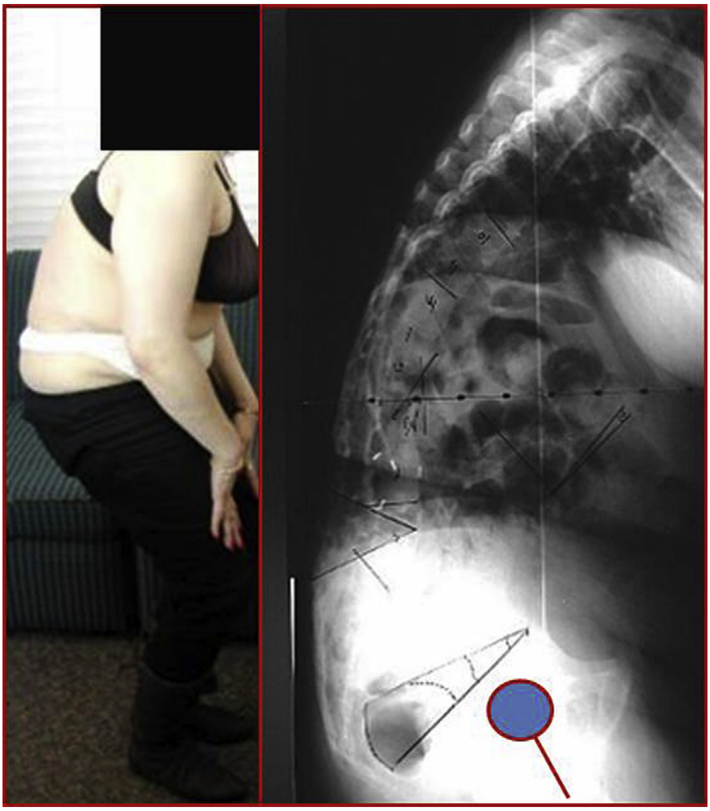

Fig. 3. Compensatory measures of positive sagittal malalignment. A 48-year-old woman with lumbar kyphosis and substantial positive sagittal malalignment shown in clinical photograph (*left panel*) and corresponding lateral standing radiograph (*right panel*) illustrates compensatory pelvic retroversion (increased pelvic tilt) and hip and knee flexion. These compensatory measures are attempts to maintain an upright posture.

and recruitment of compensatory mechanisms without influence from supports. To facilitate radiographic measurements, it is important that the radiographs include visualization of the cervical spine that is at least sufficient to localize the C7 vertebral body and allows for visualization of the bilateral femoral heads.

The PA radiographs should routinely be viewed with the heart on the left side (ie, true-left, true-right) (see **Fig. 1**C). This view enables assessment of the coronal alignment (CA) (**Fig. 4**A). Coronal decompensation is measured as the horizontal distance between a plumb line dropped downward from the center of the C7 (C7PL) vertebral body and the central sacral vertical line (CSVL), which is a line drawn vertically through the center of the sacrum. A C7PL that falls to the left or right of the CSVL is designated with negative or positive values, respectively. A CA of 0 is designated as neutral. Pelvic obliquity can also be measured based on the PA view, as illustrated in **Fig. 4**B. If pelvic obliquity is detected, lower extremity scanograms should be taken to assess limb length discrepancy. Limb length discrepancy may be primary due to congenital length differences or may be secondary due to osteoarthritis or improperly sized lower extremity joint replacements.

The PA view is also used to assess for coronal curvature of the spine (scoliosis). The location of a coronal curvature is defined by the apex of the curve. The apex is typically the disc or vertebra that is maximally displaced from the midline and minimally angulated. A deformity is considered thoracic if it has an apex between T2 and the T11–12 disc, thoracolumbar if the apex lies between T12 and L1 vertebra, and lumbar if the apex is at or distal to the L1–2 disc. In scoliosis the curve is described based on the side of its convexity. A curve convex to the right is designated as dextroscoliosis and a curve convex to the left is designated as levoscoliosis. There are always two or more scoliotic curves in the coronal plane. The largest curve is considered the major curve because it is the primary deformity force in the coronal plane. The smaller curves that are adjacent to the major curve are termed minor curves. Minor curves may be compensatory or structural depending on the flexibility of the curve on side-bending radiographs. Side-bending radiographs should be obtained with the patient in the supine position to eliminate gravity and obtain the greatest amount of correction. Compensatory curves are flexible on side-bending radiographs (typically reduced to $<25^\circ$), whereas structural

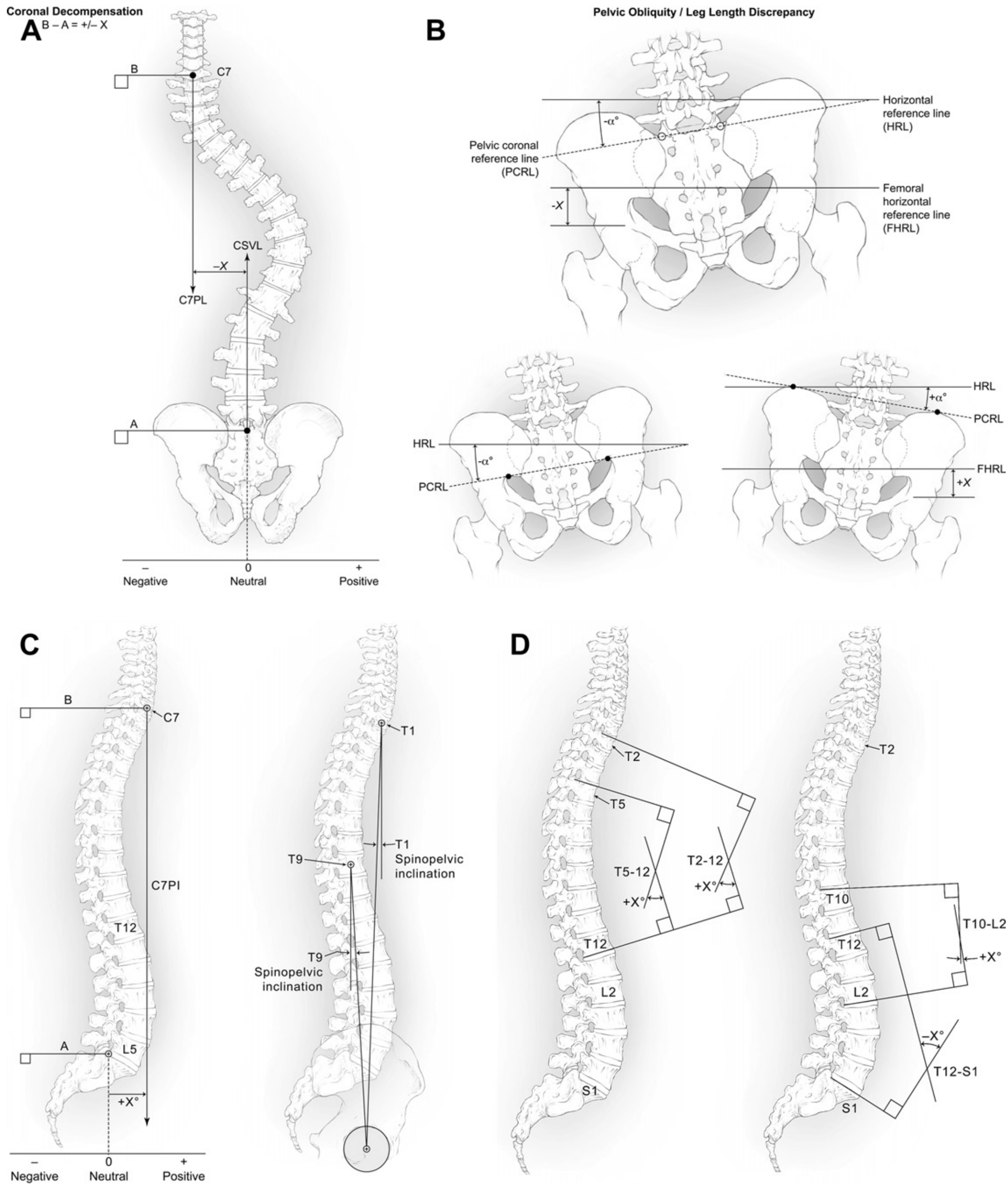

Fig. 4. Spinal radiographic measures and pelvic obliquity. (*A*) Coronal view of the spine illustrating technique to measure CA, which is the horizontal distance "X" between the C7 plumb line (C7PL) and the central sacral vertical line (CSVL). (*B*) Pelvic obliquity and leg length discrepancy. Illustrations of the technique to measure pelvic obliquity. (*C*) Sagittal view of the spine illustrating technique to measure sagittal alignment based on the SVA, which is the horizontal distance ("X") between the posterior superior corner of the sacrum and the C7PL (*left panel*). Also shown are the techniques to measure the T1 and T9 spinopelvic inclinations (T1SPI and T9SPI, respectively), which are alternative measures of global sagittal alignment that do not rely on imaging scaling. (*D*) Drawings showing methods to assess regional sagittal spinal alignment, including T2-T12 TK, T5-T12 TK, T10-L2 thoracolumbar junction alignment, and the lumbar lordosis (T12-S1 angle). PCRL, pelvic coronal reference line; HRL, horizontal reference line; FHRL, femoral horizontal reference line. (*Courtesy of* K.X. Probst/Xavier Studio, 2012; with permission.)

minor curves are rigid (typically >25° on supine side-bending radiographs). Compensatory curves develop in response to the major curve to help maintain the head over the pelvis in the coronal plane and will typically correct spontaneously after surgically correcting the major curve. However, minor curves that are structural are sources of deformity that behave independently from the major curve and, therefore, will not spontaneously correct after correcting the major curve. Therefore, structural minor curves should always be identified and incorporated into the surgical construct to reduce the risk of residual postoperative spinal deformity.

Scoliosis angles are measured via the Cobb method (see **Fig. 1**A). This technique involves selecting the vertebrae maximally tilted into the curve (end vertebra). Lines are drawn parallel to the superior end plate of the cephalad end vertebra and the inferior end plate of the caudal end vertebra. If the end plates are not clearly visualized, an alternative technique is to use the pedicle margins as the basis for these lines. Bisecting perpendicular lines from the endplate lines are drawn, and the angle determined. The Cobb technique is classically thought to have an inherent error of 3° to 5°. Therefore, generally, a change in angle between consecutive films has to be greater than 5° to be considered a true change. Intraobserver error ranges between 1% to 5% and interobserver error can be as high as 10°.[30] Modern PACS workstations and image viewers have tools to measure Cobb angles digitally. To date, studies comparing Cobb angle measurements of primary and secondary curves on digital radiographs and traditional radiographs have shown no statistical difference in the intraobserver or interobserver variance between the two techniques.[31–33] New systems that automatically measure the Cobb angle and determine rotation are currently under development and may be able to reduce intraobserver and interobserver variability. Proximal and distal neutral vertebra (not rotated in axial plane) and stable vertebra (vertebra above and below the end vertebra that is bisected by the CSVL) may also be determined because these are used to help select fusion levels in operative planning.

By convention, the lateral full-length radiograph should be oriented such that the patient faces toward the right (see **Fig. 2**A). This view allows assessment of regional and global sagittal alignment (see **Fig. 4**C–D). The sagittal vertical axis (SVA0 is a global measure of sagittal alignment and is the horizontal distance between the C7PL and the posterior superior corner of the sacrum (see **Fig. 4**C). A C7PL that falls behind or in front of the posterior superior corner of the sacrum is designated with negative or positive values, respectively. Alternative measures of global sagittal spinal alignment are the T1 and T9 spinopelvic inclinations (T1SPI and T9SPI, respectively) (see **Fig. 4**C). In contrast to the SVA, which is a measure of distance, the T1SPI and the T9SPI are angles and, therefore, not dependent on knowing the scale of the image. An SVA T1SPI, or T9SPI of 0 is designated as neutral.

Regional sagittal alignment measures include thoracic kyphosis (TK), thoracolumbar junction alignment (TLA), and lumbar lordosis (LL) (see **Fig. 4**D). By convention, kyphosis and lordosis are designated with positive and negative values. Common measures of TK are based on the vertebral end plates spanning T2 to T12 or T5 to T12. Assessment of TLA typically reflects the angle spanning the cephalad and caudal endplates of T10 and L2, respectively (see **Fig. 4**D). A common measure of lumbar lordosis is based on the angle between cephalad and caudal endplates of T12 and S1, respectively.

A comparison between the degree of deformity between weight bearing and non-weightbearing films (ie, supine) provides information regarding the rigidity of the deformity. Additional views to help determine stiffness of the deformity can also be helpful. These views include supine lateral bending films, bending films over a bolster, fulcrum bending films, and push and traction views. In the evaluation of spondylolisthesis, dynamic lateral views (flexion and extension) of the lumbar spine are used to help determine the degree of instability. Additional plain radiograph views that can be helpful in spinal deformity evaluation include oblique views to visualize the pars interarticularis, Ferguson view to better visualize the sacral region, and the Stagnara or Leeds view, which is an oblique view through the apical region of a scoliotic curve that accounts for rotation and thus allows better visualization of the pedicles.

Axial rotation on conventional radiograph can be determined using the Nash-Moe method. The Nash-Moe method categorizes vertebral rotation into five grades based on the location of the pedicle in relation to the lateral aspect of the vertebral body.[34] CT imaging may facilitate more accurate measurement of rotation than standard radiograph techniques.[35]

Overall sagittal spinal alignment is substantially affected by relationship of the spine to the pelvis.[13,20,24,26] (Schwab F, Bess S, Blondel B, et al. Combined assessment of pelvic tilt, pelvic incidence or lumbar lordosis mismatch and sagittal vertical axis predicts disability in adult spinal deformity: a prospective analysis. 2012.

Submitted for publication.) An adult patient with thoracic hyperkyphosis or loss of lumbar lordosis will attempt to compensate for positive sagittal malalignment through pelvic retroversion. Key measures of pelvic alignment include pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS) (**Fig. 5**). The PI is a morphologic parameter that is a fixed angle in each individual once skeletal maturity is reached and does not depend on the position of the pelvis. Although normative mean values for PI range from 50° to 55°, individual reported normative values encountered range broadly, from 28° to 84°.[36] Consistent with the morphologic nature of PI, it does not vary with age. (Blondel B, Schwab F, Ames C, et al. Age-related cervical and spinopelvic parameter

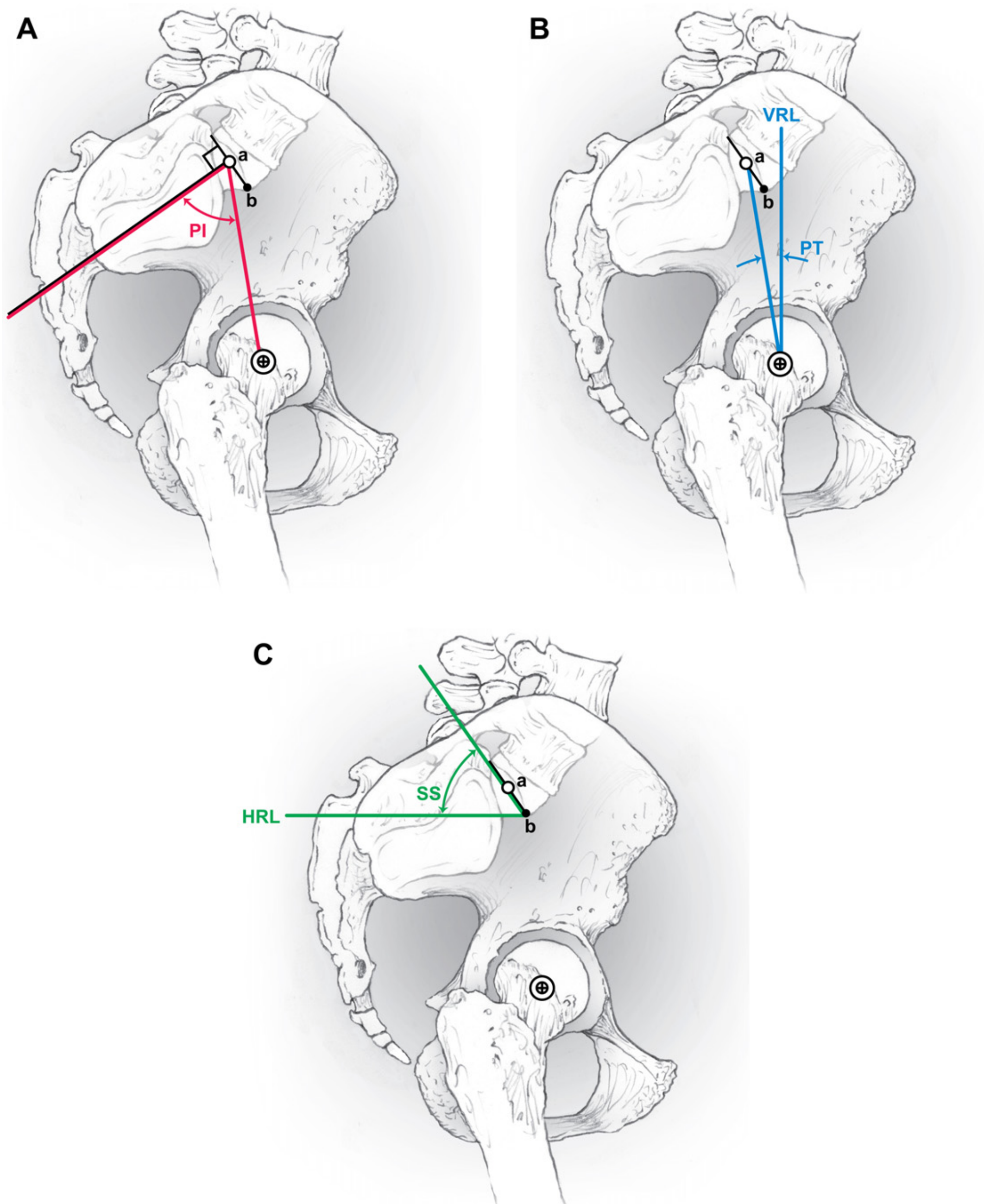

Fig. 5. Measures of sagittal pelvic alignment. PI (*A*), PT (*B*), and SS (*C*). (*Courtesy of* K.X. Probst/Xavier Studio, 2012; with permission.)

variations in a volunteer population. 2012. Submitted for publication.) The PI is measured by determining the angle between a line drawn perpendicular to the sacral end plate at its midpoint and a line from the femoral head axis to this point (see **Fig. 5**). If the femoral heads are not perfectly aligned with each other on lateral radiograph, the femoral head axis location is approximated by the midpoint of a line connecting the geometric center of each femoral head. The PT is a measure of the degree of pelvic retroversion and is a compensatory parameter, such that a patient with positive sagittal malalignment who retroverts the pelvis in an effort to maintain an upright posture will have an increase in the PT. Normative mean values for PT range from 11° to 15°, and individual reported normative values range from −5° to 31°. A PT greater than or equal to 22° has been suggested as a threshold value for moderate disability (Oswestry Disability Index [ODI] score >40) in the setting of ASD. (Schwab F, Blondel B, Bess S, et al. Radiographic spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis. 2012. Submitted for publication.) The PT is the angle determined between a vertical reference line drawn up from the center of the femoral heads (femoral head axis) and a line drawn from the femoral head axis to the midpoint of the sacral end plate (see **Fig. 5**). The SS is the angle of a line drawn along the sacral end plate relative to a reference horizontal line (see **Fig. 5**). A mathematical relationship exists among these pelvic parameters such that the PI is the sum of the PT and the SS (PI = PT + SS).[21]

Assessment of pelvic parameters can be particularly helpful for surgical planning. Because the PT is a compensatory mechanism, it can mask the degree to which a patient is sagittally malaligned. Thus, a patient may have an SVA that appears to be relatively close to normal but may be maximally compensating by increasing the PT and decreasing the SS. Not taking into account this compensation could lead to continued symptoms due to undercorrection in the sagittal plane. In addition, a relationship between PI and LL has been reported in normal subjects and it can be approximated that the LL should be within 9° of the PI.[13,20,21,26] (Schwab F, Bess S, Blondel B, et al. Combined assessment of pelvic tilt, pelvic incidence or lumbar lordosis mismatch and sagittal vertical axis predicts disability in adult spinal deformity: a prospective analysis. 2012 Submitted for publication.) This relationship can be particularly useful in patients with flat back deformity in determining the magnitude of lumbar lordosis that needs to be recreated with surgical treatment.

Advanced Imaging

Advanced imaging has become nearly standard in the evaluation of adults with spinal deformity. Common modalities include MRI, CT, CT myelography, CT angiography (CTA), and MR angiography (MRA). MRI gives excellent soft tissue detail and is useful in demonstrating disc disease, spondylotic changes, and intraspinal anomalies (**Fig. 6**). MRI should be obtained in all cases with any question of neurologic compromise unless contraindicated. Although CT imaging gives

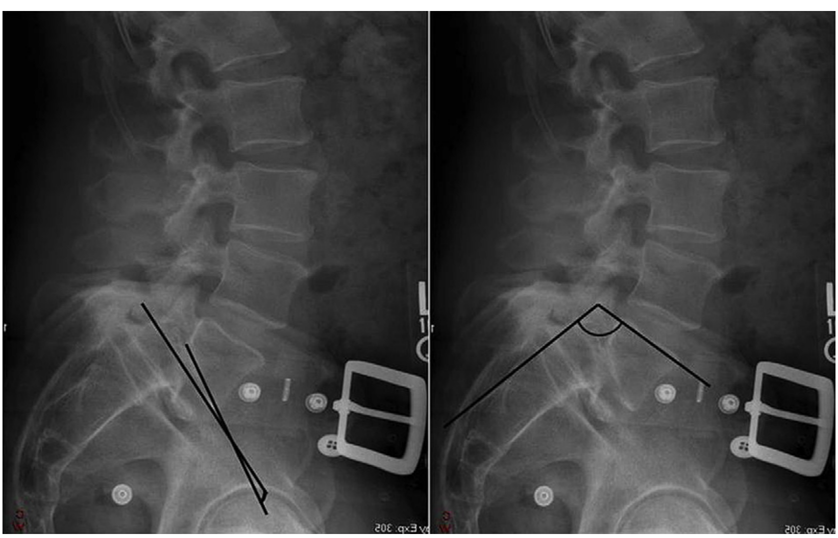

Fig. 6. Lateral radiograph demonstrating measurement of Boxall slip angle (*left*) and Dubousset lumbosacral angle (*right*).

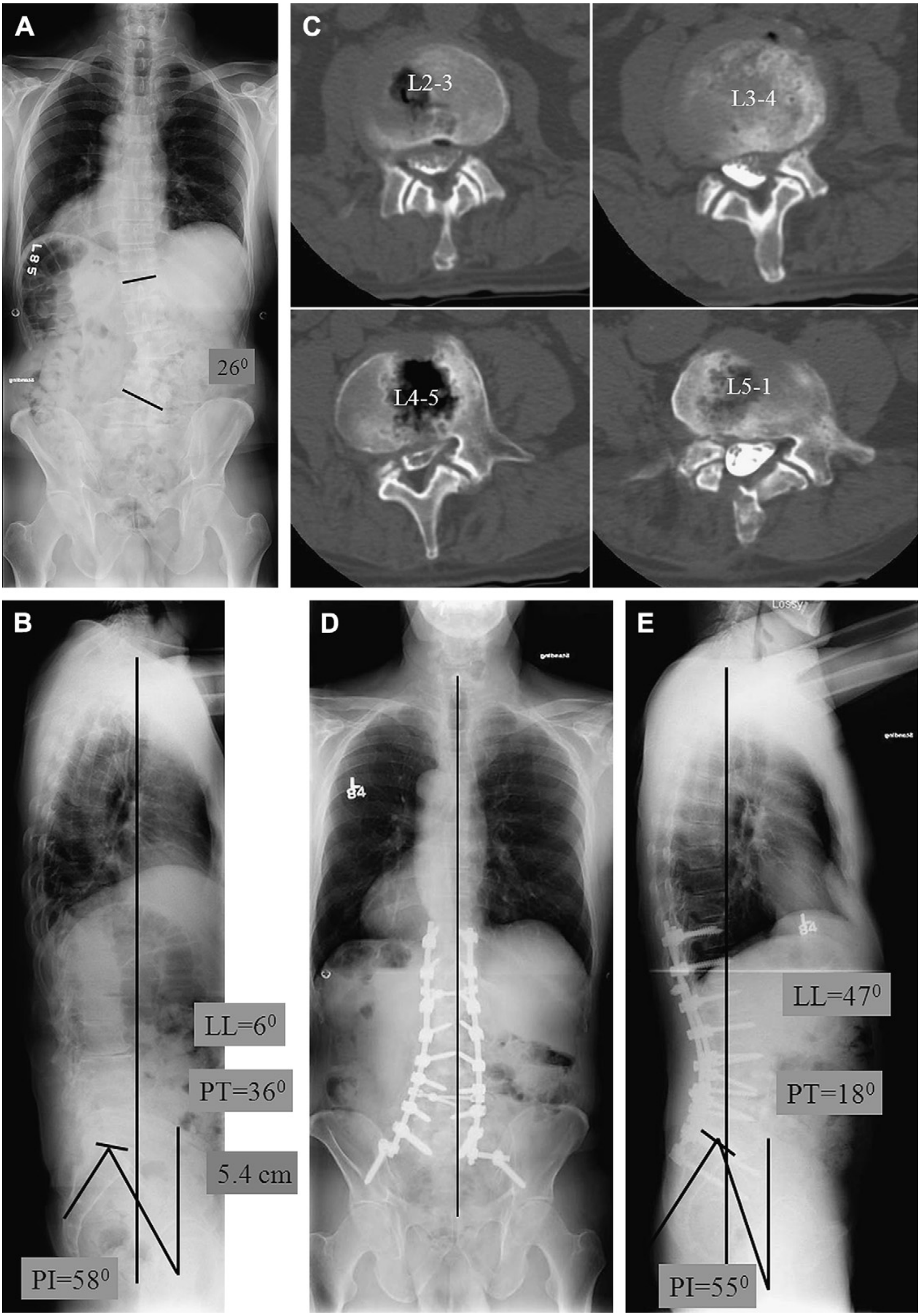

Fig. 7. Imaging studies of a 67-year-old man who presented with severe low back pain when standing, including preoperative PA (*A*) and lateral (*B*) full-length standing radiographs, CT myelogram axial images (*C*), and PA (*D*) and lateral (*E*) full-length standing radiographs at 36 months following surgical correction. See text for clinical details. LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt.

excellent bony detail and is extremely useful in preoperative planning, CT myelography has the added benefit of providing intraspinal information in addition to high-resolution bony detail. CTA and MRA are useful in the evaluation of vascular anatomy, which may have surgical approach implications.

Advances in imaging software such as multiplanar rendering (MPR) allow the surgeon to view multislice CT and MRI data in multiple and adjustable planes. This allows for more accurate preoperative measurement of pedicle diameter and a greater appreciation of the disease process. Three-dimensional reconstructions can easily be created to aid in operative planning (see **Fig. 6**). Thin-cut CT myelography plus MPR provides extremely useful information in operative planning for deformity.

CASE EXAMPLE

A 67-year-old recently retired executive presents with severe low back pain when standing that improves to only a mild ache when sitting that has been present and progressive for the last 5 years. He has symptoms of mild neurogenic claudication but denies any decreased change in radicular symptoms, sensation, motor strength, gait difficulties, or bowel and/or bladder symptoms. His visual analog score (VAS) for back and leg pain are 8 and 2, respectively, on a scale of 0 to 10. His ODI is 48 out of 100 (reflecting high-moderate disability). His past medical and surgical history are significant for hypertension, hypercholesterolemia, appendectomy, and a right L5-S1 posterior hemilaminotomy and microdiscectomy approximately 10 years ago, with resolution of right leg radicular symptoms. He has exhausted nonoperative measures, including multiple trials of physical therapy, narcotics, epidural steroid injections, and facet blocks. He presents for a fourth opinion.

Full-length standing PA and lateral radiographs demonstrate a 26° degenerative dextroscoliosis, measured from T12-L4, with an apex at L3 (**Fig. 7**A) and SVA of 5.4 cm, LL of 6°, PT of 36°, and PI of 58° (see **Fig. 7**B). Axial CT myelogram images demonstrate mild and moderate canal stenosis at the L2-3 and L4-5 disc levels, respectively (see **Fig. 7**C).

The patient elected for surgical treatment and underwent T11-S1 posterior instrumented arthrodesis and decompression, including placement of iliac screws and an L5-S1 anterior lumbar interbody fusion. The postoperative course and follow-up were uncomplicated. At 36-month follow-up, his back and leg pain had resolved (both VAS back and leg pain scores of 0) and his ODI had improved to 8 (reflecting minimal disability). PA and lateral full-length standing radiographs demonstrated no significant coronal or sagittal spinal malalignment, and radiographic parameters include LL of 47°, PT of 18°, and PI of 55° (see **Fig. 7**D, E). Note that the PI-LL mismatch is now within 9°, the PT is within normal limits (<25°), and the spine is coronally and sagittally aligned.

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