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Operative Techniques in
Orthopaedics

Advances in Preoperative Planning: When, How and What to Measure

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Spinal alignment is an important determinant of health status and disability for patients with spinal deformity. Measuring alignment of the spine is important to quantify spinal deformity, to determine the goals of surgical correction, and to guide the choice of operative techniques for surgical correction. The purpose of this chapter is to describe the metrics of spinal alignment, and to review what to measure, how to measure it, and when to make measures of alignment along the continuum of care for spinal disorders.
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Introduction

Alignment of the spinal column is important as a preoperative metric that is associated with pain, function, energy expenditure for gait, and health-related quality of life metrics. Alignment is also important as a goal for operative correction of deformity, and the choice of a surgical approach to deformity correction is largely determined by the postoperative alignment goals. Spinal alignment is highly variable between individuals, and across ages and body morphometrics. The appropriate global alignment of the spinal column may be defined as the shape which positions with cranial center of mass over the center of gravity for the body in neutral posture, or in the absence of external forces. The distribution of lordosis and kyphosis in the distinct regions of the spine is significant, and reconstruction of optimal alignments within each region of the spine is an important goal of operative spinal reconstruction. This chapter will describe the concepts of spinal alignment and balance, define normal alignment across different ages, and describe alignment metrics from the lumbopelvic region to cervical spine.

Alignment and Balance

Alignment of the spine is a static parameter based upon standing radiographs. Balance is a dynamic state of equilibrium that results in a stable position. Dubousset describes the harmony and balance of the spine as being disrupted by spinal deformity.[1] In his reflections, Dubousset recognizes that the unfused part of the spine provides the mobility that allows the body to maintain harmony and balance. While alignment goals define the parameters and metrics for our surgical plan to fuse portions of the spine, balance is provided by the corollary, the unfused portion of the spine. Balance and alignment are not synonymous. Balance of the body is dynamic, and required for stable stance and for minimizing energy expenditure in the upright posture.[2] A harmonious relationship, or a functional interplay, between the fused and unfused portions of the spine is required for balance. Alignment is a static parameter, and a measurable goal for surgical reconstruction of the spine. The reciprocal changes of the unfused spine to surgical realignment through fusion can often be difficult to predict, and may lead to significant decompensation and imbalance.[3-7]

Appropriate patient positioning is important to visualize the relevant landmarks for measuring alignment, and for an accurate assessment of deformity. Horton et al demonstrated that the optimal patient stance for assessment of spinal alignment is for the patient to stand with hips and knees extended, and for the proximal interphalangeal joint to be in the supraclavicular fossa.[8] Small changes in knee flexion, hip extension, and arm position may have a major impact on alignment of the spine.[9] The critical radiographic landmarks for the assessment of spinal deformity include the femoral heads, the sacrum including S1, T12, T3, C7, C2, and the cranial center of mass.[10] A standard 36 inch AP and lateral projection of the spine is adequate for visualization of the spine from C2 to the pelvis with appropriate distance to accommodate for magnification. Radiographic systems for

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simultaneous biplanar image capture may be useful for assessment of hip and knee positions, detection of leg length discrepancies, and for transformation of 2 dimensional images to a 3-dimensional representation of the spine.[11,12] Full length standing radiographs, or sitting images for patients who are unable to stand, including the femoral heads to C2 are fundamental to preoperative planning in deformity surgery. The operative goal of changing preoperative alignment to a more functional postoperative alignment is guided by a careful assessment of preoperative images regarding global, regional, and segmental alignment.

Preoperative Radiographic Parameters

Sagittal Alignment

Alignment of the spine in the sagittal plane is measured in a standing lateral radiograph. The measurement of sagittal alignment requires visualization of the spine from cranial center of mass to the femoral heads.

For thoracolumbar deformity, global alignment of the spine is measured by the relationship of C7 or T1 to the posterior margin of the sacrum. Metrics for global alignment of the spine include:

(1) C7 sagittal vertical axis
(2) T1 sagittal tilt (Fig. 1)
(3) T1 pelvic angle.

The C7 sagittal vertical axis is a parameter that is moderately associated with health status including ODI and SF-12 measures.[13,14] However, the C7 sagittal vertical axis alone has significant limitations because it requires calibrated films to get accurate measurement in millimeters, and because compensatory changes in pelvic tilt can significantly change the sagittal vertical axis. The T1 Sagittal Tilt and the T1 Pelvic Angle are angular metrics, and therefore independent of calibration of the film, and both metrics include the effect of pelvic tilt on global alignment by measuring from the femur. Measurements that are associated with asymptomatic patients include a C7 SVA <4 cm, a T1 sagittal tilt <0 degrees, and a T1 Pelvic Angle <14 degrees.[15-18]

The pelvic incidence is the fundamental radiographic parameter that defines the regional alignments of the spine.[19,20] Pelvic incidence is a radiographic metric that accounts for the slope of the sacrum within the pelvis, and the depth of the pelvis measured by the distance between the middle of the sacrum and the center of the femoral heads (Fig. 2). Mathematically, pelvic incidence equals the Sacral Slope plus the Pelvic Tilt. Pelvic incidence is the independent

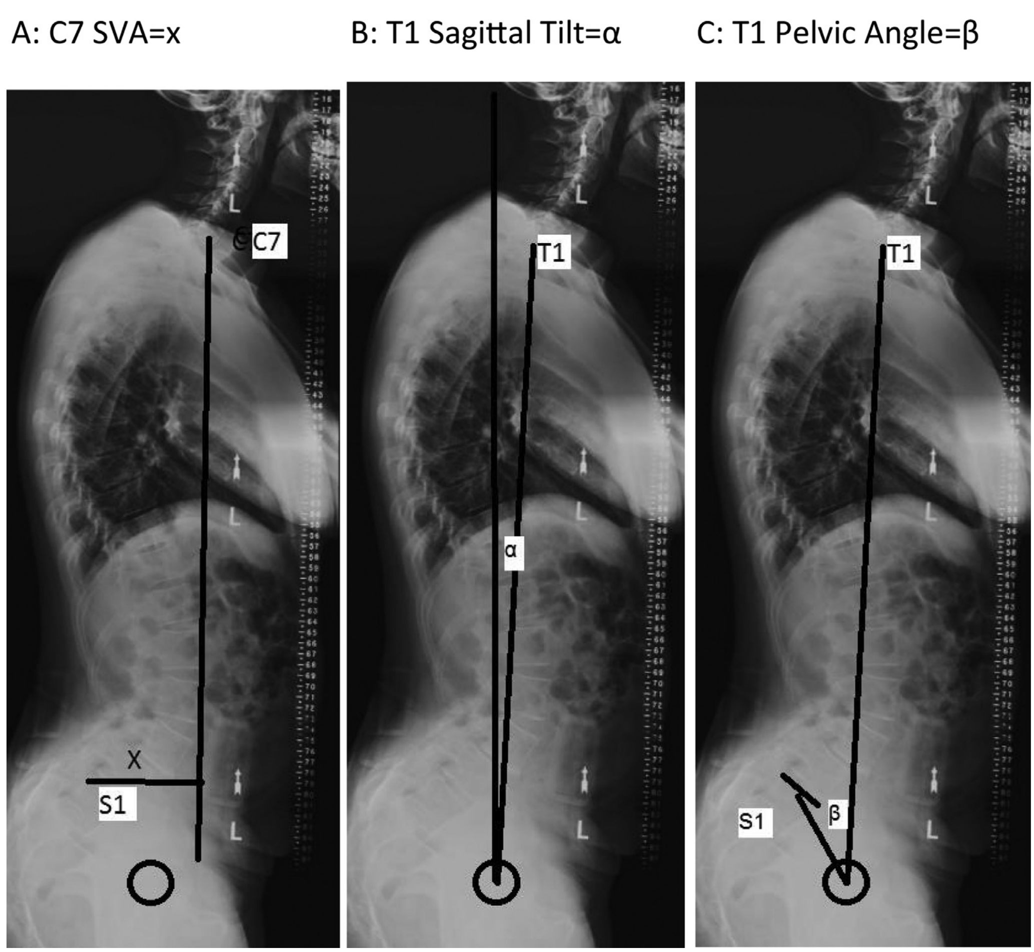

Figure 1 A. C7 Sagittal vertical axis. B. T1 Sagittal Tilt C. T1 Pelvic Axis.

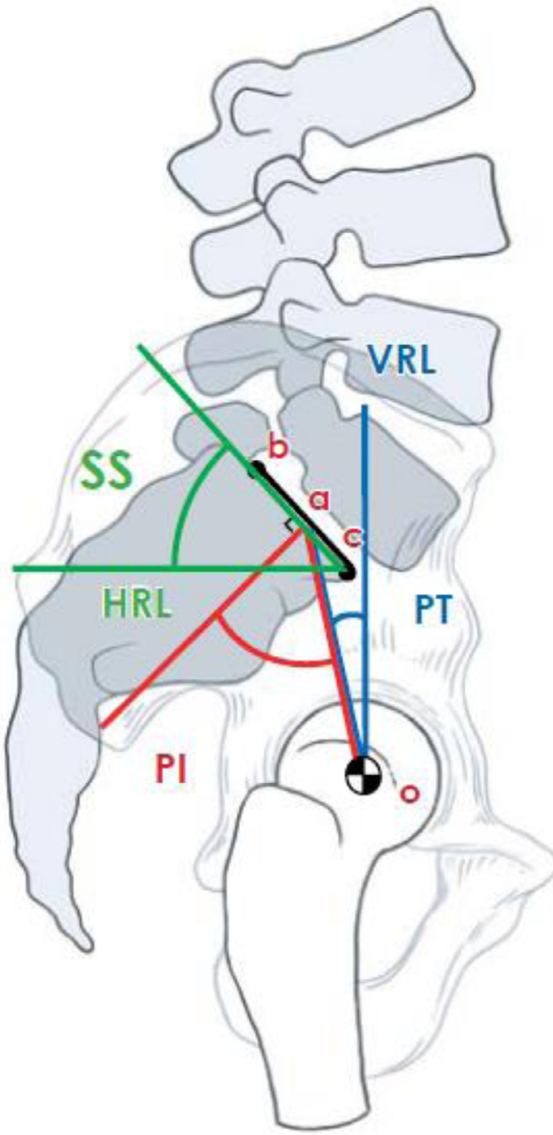

Figure 2 Pelvic parameters. PI, pelvic incidence; PT, pelvic tile; SS, sacral slope; HRL, horizontal relative line; VRL, vertical relative line. (Color version of figure is available online.)

and intrinsic anatomic parameter that determines the orientation of the sacrum within the pelvis, and the relationship between the sacrum and the center axis of gravity. Patients with a high pelvic tilt require a high lumbar lordosis in order to gain adequate sagittal alignment of the spinal column, and patients with a low pelvic incidence require correspondingly lower lordosis. The chain of correlation between regions of the spine begins with the pelvic incidence of the individual patient, and there are consequent significant correlations between pelvic incidence, lumbar lordosis, thoracic kyphosis, T1 tilt, and cervical lordosis (Fig. 3).[21]

Regional parameters for thoracolumbar alignment are lumbar lordosis and thoracic kyphosis. Lumbar lordosis is closely correlated with pelvic incidence. In the young adult with an asymptomatic spine, lumbar lordosis is within 10 degrees of pelvic incidence, and a mismatch between lumbar lordosis and pelvic incidence is associated with disability in patients with adult spinal deformity.[22,23] It is important to recognize that normal values for lumbopelvic parameters are determined by measurements in asymptomatic adults, and measurements that are associated with disability are determined by patients presenting for symptomatic adult scoliosis. There is significant variability in lumbopelvic parameters between individuals, and there is a clear trend toward a reduction of lumbar lordosis with age, and an increase in both the difference between lumbar lordosis and pelvic incidence, and the overall sagittal vertical axis displacement that is normal in older adults. Therefore, surgical goals for sagittal alignment in older adults may require significant adjustment including sagittal vertical axis goals of up to 8 cm, and lumbopelvic mismatch of up to 20 degrees.[24-27] Recognizing changes in spinal alignment with age is important for surgical planning, and for avoidance of postoperative complications including junctional pathology.[28]

Progressing from global alignment to regional alignment to segmental alignment of the spine, the relationship of adjacent segments along the spinal column has an important impact on health status and overall alignment. The patient with a dysplastic olisthesis and a high slip angle between L5 and S1 demonstrates the importance of a lordotic alignment between adjacent vertebral bodies, especially at the lumbopelvic junction. There is a high association between T1 tilt and displacement of sagittal vertical axis in children and adults with dysplastic olisthesis (Fig. 4).[29,30] Burkardt and Bridwell described the segmental relationship between vertebra in asymptomatic volunteers, and demonstrated the distribution of lordosis in the asymptomatic spine is weighted toward the segments of L4-5 and L5-S1.[31] The distribution of lumbar lordosis in preoperative planning for spinal reconstruction has been closely associated with the risk of adjacent segment pathology in both degenerative pathologies and spinal deformity. In degenerative pathology, undercorrection of lordosis between L4 and S1 is highly associated with adjacent segment degeneration and stenosis. Senteler et al demonstrated biomechanically that a pelvic incidence-lumbar lordosis mismatch of >15 degrees led to significantly higher joint reactive forces at the segment adjacent to the fusion.[32] Clinical studies confirmed a significantly higher rate of revision surgery and adjacent segment pathology in patients with lumbar degenerative pathology who were treated with fusions of the lower lumbar spine and sacrum with segmental lordosis that was mismatched to the pelvic incidence.[33,34]

In deformity, a composite measure of Global Alignment and Proportion Score (GAP Score) encompasses relative lordosis, pelvic version, spinopelvic alignment, age, and distribution of lumbar lordosis.[35] Younger patients with an anteverted pelvis and more than 50% of total lordosis in the region of L4 to S1 may be protected from mechanical complications in deformity realignment surgery, but the reliability of the GAP score requires further validation.[36,37]

A preoperative assessment of the rigidity of spinal deformity is important in planning strategies for operative correction of deformity. Standing alignment of the spine may be affected significantly by factors including symptomatic facet arthropathy and spinal stenosis, and postural variability related to pain or fatigue. An assessment of postural sagittal

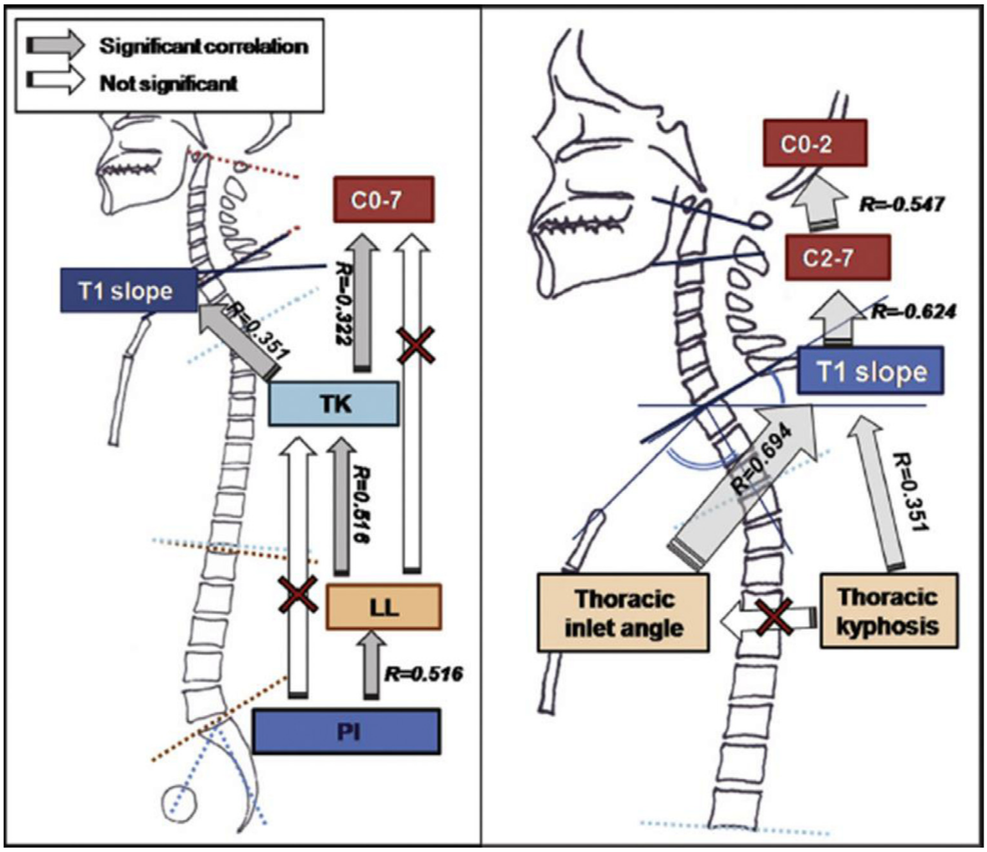

Figure 3 The chain of correlation between pelvic incidence and regional parameters of spinal alignment. (Color version of figure is available online.)

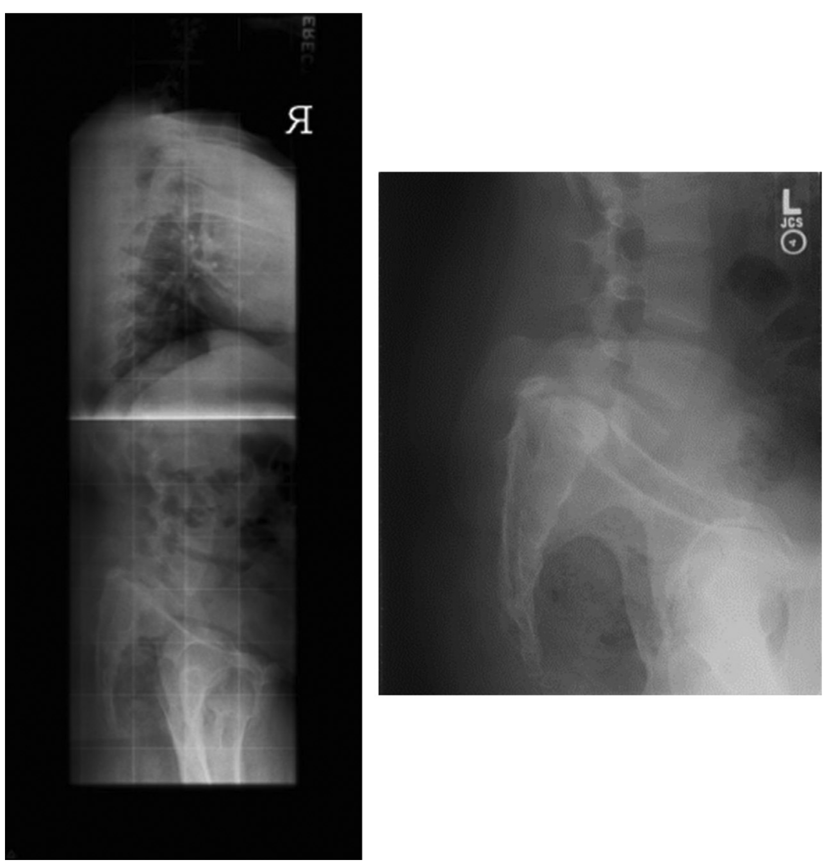

Figure 4 Standing lateral radiographs showing high grade spondylolisthesis at L5-S1.

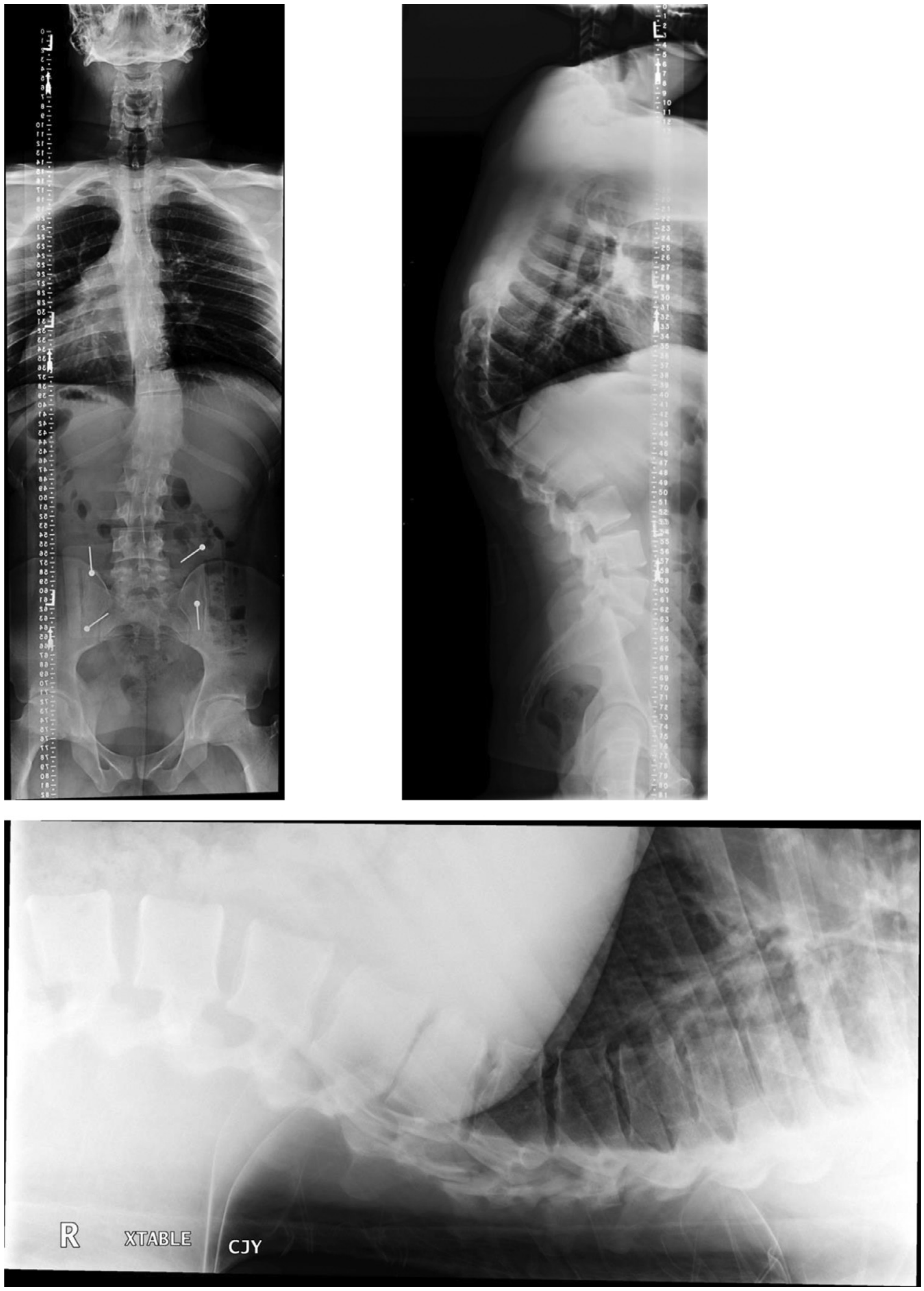

Figure 5 Standing radiographs of 21-year-old male with atypical Scheuermann kyphosis. Supine radiographs demonstrate spinal flexibility.

malalignment compared with fixed sagittal malalignment may be gained by measuring pelvic tilt. The patient with postural malalignment will present with a low pelvic tilt, while the patient with a fixed malalignment will typically have high pelvic tilt to compensate for the malalignment above the pelvis. Flexible malalignment of the spine may be identified by comparing standing radiographs to supine or prone films, or to films taken with the patient bending including over a bolster.[38-40] Figure 5 demonstrates the flexibility of the spine in a patient with Scheuermann kyphosis between standing and supine. CT or MRI scans are an opportunistic way to identify spinal flexibility. Vacuum discs on CT scan demonstrate significant flexibility of the spinal motion segments and opportunity for correction of deformity with prone or supine positioning of the patient at the time of surgery. The lumbopelvic mismatch that is apparent with the patient in a supine or prone position more accurately reflects the amount of correction that will be necessary during surgery, and is often significantly less that the standing mismatch. Therefore, preoperative planning that includes an accurate assessment of spinal flexibility is important to accurately assess the need for 3 column osteotomies compared with simple posterior column osteotomies for correction.

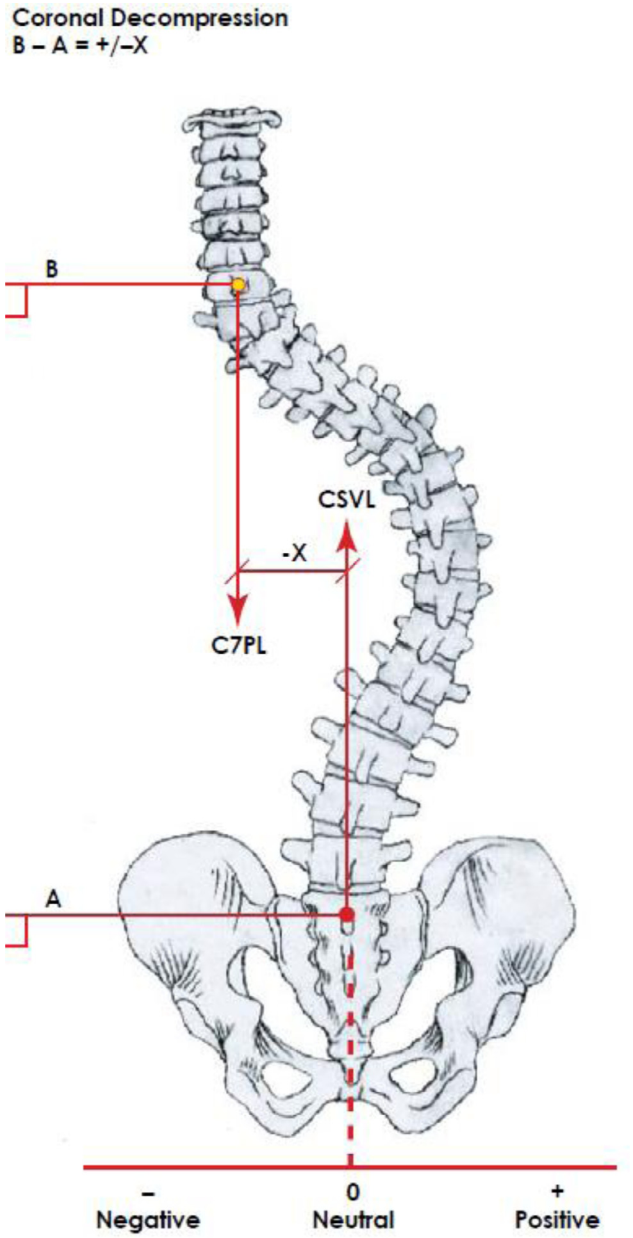

Figure 6 Schematic diagram showing global coronal alignment. This is measured by the offset between the centroid of C7 and the central sacral vertical line (CSVL). (Color version of figure is available online.)

Overall, sagittal alignment parameters include segmental, regional, and global metrics. The optimal sagittal alignment of the fused portion of the spine will interact in a dynamic harmony with the unfused spine to optimize patient function, energy conservation, and health-related quality of life.

Coronal Alignment

Coronal alignment of the spine is an important goal for preoperative planning, and specific coronal malalignment patterns are important to recognize due to a high association with postoperative malalignment of the spine. Malalignment of the spine in the coronal plane is associated with patient clinical presentation that includes truncal shortening, waist asymmetry, rib on pelvis pain, and pelvic obliquity. In contrast to sagittal malalignment when patients have many compensatory mechanisms, patients with coronal malalignment have limited ability to compensate for deformity. Coronal malalignment affects patients in both the standing and sitting positions, and can be a significant cause of pain and disability. The mechanism for compensating for coronal malalignment with pelvic obliquity is to flex the hip and knee on the inferior side of the pelvis, and hyperextend the hip and knee on the superior side. Pelvic obliquity may be the result of coronal deformity in the thoracolumbar spine, and the resultant oblique takeoff between the fractional lumbar curve and the sacrum. It is important to recognize pelvic obliquity due to spinal deformity, and pelvic obliquity due to leg length discrepancy. In the patient with a pelvic obliquity due to a leg length discrepancy, use of standing blocks to level the pelvis is important to assess spinal deformity, and a preoperative plan is most appropriately made with the pelvis in a level position.[41,42] In the patient with an apparent leg length discrepancy due to spinal deformity, surgical correction of coronal alignment to place C7 in alignment with the central sacral vertical line is the goal of coronal plane realignment.

Global coronal alignment is measured by the offset between the centroid of C7 and the central sacral vertical line (Fig. 6). In spinal deformity, coronal curves in the thoracic, lumbar and lumbosacral regions of the spine may present with significant differences in magnitude and in flexibility. In the patient with level shoulders and a well-aligned C7 plumb line to the central sacral vertical line, asymmetric correction of one curve compared to the other curves may lead to significant postoperative decompensation. Therefore, assessment of curve flexibility on bending or traction films is an important measure for surgical planning. The flexibility of the deformity may be determined on physical examination with lateral bending while standing or supine or by lifting the patient under the axilla to assess passive correction. Patients with more advanced coronal plane deformity may complain of ribs abutting the pelvis. The ribs on the concavity of the fractional curve or convexity of the thoracolumbar major curve may approximate the iliac crest and pelvic brim, and patients may complain of painful impingement most commonly in the transition from sitting to standing. Palpation of the relationship and distance between the costal margin and the pelvis will demonstrate asymmetry of trunk shift and the rib on pelvis impingement. Clavicle asymmetry, or elevation of the clavicle contralateral to the major structural curve, will alert the surgeon to the importance of including the upper thoracic curve in the instrumented construct to prevent exacerbation of shoulder asymmetry.

Obeid et al described a classification for coronal plane malalignment that is useful for preoperative planning and surgical strategies.[43] The authors describe 2 primary patterns of coronal malalignment. Type 1 is the pattern in which the coronal global malalignment falls to the side of the pelvis that is contralateral to the convexity of the thoracolumbar deformity. The operative strategy for patients with a type 1 deformity is to gain coronal realignment through shortening of the convex curve (Fig. 7). The type 2

Figure 7 Preoperative and postoperative radiographs of a patient with a type 1 coronal deformity.

pattern is more challenging regarding an operative strategy. Patients with a type 2 coronal deformity have a coronal offset of C7 compared with the central sacral vertebral line that is ipsilateral to the convexity of the deformity. Patients with type 2 coronal deformity require a correction of the lumbopelvic fractional curve that matches the correction of the thoracolumbar deformity (Fig. 8). Failure to gain adequate correction of the lumbopelvic fractional curve leads to a high rate of postoperative coronal malalignment in patients with type 2 deformity. An anterior approach to adequately correct the fractional curve from L4 to S1 may be useful as an operative strategy to adequately address the rigid deformity from L4 to S1, and to gain global coronal alignment with correction of the thoracolumbar deformity.

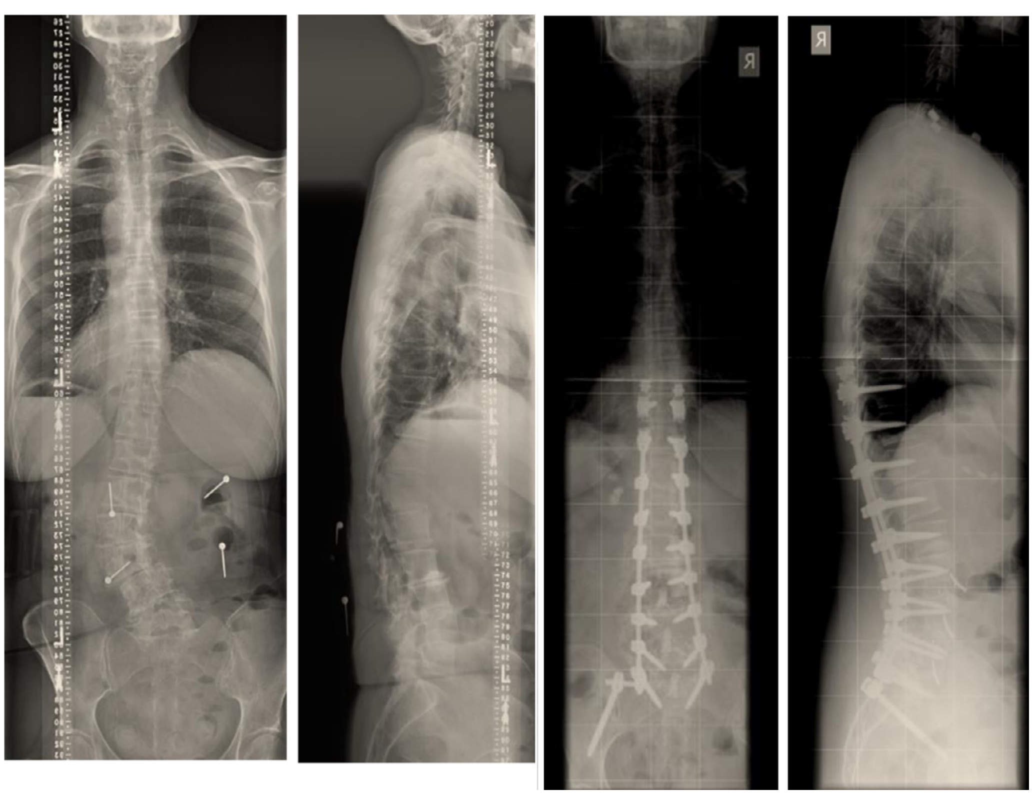

Figure 8 Preoperative and postoperative radiographs of a patient with a type 2 coronal plane deformity. (Color version of figure is available online.)

Conclusion

Spinal alignment metrics are static parameters that the surgeon can target in planning an operative strategy for spinal reconstruction in deformity. Alignment is distinct from balance, and balance is based upon the dynamic and harmonious interplay between alignment of the fused spine, and mobility of the unfused spine. Appropriate alignment goals for the spine are variable, and dependent upon factors including pelvic incidence, patient age, and compensatory mechanisms in the mobile axial and appendicular spine. Goals for global and regional alignment of the spine are established based upon measurements in asymptomatic children and adults, and correlation of health-related quality of life metrics with alignment parameters. While optimal alignment of the spine is a quantifiable goal that is useful in guiding surgical strategies for correction, it is important to understand that the correlation of clinical outcome with alignment parameters remains low to moderate, and there remain important considerations of patient comorbidities and general health that are strong predictors of the outcome of care. Therefore, it is essential to consider the patient's overall health along with their deformity in preoperative planning for spinal reconstruction.

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