Semin Spine Surg 31 (2019) 61–69

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Sagittal alignment and thoracolumbar osteotomies

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A B S T R A C T

Sagittal imbalance is most commonly seen in patients with multilevel degenerative disc disease, inflammatory arthropathies, severe osteoporosis, and untreated idiopathic scoliosis. The degree of imbalance is closely correlated with clinical symptoms. Sagittal deformity can occur from a variety of causes in both young and elderly patients, however it has been found to most likely be multifactorial. Other causes include Scheuermann's Kyphosis, iatrogenic flat-back, post-traumatic, neuromuscular, and congenital disorders such Klippel–Feil and infantile scoliosis. Clinical evaluation includes a thorough health history and physical examination, as well as more advanced methods such as surface topography and 3D postural analysis. The determination to utilize an osteotomy during deformity surgery is based on many factors including the patient's global sagittal alignment and radiographic assessment, the amount of correction needed to restore proper alignment, the relative rigidity of the deformity, and any focal areas of severe angulation. The three most commonly utilized osteotomies are discussed below including the posterior column Smith–Peterson/Ponte osteotomy, as well as the three-column pedicle subtraction osteotomy and vertebral column resection. The goal of a corrective osteotomy is to normalize the local segment's curve in order to correct the overall global spinal alignment and improve patient function. Complication rates as high as 25–40 percent have been reported in literature.

1. Introduction

There is a high degree of variation among normal sagittal alignment parameters in both healthy patients and those with severe degenerative spine disease. Given this wide range of accepted values, sagittal imbalance may be difficult to detect in certain patients.[1–3] The normal spinal column has some degree of lordosis in the cervical and lumbar regions, while the thoracic spine and sacrum are kyphotic by nature. This natural sagittal curvature permits the spine to withstand greater amounts of stress by providing a more even distribution of body weight. Therefore, loss of this natural sagittal profile can cause significant deformity, increases the energy expenditure necessary for ambulation, and decreases the patient's perceived quality of life, all to a greater extent than deformity in the coronal plane.[4–6] The thoracolumbar junction is a main point of interest given that it is the transition zone from the relatively kyphotic thoracic spine to the lordotic curve of the lumbar spine.[7]

Sagittal imbalance is seen most commonly in patients with multilevel degenerative disc disease, inflammatory arthropathies, severe osteoporosis, and untreated idiopathic scoliosis,[7–11] and the degree of imbalance is closely correlated with clinical symptoms.[11–14] Sagittal alignment is assessed both clinically and radiographically, using the chin-brow vertical angle, the sagittal vertical axis, and the kyphosis tilt angle.[3] The degree of curvature at each spinal region may be greater or less than the accepted normal range due to a combination of the natural history of the causative disease and spinopelvic compensatory mechanisms to maintain upright posture. Therefore, the goal of a corrective osteotomy is to normalize the local segment's curve in order to correct the overall global spinal alignment and improve patient function.[10] Surgical correction with posterior or three-column osteotomies will be explored further below as treatment for varying degrees of

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https://doi.org/10.1053/j.semss.2019.03.004
1040-7383/© 2019 Published by Elsevier Inc.

sagittal malalignment. One must also recognize that surgical correction of spinal deformity does not come without inherent risks. Patient expectations, comorbidities, and overall health status play an important part in overall outcomes. Surgical complications including proximal junctional kyphosis (PJK), nonunion, and over or under correction must be taken into consideration along with patient-specific factors when discussing future surgical options.[15,16]

2. Sagittal Alignment

Global sagittal alignment is overall evaluated by drawing the sagittal vertical axis (SVA), which consists of a plumb line from the center of the C7 vertebral body on a standing full-length lateral spine radiograph. The location and distance of the SVA to the posterior-superior corner of S1 helps to determine if a positive or negative sagittal balance exists.[5,17,18] In a balanced sagittal profile, thoracic kyphosis (TK) ranges from 20-40 degrees with slight increase during the natural aging process.[19] Average lumbar lordosis (LL) parameters are less clear, though various studies have cited normal ranges as between 40-60 degrees.[19–21] Pelvic incidence (PI), which determines the relative position of the sacral plate in relation to the femoral heads, ranges from 35-85 degrees. Due to the large "normal" ranges, solitary regional values are not sufficient in assessing global spinal alignment. However, the proportion of one given regional parameter to another is a more important factor in determining overall spinopelvic harmony. As a general rule, LL should be proportional to the PI, and to a lesser extent, the TK. This harmony, when existent, maintains standing posture and balance in an efficient and pain free manner. When pathology such as adult spinal deformity distorts this regional alignment, a chain of compensatory modifications develop along the standing axis resulting in a spino-pelvic mismatch with loss of function and disability.[3,22,23] Additionally, in degenerative disease states, progression of disk disease and malalignment can continue to worsen with conservative management, causing further functional impairment until surgical correction.[1,10,24] Adult spinal deformity patients with sagittal malalignment have also been shown to have a poor health-related quality of life (HRQOL) if not surgically addressed.[24–27]

2.1. *Evaluation*

Patients may present differently based on the degree of their sagittal malalignment and the presence or absence of a concomitant coronal deformity. Gross malalignment may be noted on physical exam and observing the patient's gait during ambulation. Functional disability and pain in back, legs, and buttocks are often reported in the initial visit as well. Patients may be unable to maintain cervical posture and will develop a compensatory retroversion of their pelvis and knee flexion in order to maintain a forward gaze.[2,3] Individuals with severe sagittal deformity may be forward leaning in chairs (a stooping posture) and are often fatigued from efforts to maintain erect posture, particularly with prolonged activity.[3]

Global sagittal alignment can be radiographically assessed through many different measurements including the kyphosis tilt angle, PI, pelvic tilt (PT), sacral slope (SS), chin-brow vertical angle, and the SVA as explained above.[3] In normal patients, the chin-brow vertical angle averages 0 degrees, displaying proper horizontal gaze. PI, PT, and SS are measured pelvic parameters that describe the relationship of the pelvic morphology and position to overall spinal alignment. PT is defined as the angle between a line from the femoral head axis through the midpoint of the sacral endplate and the vertical axis. This angle is regarded as a compensatory mechanism in such that it will increase, or retrovert the pelvis, in order to maintain an upright posture in patients with decreased LL and positive sagittal imbalance. PI, as defined earlier, is the angle between a line perpendicular to the sacral end plate, and a line from the femoral head center axis through the midpoint of the sacral end plate. This parameter is morphologic and static throughout adult life and is of great importance in determining the required LL during corrective surgery. Finally, SS is defined as an angle between a line along the sacral endplate and the horizontal axis. These three interrelated pelvic parameters complete the geometrical relationship of the pelvis to the axial spine, SS+PT=PI. That being said, due to the static nature of PI, as PT increases to main upright posture in adult spinal deformity, SS will inversely decrease resulting in a horizontal L5-S1 angle.[2,3,22,28]

Both clinical and radiographic measurements can be used to evaluate the amount of lordosis in the lumbar spine of each specific patient. Lordosis is often evaluated through the angle formed by the L1-L5 segments, although various studies include thoracic and sacral segments or exclude the lower lumbar vertebrae.[29–32] All five lumbar segments, however, are involved in upright functioning, and should thus be included within the evaluation of lumbar sagittal alignment.[20] The widely used Cobb Method, which measures the degree of angulation between two vertebral segments, is the gold standard to determine extent of LL with standing lateral radiographs. Imaging also generally includes CT and MRI for evaluation of underlying/associated pathologies such as spinal and neuroforaminal stenosis. One must be cognizant of the fact that these modalities are generally performed supine and may not accurately represent the true nature of the global and regional alignment.[17]

Clinical evaluation includes a thorough health history and physical examination, as well as more advanced methods such as surface topography and 3D postural analysis.[20,33,34] These tools, although not as reproducible and accurate as radiographic evaluation, may be utilized on a more routine basis due to concerns of radiation exposure and high medical utilization costs.[5,20,30,31] There are, however, issues during a clinical evaluation when comparing patients with differences in muscle development, amounts of subcutaneous fat, and other anatomic variations. Various newer methods have been developed, including autoCAD or 3D laser triangulation, in order to accurately and safely measure LL. These methods may be used for periodic monitoring and tracking deformity progression, but they cannot yet be used as a replacement for radiographic imaging.[35,36] New tools are being developed to measure the dynamic nature of lordosis during movement and gait, although their utilization is rather limited at this time due to their expensive nature and lack of availability.[37]

2.2. Causes of Malalignment

Sagittal deformity can occur from a variety of causes in both young and elderly patients, however it has been found to most likely be multifactorial. Causes include Scheuermann's Kyphosis, iatrogenic flat-back, post-traumatic, neuromuscular, congenital disorders (Klippel–Feil, infantile scoliosis, Down Syndrome), degenerative disc disease, and inflammatory arthropathies.[4,38–41]

Scheuermann's Disease, a structural hyperkyphosis involving abnormal vertebral development in which the thoracic vertebra form as a wedge shape instead of a normal rectangular shape, can progress during adolescent development with self-limitation by the time of skeletal maturity. However, since this deformity does not correct in adulthood, some adolescent patients with severe hyperkyphosis may require earlier surgical correction.[42,43] Other congenital disorders causing spinal deformity have been linked to defective embryogenesis, which may be due to genetic or molecular abnormalities associated with possible teratogens/environmental exposure or arise de novo.[44]

Inflammatory diseases, such as ankylosing spondylitis, contribute to a larger portion of deformity patients presenting in their forties or fifties, however other factors are likely at play.[10,39,45–47] De novo or degenerative causes of sagittal imbalance are probably the most common causes of adult deformity that are encountered in clinical practice. These types are generally seen in the older adult population; however, their root cause has been associated with subsequent degeneration after treatment for adolescent idiopathic scoliosis, osteoporosis, degenerative disc disease, and several other causes.[3,10] Due to the recent worldwide acceptance of spinal fusion procedures, another important, yet preventable cause of sagittal deformity which is iatrogenic (i.e flat back syndrome) which can occur at any age.[48,49] Less common causes include spinal tumors, infection, and trauma.[3]

3. Thoracolumbar Osteotomy

Patients with global sagittal imbalance have difficulty maintaining upright posture, expend excessive amounts of energy during ambulation, suffer from poor cosmesis and bodily image, and in severe cases, may have difficulty with respiration. In these circumstances, reconstructive deformity surgery including the use of thoracolumbar osteotomies may be indicated to achieve a more cosmetic result, restore horizontal gaze during ambulation, and relieve compression on the upper abdomen in cases of kyphoscoliosis.[4,39,40,50,51]

The determination to utilize an osteotomy during deformity surgery is based on many factors including the patient's global sagittal alignment and radiographic assessment as discussed earlier, the amount of correction needed to restore proper alignment, the relative rigidity of the deformity, and any focal areas of severe angulation. Given the increased surgical time under anesthesia, elevated blood loss, and the possibility of major complications, the overall functional status of the patient as well as their age and associated comorbidities must be strongly considered.[52]

Indications for an osteotomy include symptomatic flat back syndrome, sagittal malalignment consisting of loss of lumbar lordosis and increased thoracic kyphosis, and fixed sagittal decompensation. Once a decision to perform an osteotomy is made, the determination of the type of osteotomy must then be taken into consideration. There are several different types of osteotomies used in the thoracolumbar region with varying indications and amount of correction obtained.[4,10,50,53,54] The three most commonly utilized osteotomies are discussed below including the posterior column Smith–Peterson/Ponte osteotomy, as well as the three-column pedicle subtraction osteotomy and vertebral column resection. In 2013, Schwab et al developed a standardized classification system to clarify the types of osteotomies based on the amount and location of bony resection (Fig. 1). Six grades of osteotomies were proposed along with modifiers based on the surgical approach (P – posterior approach, A/P –anterior/posterior combined approach). This classification system will be further detailed below.[55]

3.1. Posterior Column Osteotomy (PCO)

A PCO, first described by Smith–Peterson in 1945 as a treatment for Ankylosing Spondylitis (AS), involves a single or multi-level posterior column release, thereby shortening the posterior column and increasing the anterior column at the level of the disc to achieve additional lordosis.[47,50,56] A PCO entails removal of the inferior aspect of the spinous process, the intervening ligamentum flavum, all posterior spinal ligaments, and complete or partial facetectomies with subsequent closure of the posterior column.[4,50,56] PCOs are indicated for AS patients with pseudoarthrosis (Anderson's Lesion), long smooth gradual kyphosis seen in Scheuermann's disease, loss of lumbar lordosis as in degenerative flatback syndrome, and in correction of mild amounts of rotation. Single level PCOs are generally performed in patients who require a relatively small amount of correction, however multilevel PCOs can be utilized for a more gradual correction of a larger deformity. Approximately 10-15 degrees of correction is obtained per osteotomy level.[4,45,50] Although this technique obtains the least amount of correction of the osteotomies, it does not come without inherent risks. These include paraplegia from stretching the cauda equina, aortic rupture, and high intestinal obstruction from tensing the superior mesenteric artery across the duodenum, all a result of lengthening the anterior spinal column. In patients undergoing PCO for pseudoarthrosis, anterior bone grafting may be indicated as the anterior column requires further support It must also be taken into consideration that in patients with a concomitant coronal deformity, a PCO may not be able to achieve the desired amount of correction, and other osteotomies described further below should be utilized.[40,57,58]

3.2. Pedicle-Subtraction Osteotomy (PSO)

PSO is a posterior closing-wedge osteotomy with an anterior cortical hinge that involves removal of the posterior elements, bilateral pedicles, and a V-shaped resection through the vertebral body that is closed anteriorly (Fig. 2A and B). It is used mainly in the lumbar region to avoid injury to the spinal

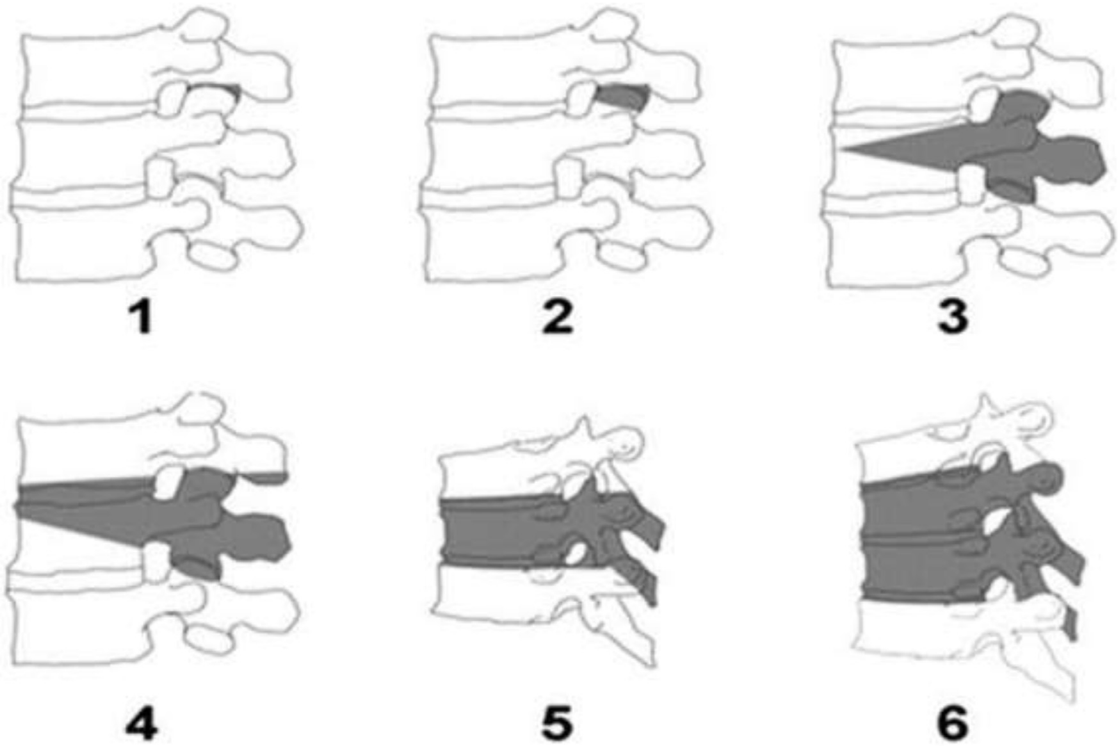

Fig. 1 – Spinal osteotomy classification: Grade 1 showing partial facet joint resection to multiple vertebral and disc resection in Grade 6.

cord, although its use in the thoracic spine has been described.[4] Indications include a sharp angular kyphosis with little flexibility, severe global positive sagittal imbalance, a mild concomitant coronal deformity, and in patients with a previous multilevel circumferential fusion. A PSO functions to correct sagittal alignment at a single level without a concurrent anterior approach. Compared to the small amount of correction obtained with a PCO, a PSO can achieve approximately 30-50 degrees of correction per osteotomy site. This large amount of angular correction however is focused at one spinal segment, as opposed to multilevel PCOs in which a more gradual correction can be obtained if feasible.[4,5,50,52,56,59,60] Choosing the osteotomy site must also be taken into consideration. As mentioned previously, performing the osteotomy in a previously fused area of the spine offers a significant amount of correction that is unable to be obtained by other means, but other technical aspects such as performing the osteotomy at the apex of the sagittal deformity, in an area with adequate proximal and distal fixation points, and at a spinal level that is parallel to the sacral end plate to avoid translocation are ideal.[52]

3.3. *Vertebral Column Resection (VCR)*

VCR is the most extensive approach involving removing of the posterior elements, bilateral pedicles, the entire vertebral body, as well as the superior and inferior adjacent discs with subsequent cage placement. It is most commonly utilized in the thoracic spine in areas where solid fusion is not present. It has been stated that on average, 45-70 degrees of correction can be obtained per level. Technical considerations for a successful procedure include obtaining secure fixation, generally three vertebrae on either side of the resection, providing provisional stabilization prior to performing the osteotomy, handling the exposed dura with extreme care, and adequate surgeon comfort level.[4,5,50,52,61] Subsequent compression and closure of the osteotomy site functions to obtain a high degree of sagittal and coronal correction, although overshortening should be avoided due to the possibility of kinking the vascular supply to the cord, tethering of the cord or dura, and creating iatrogenic neurologic compression.[4] Single-level or multilevel resection is possible, depending on the nature of the deformity. In the past, VCRs were usually reserved for en-bloc tumor excision, congenital kyphosis or scoliosis, and in cases of L5 spondyloptosis, with utilization of combined anterior and posterior approaches.[4,50,62,63] Due to the morbidity associated with a combined approach, a posterior-only approach was developed which is mainly used today.[64] This increased feasibility expanded the surgical indications for VCR to include fixed trunk translation, rigid scoliotic deformity greater than 80 degrees in the coronal plane, instances of asymmetry between the concave and convex columns of a deformity, rigid severe kyphosis, and in areas of post-infectious or post-traumatic deformity.[4,5,50,52,61]

3.4. *Complications with Three-column Osteotomies*

Performing thoracolumbar osteotomies in adult patients with spinal deformity, as compared to adolescents, has been associated with higher complication rates generally due to the increased number of medical comorbidities, decreased healing potential, and the inability to compensate for high volume blood loss. Complication rates as high as 25–40 percent have been seen in the literature. Careful patient selection, thorough pre-operative evaluation amongst multiple medical specialties, and a combined team approach in addition to extensive preoperative planning and a meticulous surgical technique have been advocated. Utilization of staged procedures for decreased time under anesthesia and early blood transfusion may also display some benefit. In a series by Hassanzadeh et al in 2013, 51 patients over 60 years old undergoing a three column osteotomy for correction of spinal deformity developed 18% major complications including motor deficits, deep wound infections, and epidural hematoma, and 39% minor complications mostly consisting of dural tears and cardiac arrhythmias. Despite the high number of complications, all patients obtained a significant improvement in their global sagittal alignment, which was maintained at 2 years post-op, with increases in all Scoliosis Research Society-2 domains and Oswestry Disability Index scores indicating improved quality of life. Given this information, these techniques should be used on a rather selective basis, taking into account the overall health of the patient, the surgeon's experience, and the availability of advanced resources.[52]

Furthermore, most studies on the complications of three-column osteotomies often report a combined incidence of complications without looking at these procedures individually. Sravisht et al sought to address this issue in a review of complications following VCR in adults by looking at the

Fig. 2 – A Preoperative AP and Lateral radiograph of a 68 year old with significant kyphosis causing Sagittal Imbalance. B Improvement of sagittal imbalance shown after pedicle-subtraction osteotomy at the L3 level.

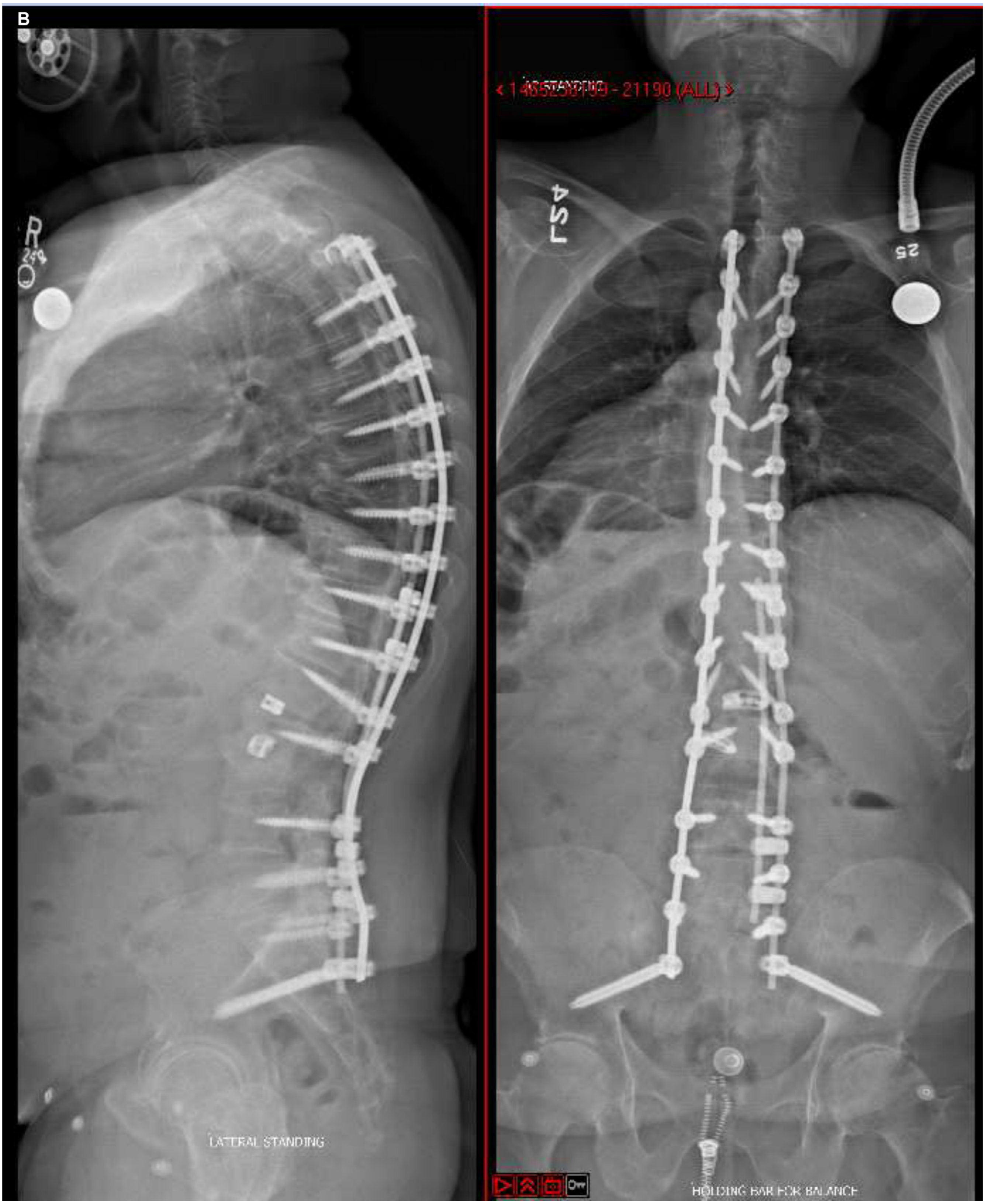

Fig. 2 **Continued.**

complication rates between VCR and PSO. This review reported a significantly higher rate of all complications in VCR patients compared to patients who underwent a PSO (RR 1.36, 95% CI 1.24-1.49, $p < 0.001$)[65]. Sravisht et al reported an overall complication rate, including nerve root injury, hematoma, hemopneumothorax, and cord injury, of 69.2%, reoperation rate of 9.6%, and neurological complication ranging from 6.3-15.8%. Nonetheless, all studies in this review reported a significant postoperative improvement in functional outcome.

Another notable complication of three-column osteotomy is instrumentation failure, a highly undesirable postoperative complication in spine surgery. In a single center retrospective analysis of patients who underwent a three-column osteotomies including VCR, PSO, hemivertebra excision, and extracavitary corpectomy, Kavadi et al reported a 27% overall incidence of instrumentation failure and pseudoarthrosis, with 86% of this failure occurring at the level of the osteotomy. The proposed hypothesis for this occurrence was increased rod stress at the point of osteotomy amongst other factors[66].

3.5. *Proximal Junctional Kyphosis (PJK)*

PJK, defined by a proximal sagittal Cobb angle greater than 10 degrees as well as a 10 or more degree increase in the postoperative proximal sagittal Cobb angle from the preoperative measurement, can occur after adult and pediatric spinal deformity correction possibly due to increased junctional stress concentrations, although the cause is multifactorial.[67,68] Seen in both adult and adolescent patients, other causes may include vertebral compression fractures as a result of poor bone quality, over or under correction of the global sagittal alignment, failure of the posterior spinal ligaments, or progression of disc disease and resultant deformity.[69] The risk is increased by increasing age, combined anterior/posterior approach, proximal thoracic instrumentation, correction of thoracic kyphosis greater than 50%, and instrumentation to the sacrum. The risk is the highest within the 2 years directly following surgery, after which the likelihood of PJK developing markedly decreases.[69,70] Newly diagnosed PJK is not an absolute operative indication, although a thorough evaluation of the patient and radiographic parameters must be conducted to determine the appropriate course of action.[16,68] According to the ScoliRisk-1 data, an overall incidence of PJK after fusion to the sacrum was 23.7% with only 9.6% of all patients being symptomatic and requiring revision surgery. Comparing asymptomatic patients with PJK and patients without PJK, there were not significant differences in patient functional outcome scores or health related quality of life at baseline and follow-up. Given this known complication however, there have been a variety of methods explored for PJK prevention including pedicle screw cement augmentation,[71] transverse process hooks at the uppermost instrumented vertebrae as opposed to pedicle screws,[72] and prophylactic vertebroplasty at the proximal aspect of the construct.[73]

3.6. *Anatomical Spinal Osteotomy Classification*

As previously mentioned, Schwab's classification system proposes six grades of anatomical resection which correspond to increasing degrees of destabilization. Grade 1, a posterior-only approach, is defined as a partial facet joint resection, specifically the joint capsule and inferior facet. Grade 2 entails complete resection of the facet joint. Resection generally includes the inferior and superior facets, the ligamentum flavum and other posterior elements, most notably the lamina and spinous process. This grade of resection can be done with a posterior approach or rarely in combination with an anterior release.[55] Smith–Peterson's technique and the Ponte osteotomy are considered grade two with the current definitions.[47,55] Grade 3, which is either performed through a posterior or combined anterior/posterior approach, is defined as pedicle and partial body resection without violation of the adjacent disc space. This osteotomy is a partial wedge resection of the posterior vertebral body and posterior elements including pedicles.[55] The PSO osteotomy discussed above is most closely characterized as grade 3 osteotomy under this classification system.[50,74] Grade 4 is similar to grade 3, however it involves a wider wedge resection as well as at least partial resection of the vertebral endplate and adjacent disc space.[55] Grade 5 of the classification system is defined as complete vertebral resection with both accompanying discs. This grade, with the availability of posterior or combined anterior/posterior approaches, generally includes rib resection if performed in the thoracic spine. VCR, as described above, is an example of grade 5 osteotomy. Grade 6 osteotomy is similar to a grade 5, however involves the resection of multiple adjacent vertebrae and intervertebral discs. Though grade 6 osteotomy often involves complete resection of multiple vertebrae, only removal of one complete vertebral body and partial resection of another adjacent vertebrae is necessary for the osteotomy to qualify as grade 6. Both coronal and sagittal correction can be achieved with the higher grade osteotomies. The goal of this anatomical classification system was to provide a reliable and simplified method for differentiating various types of osteotomy for sagittal alignment correction.[55]

4. Conclusion

Global sagittal alignment is important to consider in patients of all ages presenting with spinal deformity and impaired functional status. In younger patients, this is typically the result of congenital or idiopathic deformities, while middle-aged patients may develop a deformity secondary to inflammatory diseases or trauma. In the elderly population, degenerative spine disease and iatrogenic flatback syndrome are the major causes of sagittal deformity. Various studies have been performed to establish normal spinopelvic parameters, the causes and prevention of deformity, surgical and non-surgical risk factors, and most importantly, patient outcomes with various treatments. The normal ranges of kyphosis and lordosis along the thoracolumbar spine vary amongst the literature, however radiographic parameters and clinical evaluation can aid in determining severity of malalignment and the impact on the patient's global functional status and quality of life. Though there are many factors involved in evaluating a patient with a sagittal deformity, thoracolumbar osteotomies continue to be the mainstay of treatment targeted at correcting local areas of curvature in order to create overall spinopelvic harmony. Patients have benefited greatly from sagittal correction as evidenced by improved HRQOL and overall functional status. Further studies to advance sagittal curvature classification systems for use in treatment algorithms are currently being investigated, although no definite system is in place. Given the complexity and complications of the above-mentioned surgical techniques in the face of patient medical comorbidities and advanced age, surgeons must rely on case-by-case clinical evaluation to determine the best course of action to treat this evolving problem.

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