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Measuring, Preserving, and Restoring Sagittal Spinal Balance

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The importance of sagittal balance and its implications in reconstructive spinal surgery has gained significant attention over the past decade. Despite marked progress, our understanding of sagittal spinal contour and its relation to posture, locomotion, and energy expenditure remains incomplete. A great deal of practical as well as purely conceptual information and data have been recently accrued through focused inquiry. In fact, in a recent retrospective analysis of 752 patients with adult spinal deformity, Glassman and colleagues [1] showed that the severity of symptoms increases linearly with progressive worsening of sagittal plane imbalance. Moreover, they determined that although proximal thoracic kyphosis is frequently tolerable, sagittal deformity in the lumbar spine is often associated with poor clinical performance.

In this article, we will review the concepts of global, regional, and local sagittal balance. The role of the pelvis is decribed with a particular focus on changes in pelvic orientation that accompany compensatory behaviors in sagittal imbalance. The proper technique for patient positioning and basic strategies for preserving sagittal balance when performing lumbar and lumbosacral fusion procedures are discussed. Finally, in the event that restoration of sagittal spinal balance is required, osteotomy techniques are reviewed as well as principles that underpin their selection.

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Measuring sagittal alignment

Global sagittal balance

The most commonly practiced technique to measure sagittal alignment is to drop a plumb line from the middle of the C7 vertebral body down to the sacrum on a 14-in × 36-in lateral scoliosis radiograph. This is also known as the sagittal vertical axis (SVA) and is a measurement of global sagittal alignment [2–4]. The SVA typically falls anterior to the thoracic spine and through the apical lumbar vertebral body and superior sacrum. By convention, a plumb line falling anterior to the posterior superior corner of the sacrum is considered positive. If the plumb line falls dorsal to this point, the patient is said to have negative sagittal alignment. Some studies [5] have used the center of the dens as the superior reference point instead of the C7 vertebral body; however, the inability to visualize this structure consistently with clarity on routine long-cassette radiographs has limited its routine usefulness.

Many authors have studied the sagittal plane in healthy subjects in an attempt to elucidate a set of normative values. These normal values seem to be age dependent, with pediatric subjects possessing slightly more negative balance than their adult counterparts. Vedantam and colleagues [3] showed that the SVA was -5.7 ± 3.5 cm in the pediatric population. In an analysis by Gelb and colleagues [4], adults were found to be slightly less negative in their sagittal balance, with a mean SVA measuring -3.2 ± 3.2 cm. Interestingly, in their study of asymptomatic adult volunteers, Jackson and McManus [2] found a wide range of normative SVA values (range: -6.0 to $+6.5$ cm). This study stands in contradistinction to

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the work of Farcy and Schwab [6], who examined sagittal alignment in the context of lumbar flat-back deformity and determined that deviation of the SVA greater than 4 cm from the anterior sacral promontory was associated with pain and poor response to nonoperative therapy. Recent work by Schwab and colleagues [7] has focused on center-of-gravity analysis using a force plate and has shown that the SVA approximates a more important global balance parameter, namely, the center-of-gravity line. In fact, a decade ago, Dubousset [8] proposed the concept of the cone of stability to illustrate the narrow range within which the center of gravity must fall in the standing patient to minimize energy consumption and maintain overall balance.

Of additional importance in global assessment of spinal balance is recognizing the dynamic interplay between regions of the spinal column as well as with the pelvis. A patient with thoracic hyperkyphosis attempts to maintain global sagittal balance initially by hyperlordosing their lumbar spine. Similarly, normal cervical lordosis can also be purposefully accentuated to achieve overall balance. In this manner, there is a reciprocal relation between the various regions of the spine to result in global balance. For example, patients with adolescent idiopathic scoliosis often have a hypokyphotic thoracic contour that is balanced by a straight to kyphotic cervical spine. In their analysis of 38 subjects with idiopathic scoliosis, Hilibrand and colleagues [9] found subaxial cervical kyphosis of $6^\circ \pm 11^\circ$ that was significantly correlated with preoperative hypokyphosis of the thoracic spine. The orientation of the various regions of the spine, particularly the cervical spine, may be more complicated than simply to counterbalance other regions of the spine. Although without experimental or clinical validation as yet, it is theorized that alignment of the spinal column may be most critical in generating appropriate positioning of the cranium in space such that vestibulo-ocular equilibrium is achieved.

With specific regard to the role of the pelvis in global sagittal balance, important work has been put forth by Jackson and colleagues [2,10,11]. In a methodologically sound analysis, they found a significant correlation in healthy and diseased subjects between sacral inclination and segmental lumbar lordosis. With the patient's knees fully extended, the correlations indicated that as segmental lordosis decreases, the pelvis rotates posteriorly around the hip axis, thereby resulting in a more vertical sacral inclination (Fig. 1).

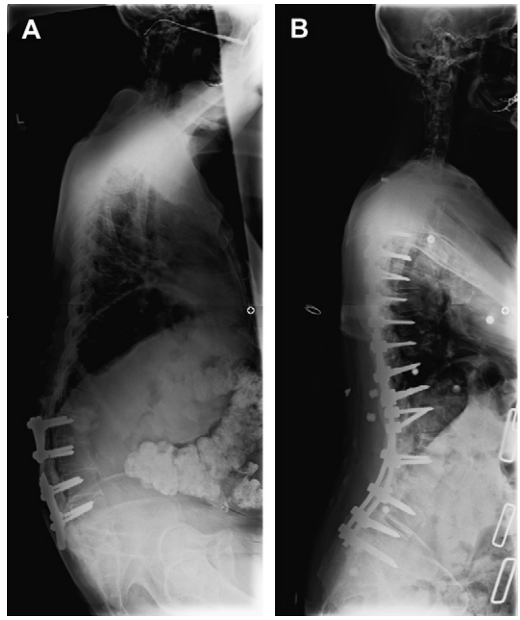

Fig. 1. (*A*) Radiograph of a patient with iatrogenic fixed lumbar kyphosis. Note the posterior rotation of the pelvis and retroversion of the sacrum in an attempt to compensate for the profound sagittal imbalance. (*B*) After surgery, sagittal balance and normalized sacral-pelvic orientation are restored with two pedicle subtraction osteotomies, achieving almost 70° of correction in the sagittal plane.

This important lumbosacral relation is the primary mechanism by which the pelvis can be effectively used to compensate for otherwise abnormal sagittal spinal alignment. Paramount to consider when performing reconstructive spinal surgery is that fusion to the sacrum disenables the ability to perform this compensatory pelvic rotation, underscoring the importance of optimizing sagittal alignment when performing a lumbosacral fusion. In the authors' practice, sacral inclination on preoperative radiographs is carefully accounted for and taken into consideration when computing the degrees of correction required to restore sagittal spinal balance.

Regional and local sagittal balance

In addition to global sagittal balance, regional and local alignment is important for normal pain-free activity, because a normal SVA is not always consistent with acceptable sagittal balance. For instance, a patient can achieve normal global sagittal balance in the face of profound focal thoracic kyphosis by lumbar hyperlordosis and retroversion of the pelvis. Such compensatory behaviors are typically painful over time and can lead to muscle fatigue, accelerated hip degeneration, and structural changes in the osseous spinal anatomy. Normative values for each region of the spinal column have been studied as well as the role that certain spinal segments play in establishing regional contour.

Hardacker and colleagues [5] noted that 40° of lordosis occurs between the occiput and C7, 30° of which is generated from the occiput to C2. By default, the subaxial cervical spine therefore contributes approximately 10° of lordosis to overall cervical lordosis and does so by the wedge shape of the vertebral bodies in concert with lordotic disc morphology. Numerous studies have analyzed sagittal thoracic and thoracolumbar alignment [2,3,12]. The range of thoracic kyphosis in normal patients of all ages has been reported from 9° to 63°; however, mean thoracic kyphosis seems to be fairly consistently in the range of 30° to 40°. From a technical standpoint with regard to measurement, the ideal method is a Cobb angle from the superior end plate of T1 to the inferior end plate of T12; however, because the proximal thoracic segments are often poorly visualized on lateral radiographs, many studies use T4 or T5 as the upper measured vertebra. As determined by Bernhardt and Bridwell [12], the segmental contribution of the upper thoracic vertebrae to overall thoracic kyphosis is approximately 1° to 3° per level, often allowing one to infer overall thoracic kyphosis without measuring the upper segments per se.

As one moves caudally down the spinal column to encounter the thoracolumbar junction, T10 to L2, a sagittal alignment and anatomic transition occurs as the structural support of the rib cage ceases. The comparatively rigid thoracic spine transforms into the more flexible lumbar spine marked by larger vertebrae, lordotic discs, and sagittal facet orientation. Gelb and colleagues [4] showed that the disc at L1 to L2 is the first lordotic segment and that the thoracolumbar junction is therefore usually neutral or slightly kyphotic in normal healthy patients. When measured from the top of the L1 vertebral body to the superior sacral end plate, a smooth lordotic sagittal contour is noted in healthy subjects. According to Gelb and colleagues [4], segmental measurements in the lumbar spine are as follows: L1 to L2, $-4° \pm 5°$; L2 to L3, $-10° \pm 5°$; L3 to L4, $-14° \pm 17°$; L4 to L5, $-24° \pm 7°$; and L5 to S1, $-24° \pm 7°$. Similar values were discovered by Bernhardt and Bridwell [12] in a study in which they determined the mean lumbar lordosis as measured from T12 to S1 to be 61°.

Wambolt and Spencer [13] examined the roles of the lumbar vertebral bodies and discs and their relative contribution to overall lumbar lordosis. In a population with a mean lumbar lordosis of 59°, these authors determined that 47° of lordosis was contributed by the discs and only 12° was contributed by the vertebral shape. Studies have demonstrated that the sagittal apex of lordosis in the lumbar spine is usually at L3, L4, or the intervening disc space. Of profound clinical importance, the segments L4 to L5 and L5 to S1 together contribute greater than 60% of overall lumbar lordosis [2,4,12]. Given that this is the most common region of symptomatic degenerative spinal pathologic change, and therefore surgical intervention, understanding this concept is critical to the preservation of sagittal balance.

Preserving sagittal alignment

Preservation of sagittal alignment during spinal surgery can be accomplished by proper patient positioning as well as by sound surgical technique. From the standpoint of patient positioning, one should never perform a lumbar or lumbosacral fusion procedure with a patient on a kyphosing frame or in a knee-chest position. Prone positioning on a Jackson table (Orthopedic Systems Inc., Union City, California) with approximately 30° of hip flexion and 70° to 90° of knee flexion is ideal and is routinely used in the authors' fusion cases. Using the Jackson table, the chest pad can be "built up" with towels to accentuate the natural lumbar lordosis even further.

With regard to the surgical technique used to preserve sagittal alignment, one must be particularly careful to avoid destabilizing the segment rostral to a fusion in any manner, particularly the lamina and facet joints. Failure to adhere to this principle, particularly in cases in which a long fusion exists below a violated posterior tension band, can result in dramatic loss of sagittal alignment because of postoperative proximal junctional kyphosis. Strategies are ideally used to reconstitute collapsed disc spaces from degenerative disease. This can be performed from an anterior approach using lordotic threaded cages or custom-cut allograft wedges. Alternatively, segmental lordosis can be preserved and enhanced using interbody devices placed anteriorly in the disc space through a transforaminal posterior approach. Using this technique, the authors frequently perform a Smith-Petersen osteotomy (SPO) at the level of surgery and compress across the interbody to close the osteotomy. They have found this strategy to be valuable in preserving segmental lordosis in patients without an ankylosed anterior spinal column.

Restoring sagittal alignment

Principles of sagittal correction

Osteotomies are the primary tool in the surgical armamentarium by which the surgeon can introduce mobility into the spinal column and effectively restore sagittal balance. The three most commonly implemented osteotomies in deformity surgery are the SPO, pedicle subtraction osteotomy (PSO), and vertebral column resection (VCR). The choice of osteotomy depends on the goals of the procedure, correction requirements, native bone quality of the patient, and anatomic variations that may be present. Each of the osteotomy techniques has specific advantages as well as inherent limitations. They can be used individually or together in combination to achieve the desired correction.

In theory, the SPO offers up to 10° of correction per level; however, 3° to 7° per level is more commonly achieved. It can be performed at any level in the thoracolumbar spine and is best accomplished at a level at which there is a disc that is not ankylosed. This is usually clearly visualized on a preoperative CT scan. The authors also frequently order lateral scoliosis radiographs with the patient positioned supine over a bolster to get an idea before surgery about the sagittal curve flexibility. The taller the disc, the more effective is the osteotomy, because this technique requires posterior osteotomy closure and simultaneous anterior opening. If a SPO is planned at a level in which the disc space is collapsed but not ankylosed, an interbody spacer can be placed through a transforaminal route into the anterior aspect of the disc space. The SPO can then be closed down over the interbody spacer leading to greater segmental correction and improvedinterbody arthrodesis.

The PSO, a far more powerful technique thank SPO, hinges on the anterior column and involves middle and posterior column shortening. It can reliably achieve between 30° and 40° of correction at a single segment. The VCR, an extension of the pedicle subtraction technique, typically yields a bit more correction than a standard PSO because of the distance and height of the anterior pivot, which places the correction arc point anterior to the vertebral body.

The indications for each of these osteotomy techniques include fixed segmental kyphosis or globally positive sagittal imbalance. The SPO requires a mobile anterior column, which is not always the case. A PSO, by contrast, does not possess the same limitation, because the bony resection is carried through into the anterior column. Although a PSO is commonly performed for fixed sagittal correction, it can also be used for coronal correction or combined sagittal-coronal correction. The PSO can also be used in nonfixed deformity if one prefers a single osteotomy over multiple SPOs to achieve the desired correction. A VCR, the most powerful osteotomy technique, is particularly valuable in the setting of sharp angular deformities. After accruing a considerable amount of experience using all three types of osteotomies over several years, we have come to prefer a PSO for fixed deformity in the lumbar spine and up to T10. We prefer a VCR for fixed deformity in the thoracic spine above T10. The thoracolumbar region (T10–L1) is a zone in which a PSO or VCR can be used well, depending on the anatomy, clinical situation, and correction goals.

A PSO in the thoracic spine is limited by the more triangular shape of the thoracic vertebral bodies. As a result, the preserved anterior bone that must act as the pivot point is insufficient. The closure then may be more of a planum fracture than a true rotational correction. This can result in suboptimal correction, or worse, loss of segmental correction with or without subluxation. A VCR, by contrast, allows the surgeon to use the remaining end plates as a closure orientation platform in a vertebral body–to–vertebral body closure. Alternatively, an anterior pivot point can be created by inserting a cage at the anterior aspect of the vertebral body resection space.

The choice of osteotomy is based on the bone quality, local anatomy, pathologic findings, and amount of correction needed. We have developed a method that allows rapid, easy, and precise mathematic calculation of the degrees of correction needed in any plane. Our method, which takes advantage of simple trigonometry, has had a high level of correlation between the calculated degrees, bony resection based on these parameters, and clinical result [14,15]. The distance from the planned osteotomy level to C7 is measured. The distance from C7 to the S1 plumb line on a standing 36-in film is then measured. This establishes a right triangle, and a simple trigonometric calculation is performed: $(\text{opposite/adjacent})^{-1} =$ Angle. In this case, it is $(\text{C7}-\text{S1 plumb line distance/osteotomy to C7 distance})^{-1} =$ Angle needed for correction.

Once the degrees of the angle needed for correction are known, the surgeon can make the decision as to what single osteotomy or combination of osteotomies is needed to accomplish the planned correction based on the expected correction with each type of osteotomy and the unique patient characteristics that may enhance or limit an osteotomy correction. For instance, if the surgeon knows that 45° of correction is needed, it is unlikely to be achieved by three or four SPOs. More likely, a single PSO with one or two SPOs would be adequate. This type of calculation and information enables the surgeon to develop a comprehensive surgical plan that realistically achieves the goals of correction.

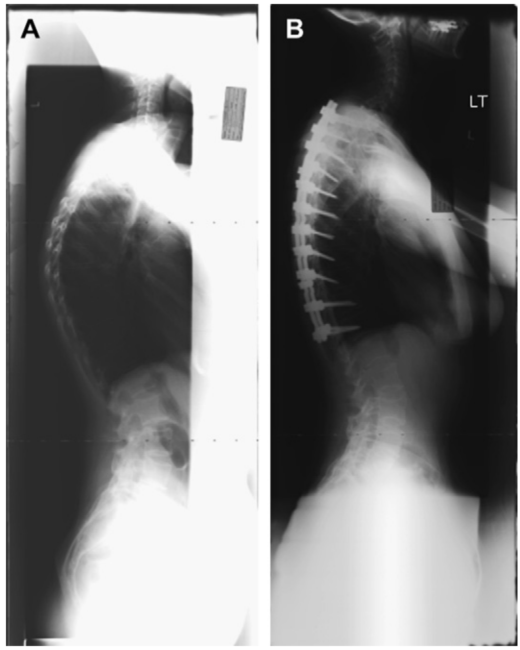

Fig. 2. (*A*) Preoperative radiograph of a patient with Scheuermann's kyphosis with sagittal imbalance causing lumbar compensation with hyperlordosis, resulting in back pain. (*B*) This was corrected with multiple SPOs. With normalization of the thoracic sagittal curve, the lumbar hyperlordosis and low back pain resolved.

Key procedural steps

Smith-Petersen osteotomy

The most important aspect of this osteotomy is removal of the superior facet. The osteotomy is begun by using an osteotome to resect the inferior facet of the cephalad vertebra the desired number of millimeters. A drill or rongeur is then used to create a chevron-like resection of the inferior and superior facet complex and the inferior edge of the superior lamina of the osteotomy level. The ligamentum flavum is then resected to expose the dura. Gel foam is used to deal with epidural bleeding. Once all osteotomies are completed, the pedicle screws or other implants are placed into screw holes that have been previously prepared before the osteotomies. Closure is achieved by compression, postural effects, table manipulation, cantilever correction, or some combination of these (Fig. 2).

At times, to maximize the correction at a level and improve fusion, an interbody device is placed in the anterior one third of the disc space. This increases the height of the disc and provides an anterior pivot. The axis of rotation moves forward to the pivot, increasing the correction angle of closure. It also has the advantage of providing graft in the anterior column for fusion. This can be done using a unilateral or bilateral transforaminal lumbar interbody fusion (TLIF) technique, because the facets are already resected by the osteotomy (Fig. 3). It is important not to place an implant that does not taper or covers a large part of the end plate because this has the potential to block the closure of the posterior disc space and, as a result, the osteotomy.

Pedicle subtraction osteotomy

After placing pedicle screws above and below the osteotomy level, the PSO begins with placement of a pedicle preparatory hole. With no implant in place, a prepared and tapped pedicle is useful to maintain orientation while the bony removal is taking place. The bony removal of the posterior elements then begins. The removal should be centered at the pedicle that is to be removed. The amount of bone to be removed should be calculated to match the amount of closure needed. It should involve the superior and inferior facets of the osteotomy level, the inferior facet of the cephalad level, and the superior facet of the level below. In the case of a prior posterior fusion mass, removal of the fusion mass is performed. This is done with osteotomes, rongeurs, and curettes to

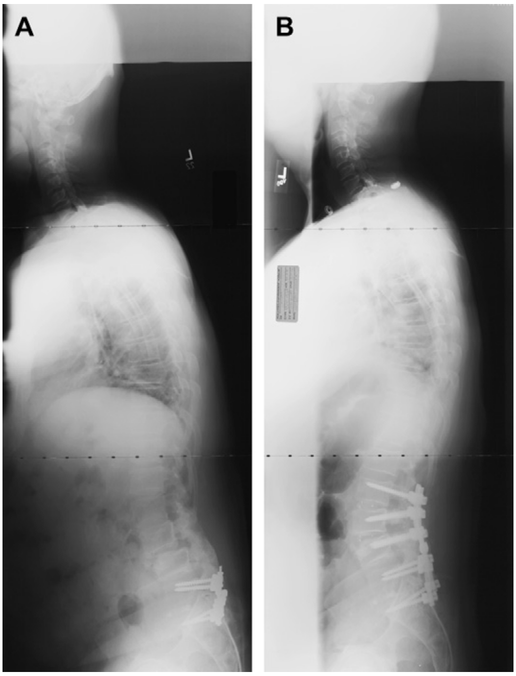

Fig. 3. (*A*) Patient with prior lumbar fusion from L4 to S1 now with degeneration above the fusion and positive sagittal imbalance causing difficulty in standing and walking because of sagittal imbalance as well as pain. (*B*) To achieve acceptable correction, anterior interbody devices were placed anteriorly in the disc space to allow disc height restoration and maximum correction with the SPOs. This avoided the need for a PSO and extension of the construct to the structural thoracic spine.

save all bone for later fusion. The osteotomy can be fine tuned with a high-speed drill. It is helpful to undercut the posterior bone edge in a "keystone" fashion. This decreases any dural impingement risk on closure. Others may cut a small hole in the bone overlying the dura at the level of closure.

The pedicle is then fully removed with a rongeur and a drill. Care should be used to remove the pedicle base fully. Small spicules of bone can result in radiculopathy once the osteotomy is closed. In revision cases, it is also important to remove all scar tissue from the dura to avoid soft tissue crowding once closure has been done. Once the pedicle has been removed, dissection of the lateral vertebral body wall is done bilaterally. Penfield dissectors and elevators are used, with the dissection being performed from the level of the disc that lies immediately above the resected pedicle caudally as much as the resection needs to go. The body should be dissected all the way to the anterior vertebral body to get adequate exposure and resection. The segmental artery is swept caudally subperiosteally. This can typically be done without difficulty over two thirds of the vertebral body. If the vessel begins to bleed, bipolar cautery can be used. If this does not work, pack the area. Bleeding typically resolves with osteotomy closure. We have not had to extend our exposure or alter the procedure because of segmental arterial bleeding. If bleeding was profuse and unable to be controlled by the previous steps, it would be reasonable to consider performing a flank incision for control of the segmental bleeding at the aorta should all else fail.

The bone is removed with osteotone and a drill in a precise wedge based on the calculated degrees of closure. The apex of the wedge is at the anterior vertebral body wall. This wall should be preserved as a pivot point. The base of the osteotomy is at the floor of the spinal canal. This is more easily done today with specialized vertebral body retractors to assist in exposure. The cancellous bone is then removed with curettes and rongeurs in a wedge-shaped fashion matching the cuts on the lateral walls. Again, all bone is saved for later grafting. Drills can be used for final shaping. The final bone resection is the posterior vertebral body wall, or the floor of the spinal canal. The lateral edge can be removed with rongeurs. The final removal is an impaction technique into the vertebral body cavity created by the resection. This can be done with curettes or with specialized impactors, which, again, makes the procedure a bit more smooth (Fig. 4).

It is important to place a temporary holding rod to maintain vertebral body orientation and prevent early collapse and closure of the osteotomy when the posterior wall is removed. This is occasionally necessary earlier in the procedure should the osteotomy begin to sag closed. With all bone resected and the canal and root exit zones inspected for any tissue that could impinge on neurologic structures, the osteotomy is closed. Typically, little compressive pressure is needed on the screws above and below the osteotomy. The osteotomy is closed by gentle pressure on the spine on each side of the osteotomy by hand. If a standard operating room table is used, the patient's body can also be flexed. The closure is further completed by hyperlordosing the rod in the area of the osteotomy and adding cantilever force. Final closure is performed by gentle rod compression. If more force is needed and there are

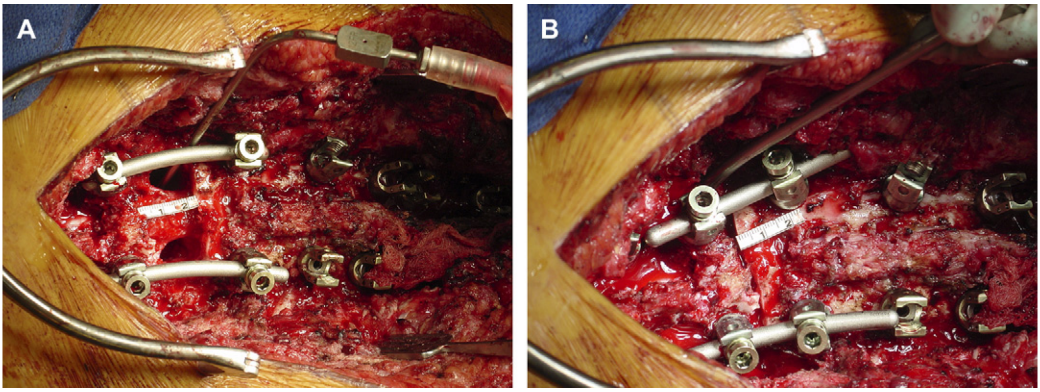

Fig. 4. (*A*) Intraoperative photograph of a PSO resection cavity with the cauda equinae and exiting nerve roots exposed before closure. (*B*) After closure, the edges of the fusion mass are approximated and the osteotomy is fully closed.

posterior elements, a compression hook combination can be put in the bone above and below the osteotomy. A third rod can be used to get added compression. Once the final rod is in place, the third rod and its hooks are generally removed. Anteroposterior and lateral 14-in $\times$ 36-in scoliosis radiographs are used to confirm osteotomy closure and ensure that there is no translation. The posterior elements should be completely or near completely closed and not translated. Inspection of the lateral wall closure and the root exit zones is done. The roots above and below the pedicle are now contained in a superforamen. Attention should also be given to ensure that there has been no translation or subluxation at the level of the osteotomy closure. If subluxation occurs, it is typical that the spine caudal to the osteotomy translates anteriorly relative to the spine cephalad

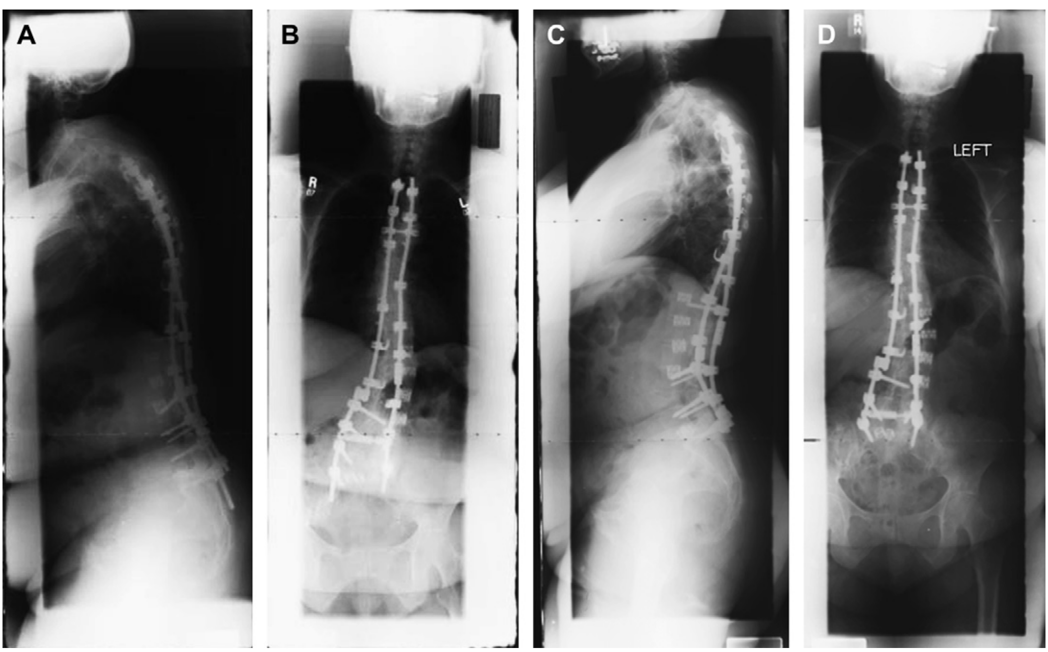

Fig. 5. (*A, B*) Fixed iatrogenic sagittal and coronal imbalance resulted in difficulty in standing and walking. (*C, D*) Asymmetric or quadrilateral PSO corrected the sagittal imbalance completely and significantly improved the coronal imbalance.

to the closure. When this occurs, the closure should be manipulated to restore alignment (Fig. 5).

Vertebral column resection

This technique is an extension of the PSO. The distinct difference is that the entire vertebral body and both adjacent discs are resected. As with a PSO, all implants are placed by means of a midline incision, with the exception of the osteotomy levels. Access and dissection of the ribs that articulate with the discs above and below the osteotomy level are then performed. Approximately 2 to 3 cm of the rib should be removed from both sides of the vertebra to be resected to enhance closure of the osteotomy. This is typically done for the ribs intersecting the disc spaces cephalad and caudal to the body that is to be resected. This helps with access for resection and exposure of the lateral disc, which facilitates arthrodesis of the end plates as well as closure. A lateral extracavitary dissection is then performed to the anterior vertebral body. It may be necessary to coagulate one or both segmental arteries at the level of resection. More often, the segmental arteries can be spared by sweeping them off of

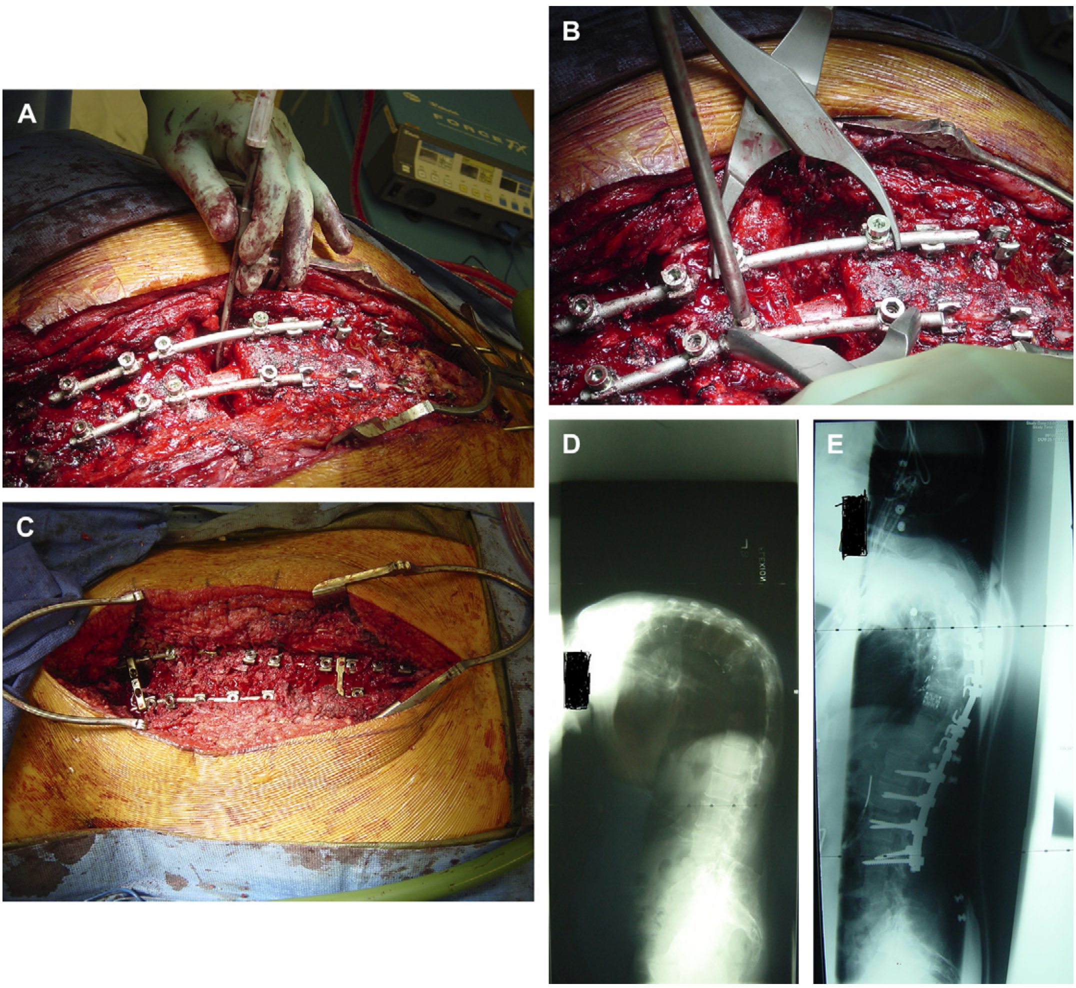

Fig. 6. (*A*) VCR in a patient with severe circumferentially fixed thoracic kyphosis. Note the visual roll off of the kyphosis. (*B*) Compressors close the osteotomy on a custom-cut anterior pivot to allow the desired sagittal correction. (*C*) Osteotomy is fully closed. Note the sagittal correction visually demonstrated when compared with the image in A. (*D*) Preoperative radiograph of the fixed kyphosis. (*E*) Postoperative sagittal correction with a single VCR at the apex of the previous kyphosis.

the bone subperiosteally. With the rib heads removed, attention is turned to the vertebral resection.

The bony vertebral resection begins with posterior removal of the lamina or fusion mass and the pedicles. This is done with a rongeur, saving bone for fusion, and a drill. Occasionally, both of the thoracic roots at the cephalad end of the resection site are sacrificed by tying them off proximal to the ganglia with 2-0 silk ties and then cutting them. This facilitates access to the vertebral body. In many cases, the nerves can be spared. Vertebral body wall retractors from the PSO set can be inserted to facilitate vertebral body resection. The vertebral body is then fully resected to include the discs above and below the body. Temporary holding rods are important early in this procedure because of the complete instability created by the total removal of a vertebra. This reduces the risk of subluxation or translation.

The vertebral body resection is begun by using a specialized osteotome to resect the lateral one third of the vertebral body above and below the discs that are caudal and cephalad to the body that is being resected. Curettes are used to resect the cancellous bone, and rongeurs and drills are used to remove the cortical bony shell completely. The end plates of the discs above and below the resected vertebra are removed. A 15-blade scalpel is used to resect the lateral annulus at the remaining end plate and the posterior lateral aspect of the disc. Curettes and pituitary rongeurs are used to remove the discs completely. The end plates of the vertebral bodies above and below the resection are arthrodesed with curettes, rasps, and drills. The posterior vertebral body wall is then carefully removed with PSO impactors. Care must be taken to remove all bone and disc material completely.

Closure is more complex because of the complete instability of the spine. We prefer to perform a construct-to-construct closure through a domino. In this technique, temporary rods are placed through two or three screws above the osteotomy, and a second rod is placed similarly below the osteotomy. Both rods pass through a domino connector at the site of the closure. Once this is secured, the temporary holding rod on the opposite side is removed and replaced with a similar construct. Closure is then begun, with compressors closing the two constructs through the domino. If the closure is an end plate–to–end plate closure, this is done until bony approximation occurs. More commonly, an anterior cage is placed as a pivot point after partial closure. This cage should be an anterior pivot only and should cover a minimal amount of the end plate to allow continued sagittal correction and closure of the posterior aspects of the vertebral bodies. After the closing vertebral bodies engage the cage, a gradual posterior closure is performed while pivoting on the cage. When the desired correction is obtained, permanent rods are placed and the final arthrodesis is performed. At no time is the spine not secured with at least one rod (Fig. 6).

Summary

The past decade has witnessed dramatic improvement in understanding and treatment of sagittal plane deformity. We have reviewed several studies that have clarified normative values for sagittal plane geometry as well as the role of the pelvis as we understand it today. In the treatment of lumbar degenerative disease with a fusion procedure, proper patient positioning and adherence to a thoughtful surgical plan are critical in the preservation of sagittal balance. In the event that restoration of sagittal alignment is required, it is best accomplished by the use of osteotomies, the techniques for which have been described.

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