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Surgical Strategies and Choosing Levels for Spinal Deformity: How High, How Low, Front and Back

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The fundamental principles that guide spine deformity surgery are achieving a balanced spine with solid fusion while maintaining as much motion as possible [1]. Careful preoperative planning and curve evaluation are essential. The goals of surgery depend on the patient's age, deformity, and symptoms. In the patient with adolescent idiopathic scoliosis, goals include maximal correction, fusing as few levels as possible, and prevention of later decompensation. In adults, final curve correction is less important than maintaining coronal and sagittal balance and addressing symptomatic levels.

Spine deformity surgeons agree that selective fusion of the major curve and allowing the compensatory curve to correct spontaneously are preferred, although how much spontaneous correction to expect can be difficult to predict. Advanced segmental instrumentation systems allow for greater correction, an improved sagittal profile, and shorter constructs [2].

The introduction of new instrumentation systems, techniques, and classification schemes has also led to considerable variation among spine surgeons in their decision making [3,4]. The selection of appropriate fusion levels remains essential, however. Fusions that are too long sacrifice motion segments, have higher rates of pseudarthrosis [5], and can result in worsening of the uninstrumented curves. Fusions that are too short can result in ‘‘adding on’’ of additional levels distally to the instrumented curve [6]. Studies have shown that one or two long or short fusion levels can make the difference between a satisfactory outcome and decompensation [7].

Preoperative radiographs

Plain radiographs during preoperative evaluation comprise anteroposterior (AP) and lateral full-length images that include the cervical spine, pelvis, and femoral heads. Supine side-bending films should also be included. In patients with sagittal deformity, such as Scheuermann's kyphosis, a lateral radiograph with a bolster placed under the apex of the kyphosis should be obtained to assess flexibility.

Radiographic evaluation of the curve begins with measurement of the Cobb angle, the amount of correction on bending films in degrees and percentage correction, and the amount of deviation from the apical vertebrae to the central sacral line. The end vertebrae for measurement are the vertebrae that are maximally tilted into the concavity at the proximal and distal extents of the curve. The central sacral line is a vertical line drawn from the center of the sacrum perpendicular to the horizontal or, alternatively, a line drawn across the crests of the iliac wings. Global coronal balance is measured by the amount of decompensation on a standing radiograph, which is the distance between a vertical plumb line from the body of C7 and the central sacral line and is normally less than 2 cm. The stable vertebra is defined as the vertebral body bisected by the central sacral line on a coronal image. The stable zone of Harrington is the area defined by two vertical lines drawn from the S1 facets on a standing AP radiograph. The neutral vertebra is the first vertebra distal to the apex of the distal

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structural curve with neutral rotation, in which the pedicles are symmetric within the vertebral body. The horizontal vertebra is the vertebra with end plates parallel to the sacrum.

Usually, the end vertebra is proximal to the neutral vertebra, and the neutral vertebra is just proximal to the stable vertebra. Interobserver reliability of the end, neutral, and stable vertebrae has been shown to be poor [8], which can have significant consequences on the selection of fusion levels and postoperative outcomes.

In neutral sagittal alignment on a lateral radiograph, a plumb line drawn from the center of the body of C7 should pass through the posterior-superior aspect of the superior S1 end plate. The sagittal vertical axis is measured by the distance between the plumb line and anterior aspect of S1 and should normally be within 2.5 cm. A plumb line falling posterior to S1 is considered to represent negative sagittal balance, and one falling anterior is considered to represent positive sagittal balance. Normal thoracic kyphosis has been reported as 37° to 42° measured from the superior end plate of T3 to the inferior end plate of T12. Normal lumbar lordosis is defined as 50° to 75° from the superior end plate of L1 to the superior end plate of S1 [9]. With aging, thoracic kyphosis increases and lumbar lordosis decreases. The thoracolumbar junction should be straight or have less than 5° of kyphosis.

Side-bending films are the standard, but fulcrum-bending and traction radiographs may show greater correction in some situations. Fusion levels based on bending films need to be chosen with caution. Vaughan and colleagues [10] reported that fusions based on traction films rather than standing radiographs were 1.4 levels shorter in patients with adolescent idiopathic scoliosis with curves greater than 60° and that decompensation occurred in 13 of 18 of their patients.

Curve selection

Curve evaluation includes deciding which curves to fuse and the amount of correction to achieve. The surgical treatment of adolescent idiopathic scoliosis emphasizes selective fusion of the structural curves and anticipating partial spontaneous correction of nonstructural curves. Structural and nonstructural curves are differentiated by the degree of correction with supine side-bending films. The Lenke [11] classification for adolescent idiopathic scoliosis defines curves based on the ability to correct to less than 25° and the amount of deviation from the apex in the lumbar spine. An alternative definition is correction of 50% to less than 40° in the thoracic spine and 30° in the lumbar spine [12]. The amount of apical deviation and rotation should also be considered [13]. Puno and colleagues [14] found that patients who had been treated in accordance with the Lenke classification generally had better correction, less decompensation, and sometimes shorter fusions than those who had not (Fig. 1).

The amount of correction can range from fusion in situ to complete correction. How much correction is desirable depends on the expectations and physiology of the patient, the risk-benefit ratio of use of extensive instrumentation and osteotomies, and the judgment and experience of the surgeon. With the use of Harrington instrumentation, side-bending radiographs predicted the amount that could be corrected without osteotomies. Although newer instrumentation systems made it possible to achieve greater correction of the instrumented curve, overcorrection can result in an increased incidence of postoperative decompensation. If a compensatory curve is to be left uninstrumented, the amount of spontaneous correction needs to be measured. If necessary, consideration should be given for undercorrection of the major curve or inclusion of all or a portion of the minor curve. Margulies and colleagues [15] presented an algorithm based on the principle that the amount of correction in instrumented curves should not exceed the degree of spontaneous correction in noninstrumented adjacent curves. Of the 16 patients who did not follow the algorithm, all developed imbalance.

Special attention should be paid to upper thoracic curves. If the curve is structural and not instrumented, particularly if the shoulder on the concavity of the curve is higher, balanced or subtle shoulder asymmetry can become noticeable after surgery [14]. Spinal balance includes the maintenance or achievement of level shoulders.

Upper instrumented vertebra

Fusion levels are selected to balance the head and shoulders over the pelvis to prevent postoperative decompensation. The proximal extent of the fusion should include the entire measured

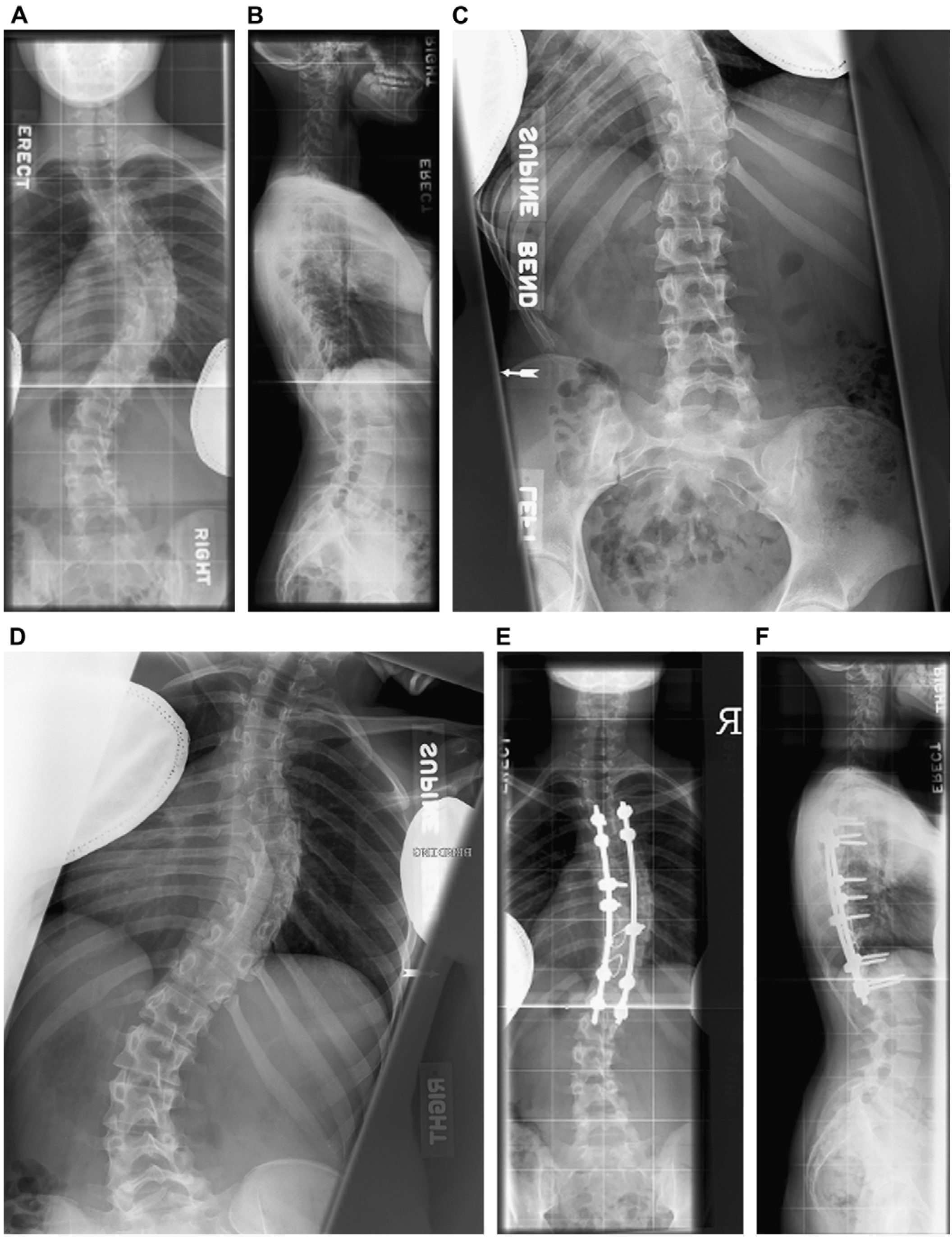

Fig. 1. A 17-year-old girl with progressive adolescent idiopathic scoliosis. AP (*A*) and lateral (*B*) views show 36° lumbar and 64.6° thoracic curves that correct on bending films to (*C*) 9.9° and (*D*) 46°. The patient underwent selective thoracic fusion from T4 to T12 with pedicle screws and sublaminar wires; laminotomies were performed at some thoracic levels in order to improve visualization of the pedicles. (*E, F*) Postoperative radiographs show a 25° lumbar curve and 32.5° thoracic curve.

curve, and the upper instrumented vertebra should be a stable vertebra. If kyphosis greater than 5° is present, instrumentation should not end at the apex. Some authors also recommend against ending a fusion proximally at the thoracolumbar junction or ending at this area only if it is flat. Avoiding the thoracolumbar junction may require proximal extension of the fusion with increased risk of pseudarthrosis, however [13].

Lowest instrumented vertebra

Based on a landmark study by King and colleagues [6], ending a fusion at the stable vertebra to place the fusion mass on a stable base has become standard. At that time, instrumentation consisted of Harrington rods with two-point distraction and a force in one plane. The stable vertebra was determined on the standing AP radiograph. King also recommended avoiding fusion to L4 or distally when possible, because of an increased risk of development of back pain [1].

The ideal goal for the last instrumented vertebra is to be the stable, neutral, end, and horizontal vertebrae on the final follow-up standing AP radiograph. Instrumentation should not end at a maximally rotated vertebra. As more attention was paid to the three-dimensional nature of the deformity, it was realized that the stable vertebra may change from the preoperative studies because of intraoperative derotation bringing a more proximal vertebra into the central sacral line [16]. At our institution, the stable vertebra is determined on supine side-bending radiographs and confirmed by intraoperative radiographs after initial instrumentation.

With newer instrumentation systems, authors are reporting satisfactory results despite ending fusions at levels proximal to the stable vertebra. Burton and colleagues [17] preserved at least three motion segments with no fusion distal to L3 by ending at the "caudal foundation vertebra," which was usually at or just proximal to the end vertebra. They reported an average correction of 63% at last follow-up in 100 patients. Suk and colleagues [7] reported on long thoracic curves treated with segmental pedicle screw fixation and found that fusing to the neutral vertebra or one proximal resulted in satisfactory balance in all 14 patients in their study.

The distal end of the fusion mass in the lower lumbar spine is a matter of significant debate. Fusions ending at L5 lead to L5-S1 disc degeneration in as many as 66% of cases. If the L5-S1 disc is normal, it may be appropriate to stop the fusion at L5. In the degenerative spine, the L5-S1 level may have little motion because of autofusion, which also makes fusion to the sacrum unnecessary.

Long fusions that include the sacrum have high rates of pseudarthrosis. Indications for fusion to the sacrum in adults include L5-S1 spondylolisthesis, previous L5-S1 laminectomy, L5-S1 stenosis, oblique take-off of L5, and severe degeneration. Steps that may decrease the pseudarthrosis rate include bi- or tricortical S1 screws; achievement of neutral or negative sagittal balance; and the addition of interbody techniques, including anterior interbody fusion, posterior lumbar interbody fusion (PLIF), or transforaminal lumbar interbody fusion (TLIF). Iliac screw fixation "protects" the L5 and S1 screws and increases the fusion rate [13]. However, iliac screws may alter the patient's gait and sometimes require later removal because of prominence.

Sagittal plane

Careful attention must be paid to the thoracic kyphosis, thoracolumbar transition, and lumbar lordosis. Restoration of the sagittal balance, preferably with normal sagittal contour, should be a goal of surgery. Fusion should always be continued above the apex of thoracic kyphosis to minimize the risk of junctional kyphosis. Instrumentation should end at a neutral vertebra in the sagittal plane defined by the C7 plumb line. The sagittal plane should also be considered when choosing the lowest instrumented vertebra because of the risk of distal junctional kyphosis. Lowe and colleagues [18] recommended extending the fusion one level distally if kyphosis of greater than 10° is present at that level.

In Scheuermann's kyphosis, poor selection of fusion levels is thought to contribute to the high rate (25%–30%) of junctional kyphosis. Other possible causes include overcorrection to less than 40° of kyphosis or by more than 50% of the original measured curve. The upper instrumented vertebra should be the uppermost measured in the curve and is usually T2 or T3. The lowest instrumented vertebra should be extended to the first or second lordotic disc, marked by the convergence of the end plates posteriorly [19].

In adult patients, fixed sagittal deformity represents a challenging problem. Lumbar lordosis must be restored to achieve a satisfactory outcome. Lordosis can be reconstituted through osteotomies or structural interbody techniques. Berven and colleagues [20] reported on patients with a large (greater than 5 cm) fixed sagittal plane deformity treated with combined AP surgery. The authors advocated anterior and posterior surgery for patients with lumbar hypolordosis (less than 30°), open disc spaces in the lumbar spine, and prior pseudarthrosis. Pseudarthrosis and severe deformity were managed with osteotomies and vertebral column resection. A high rate of complications during surgery and long term was reported, with 40% of patients undergoing additional surgery.

Adult deformity

Adult idiopathic scoliosis and degenerative scoliosis are often treated using guidelines extrapolated from adolescent cases, but these must be considered carefully because of the additional components of pain and degeneration present in the adult spine. Fusion levels may be dictated by the need to decompress foraminal, lateral recess, or central stenosis. Degeneration of the facet joints and discs causes less flexibility and less spontaneous correction, and rotatory and lateral listhesis further complicate the selection of fusion levels. Fusions should not end adjacent to a level of lateral listhesis, and this level should be included in the fusion. Fusion stopped adjacent to a severely degenerated disc has a risk of progression or rapid degeneration, especially if there is fixed tilt or subluxation, unless the degeneration is so severe as to have resulted in spontaneous fusion of the facets or disc. The facet and the interspinous ligament of the level adjacent to the proximal extent of the fusion should not be disrupted. Goldstein and colleagues [21] found that patients with adult idiopathic scoliosis were commonly fused caudal to the stable vertebra because of degeneration, including all patients fused to L5 or S1. Use of the stable zone to determine the lowest instrumented vertebra may allow a more proximal lowest level than the central sacral line (Fig. 2).

The most important factor affecting the outcome in adults is a balanced and physiologically

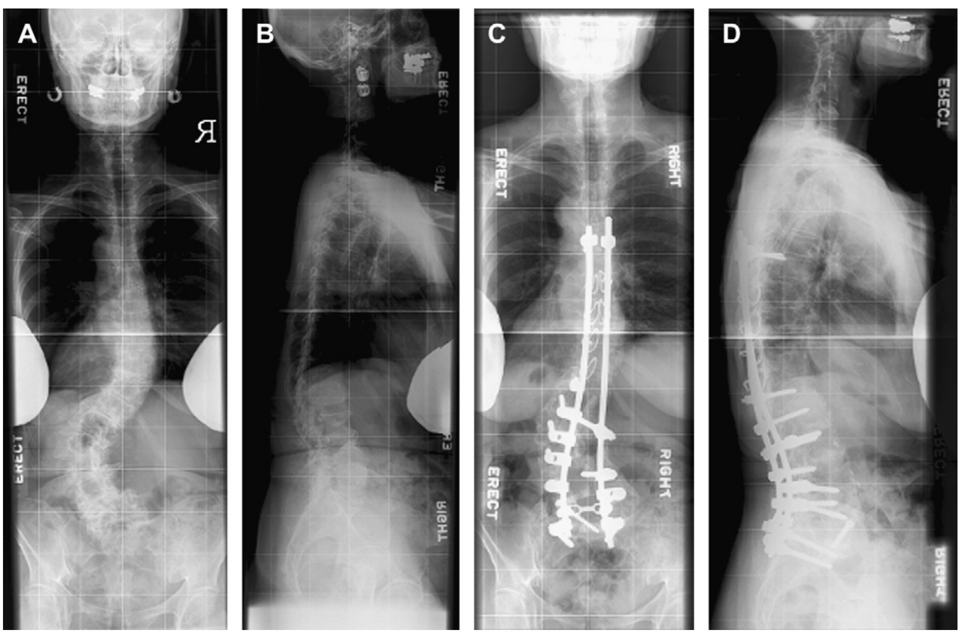

Fig. 2. A 72-year-old woman presented with chronic lower back pain, left lower extremity radiculopathy, and progressive deformity refractory to conservative treatment. Preoperative AP (*A*) and lateral (*B*) radiographic views show a lumbar curve of 65.6°. The patient underwent two-stage surgery with anterior fusion from T12 to the sacrum, followed by lumbar decompression and posterior spinal fusion from T7 to the sacrum. Two-year postoperative AP (*C*) and lateral (*D*) radiographic views show a solid fusion mass and good coronal and sagittal balance.

contoured sagittal plane [2]. Sagittal balance above the fusion is crucial. Emphasis should be placed on restoration rather than maintenance of lumbar lordosis, because degeneration often leads to hypolordosis of the lumbar spine. Often, rotational correction of the degenerated spine can result in improvement of scoliosis and lordosis simultaneously.

In contrast to idiopathic scoliosis, degenerative scoliosis is characterized by advanced degeneration and mostly lower lumbar curves [22]. It is important to be cognizant that the indications for surgery in these patients are symptoms associated with stenosis, facet joint arthrosis, and subluxation rather than deformity. The goals of surgery should be focused on decompression, normalization of the sagittal plane, and balance in the coronal plane. Although symptoms are related to stenosis, fusion is often necessary to achieve adequate decompression and to prevent instability and progression [13]. Fusion from the thoracolumbar junction to the lumbosacral junction may be indicated for some degenerative lumbar curves. The extent and morbidity of stabilization surgery may make it tempting to pursue a more conservative approach, but limited decompression has high rates of failure. If a curve is of smaller magnitude (less than 20°) and has no significant apical deviation or rotation, it may be more radiographically than clinically significant. A more limited fusion may be attempted even if the superior and inferior ends are not parallel to the sacrum, with the understanding of the risk of later adjacent segment problems (Fig. 3) [13].

A common degenerative pattern in the lumbar spine is L3-L4 rotatory subluxation, L4-L5 tilt, and L5-S1 degenerative disc disease. If the patient is well balanced, the fusion may be limited to the levels being decompressed. Interbody techniques can improve local lumbar lordosis and lateral listhesis and restore height for indirect decompression. If L5-S1 stenosis or spondylolisthesis makes fusion to the sacrum necessary, interbody fusion, and, possibly, pelvic fixation, should be considered if the proximal extent of fusion is to the thoracolumbar junction or higher.

The proximal level of the fusion should be chosen based on the stable zone, restoration of

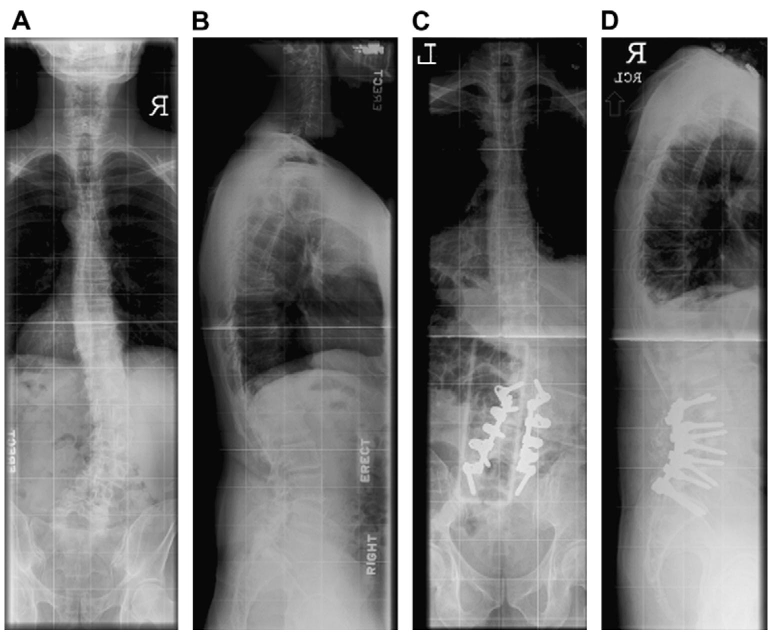

Fig. 3. A 62-year-old man with degenerative scoliosis had initially undergone limited decompression that led to collapse and progression of the deformity and worsening of symptoms. Preoperative AP (*A*) and lateral (*B*) radiographic views show a lumbar curve of 32° with good coronal and sagittal balance. Decompression and posterior spinal fusion from L2 to the sacrum were performed. The horizontal vertebra was used as the upper instrumented vertebra to save levels because of the patient's activity level. Postoperative AP (*C*) and lateral (*D*) radiographic views show maintenance of coronal and sagittal balance and physiologic lumbar lordosis.

sagittal alignment, and, when appropriate, transition to normally aligned proximal segments. Proximal pull-out and adjacent segment degeneration remain problematic. The upper instrumented vertebra should be a healthy segment without significant degeneration, instability, or imbalance. Many degenerative lumbar curves involve L1 to L5, and some authors believe that the fusion may be stopped at the thoracolumbar junction if there is no evidence of degeneration and kyphosis. Others advocate fusing to T10 or proximally because of the additional stability imparted by the rib cage [23]. It is unclear whether more proximal fusion prevents adjacent segment degeneration.

Anterior surgery

The purpose of anterior surgery is to achieve greater correction and higher fusion rates. Additional advantages include improvement of the sagittal profile and, possibly, pain reduction. Thoracoscopic surgery may offer less incisional pain, better visualization, less blood loss, and less pulmonary compromise but has a steep learning curve and is best used at specialized centers [19].

Anterior-only surgery has been reported to save fusion levels in certain types of curves in adolescent idiopathic scoliosis [24]. Kuklo and colleagues [25] compared anterior and posterior surgery for single overhang thoracic curves and reported that in the anterior group, fusions ended at or above the stable vertebra in 97% of cases versus 65% of cases in the posterior group and averaged 1.5 levels saved. The posterior group included hook and pedicle screw instrumentation.

With modern instrumentation systems, adolescent idiopathic scoliosis can usually be treated with posterior-only surgery, including large-magnitude curves. Proposed indications for anterior release include a large stiff curve and to prevent crankshaft phenomenon in immature children. Burton and colleagues [26] performed posterior-only surgery for thoracic curves between 70° and 90° and reported an average final correction of 64%. These investigators concluded that significant correction could be achieved through posterior-alone surgery even for large stiff curves.

Most studies show better results after combined AP surgery for Scheuermann's kyphosis [19]. Anterior release is performed by cutting the anterior longitudinal ligament of the rigid apex, correcting the kyphosis, and placing structural graft in the intervertebral disc spaces. Posterior-only surgery has been associated with less correction, higher rates of pseudarthrosis, and loss of correction with time [27]. It may be appropriate for patients with kyphosis that corrects to less than 50° and adult patients whose main complaint is pain [28]. Recently, Lee and colleagues [29] presented results of posterior-only surgery using pedicle screw fixation for kyphosis with curves of greater than 70°. The posterior group had similar correction (54.2% versus 41.2%) and superior maintenance of correction (51.8% versus 38.5%) compared with the combined group, with a minimum of 2 years of follow-up.

In adult deformity, indications for combined AP surgery include a long fusion to the lumbosacral junction; a large coronal deformity, defined as a greater than 60° structural curve or greater than 5 cm of decompensation; or the need to improve sagittal alignment significantly with anterior structural support. The additional correction must be balanced with the accompanying increased morbidity [30]. Patients at increased risk for pseudarthrosis because of smoking, osteoporosis, or previous pseudarthrosis may also be appropriate candidates for AP surgery.

Instrumentation

Although the choice of instrumentation ultimately depends on the patient's anatomy and the surgeon's preference and experience, the three-column purchase of pedicle screw fixation lends it superior stability and pull-out strength. Pedicle screws are the best form of fixation in the setting of decompression when the posterior elements are removed. Liljenqvist and colleagues [31] compared hooks with pedicle screws and found that the screw group had significantly greater curve correction, better maintenance of correction, shorter fusion length, and less operative time and blood loss. Other authors have presented similar results [32]. Pedicle screws have been shown to be safe, but the surgeon must be mindful of smaller distorted pedicles in spinal deformity and shifting of the spinal cord into the concavity of the spinal canal.

The extent of instrumentation with pedicle screws can vary considerably, ranging from fixation at every level to only the ends of the construct. Although segmental placement of pedicle screws provides more stability, bilateral screws at every level may not be necessary in most cases. A biomechanical study by Deviren and colleagues [33] found that in the posterior-only surgery model, the minimum construct was as stable as others; however, with anterior annulotomies and posterior facetectomies, the segmental construct was necessary to provide stability. The authors speculated that a construct with fixation at only the upper and lower ends may be sufficient in posterior-only surgery. Segmental fixation of the lumbar spine is preferred because of the greater motion and higher rates of pseudarthrosis and to restore optimal lordosis.

Other considerations

Flatback deformity is a postsurgical loss of normal lumbar lordosis causing fixed forward inclination with an inability to stand upright, pain, and functional impairment. It was historically most commonly caused by Harrington distraction instrumentation. With the increase in lumbar spinal fusion, there has been an increase in flatback deformity secondary to failure to maintain or enhance lordosis. The best strategy for flatback deformity is prevention through careful preoperative planning before performing a long spinal fusion, with attention to sagittal balance. Distraction of the spine should be avoided distal to L1 or L2, and fusions should be stopped at L3 unless absolutely necessary. In short fusions of the degenerative lumbar spine, it may be necessary to increase the lordosis in anticipation of further loss of curvature in the future. Intraoperative positioning is critical to avoid any position that causes a decrease in lordosis (as does the Wilson frame), and the hips should be fully extended [9]. Anterior fusion with structural graft also helps to restore lordosis. It is important to be mindful of other conditions that can lead to the patient having difficulty in standing upright, including hip pathologic changes, spinal stenosis, painful pseudoarthrosis, and trunk muscle weakness.

Summary

There are multiple and sometimes conflicting considerations that must be reviewed when planning surgical stabilization of spinal deformity. Although there may be significant variation in surgeon decision making, careful adherence to primary principles, such as achieving coronal and sagittal balance in all patients and minimizing fusion levels, particularly in young patients, should be of paramount importance. Although this article did not address complications, the surgeon should be aware of the potential for increased morbidity when electing to perform surgery of greater magnitude on patients. Ultimately, however, the surgeon must decide which fusion levels and techniques are likely to give a particular patient the most predictable result that can be achieved with the least risk and future consequences.

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