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Surgical considerations for major deformity correction spine surgery

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Spinal deformity is defined as abnormality in alignment, formation, or curvature of one or more segments of the spine. Its characteristic clinical presentation and radiographic appearance differ according to patient age and the underlying cause. The most common deformity in the pediatric population is adolescent idiopathic scoliosis, whereas in adults many patients present with *de novo* deformity secondary to degenerative disease. Although the specific goals differ between patients, the broad aims include restoration of regional and global alignment, decompression of neural elements as necessary, and establishment of a solid fusion. Surgeons perform deformity correction by various approaches and techniques to achieve the desired correction while minimizing perioperative risk.

Introduction

Spinal deformity comprises a spectrum of disease in which there is abnormal alignment, formation, or curvature of the spine. It may be isolated to a single plane or involve a combination of axial, coronal, and sagittal plane deformity. Scoliosis, classically defined as a curvature of >10° in the coronal plane,

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typically involves concomitant rotational deformity and is often associated with sagittal plane deformity. Recent data, particularly on adult spinal deformity (ASD), have shown the critical importance of deformity in the sagittal plane, which results in global malalignment in the generation of pain and disability [1]. Loss of lumbar lordosis (LL) or flatback syndrome, in isolation or in combination with thoracolumbar kyphosis or thoracic hyperkyphosis, is the most common form of sagittal plane deformity in adults, which may result in an inability to maintain normal upright posture and horizontal gaze when severed [2].

Several disease processes may produce spinal deformity, including congenital anomalies of vertebral formation, neuromuscular disease, intrinsic spinal cord abnormalities (e.g., intramedullary tumor), infection, trauma, and degenerative disease. Scoliosis, in particular, may arise from any combination of these processes; however, there is no common discernable cause, and hence it is termed idiopathic scoliosis. In skeletally immature patients, idiopathic scoliosis – which has its highest incidence in adolescence – is the most common form of scoliosis. In young adults, idiopathic scoliosis remains the most common spinal deformity, whereas in older adults, degenerative scoliosis or kyphoscoliosis and iatrogenic deformities predominate [3]. In the elderly, the prevalence of scoliosis may be as high as 68% [4]. This study focuses on the most common forms of spinal deformity in the skeletally immature and mature spine: adolescent idiopathic scoliosis (AIS) and degenerative kyphoscoliosis, respectively.

Rationale for major deformity correction

The indication for deformity correction differs between adolescents/young adults and older individuals because of distinctions in their respective deformity types and clinical presentation. The former group characteristically present with coronal plane abnormality (scoliosis) and concerns of curve progression and cosmesis, whereas the latter most commonly present with degenerative kyphoscoliosis associated with sagittal malalignment and stenosis, with consequent pain and disability [5,6]. Surgery, when indicated, should address the specific deformity pattern and the patient's clinical presentation.

Adolescent idiopathic scoliosis

Observation is the appropriate treatment for AIS with small to medium-sized curves (<20–25°) in patients who have reached or surpassed their peak height velocity [6]. Similarly, in adults with idiopathic curves that are asymptomatic or minimally symptomatic, observation is often appropriate. Even in those with superimposed degenerative changes, the expected slow progression supports at least a trial of observation with nonoperative therapies in the majority of cases [6]. In skeletally immature patients with idiopathic scoliosis, bracing is an important nonoperative therapy [7]. It is indicated to slow progression and avoid surgery or permit growth in a child who likely requires surgery, but has not yet reached the peak growth velocity. In general, surgery is indicated for AIS when there is demonstrable or expected curve progression on serial clinical and radiographic examination. Thus, the goal is to treat or prevent development of a significant clinical deformity and its potentially associated functional limitations and cosmetic implications. On the contrary, in adults, operative treatment of idiopathic scoliosis is more commonly directed at relieving symptoms.

Degenerative scoliosis

Degenerative kyphoscoliosis is the most common deformity that develops *de novo* in adults. This form of scoliosis results from the consequences of degenerative disease affecting the disks and facet joints [8]. Symptoms of ASD include back pain, leg pain, postural fatigue, and difficulty ambulating, and they appear from a combination of neural compression, degenerative disease of the disks and facet joints, and spinal malalignment [9–11]. In particular, positive sagittal malalignment, in which the trunk and head are pitched forward relative to the pelvis and lower extremities, is common in ASD. This form of imbalance is correlated with pain, disability, and decreased health-related quality of life (HRQOL) [12–17]. In fact, in ASD, malalignment in the sagittal plane is more sensitive to clinical outcomes than either coronal curve magnitude or coronal malalignment [16,17]. As such, restoration of global alignment with a focus on the sagittal plane is a major goal of deformity correction surgery in adults. The higher requirement for neural decompression via laminectomy and facetectomy is another factor that distinguishes the operative treatment of adult and pediatric deformity [18]. Several studies have demonstrated the benefit of operative management for ASD in improving HRQOL and reducing pain and disability [10,11,19–21].

Surgical considerations

Spinopelvic alignment

Central to our understanding of spinal deformity, particularly ASD, is the concept of spinal balance. Dubousset [22] conceptualized this as a hypothetical cone with its apex at the feet and base extending to the head. Within the cone, an individual can maintain upright posture with minimal energy expenditure and without pain. Progressive deviation from the center of the cone, as with spinal deformity, leads to a higher consumption of energy to compensate and sustain upright posture. Compensation for positive sagittal malalignment involves retroversion of the pelvis, bending at the hips and knees, and straightening of the upper thoracic spine. Failure of these compensatory mechanisms is associated with deviation outside the limits of the cone and may result in an inability to stand upright independently [23].

In addition to the alignment of the spinal column itself, spinopelvic alignment is critical in determining global alignment, and thus represents an essential component of surgical planning [24]. Global alignment, regional spinal alignment, and spinopelvic alignment are measured by standard radiographic parameters that facilitate planning of the operative strategy (Fig. 1). Briefly, global alignment can be measured as the sagittal vertical axis (SVA), which is the horizontal offset between a vertical plumb line from the center of the C7 vertebral body and the posterior superior corner of S1. Coronal alignment is measured as the distance from the plumb line to the center of S1 (C7PL) on an

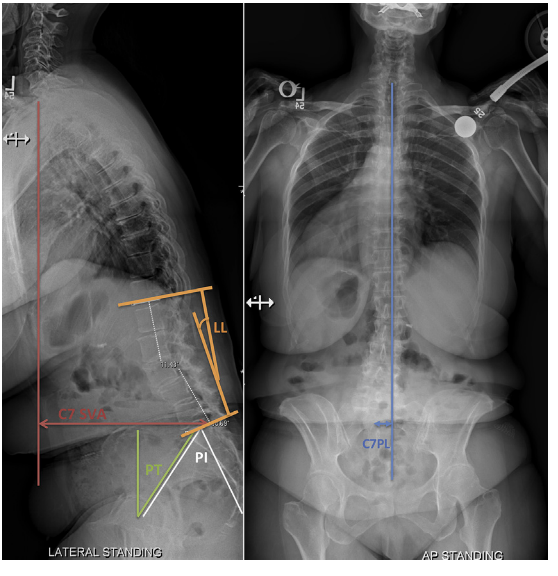

Fig. 1. Lateral (left) and anteroposterior (right) long-cassette radiographs of a 65-year-old patient with severe positive sagittal malalignment. Colored lines demonstrate standard radiographic deformity measurements, including C7 sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), lumbar lordosis (LL), and C7 plumb line for measuring global coronal alignment. See text for description of these measurements.

anterior–posterior (AP) radiograph. Regional alignment, including thoracic kyphosis (TK) and LL, as well as any coronal curvature is measured using the Cobb technique. Key spinopelvic parameters include the pelvic incidence (PI) and pelvic tilt (PT). The former is a morphogenic parameter that does not typically change after skeletal maturity is reached. It is measured as the angle between a line perpendicular to the S1 endplate and one drawn from the center of the femoral heads to that of the S1 endplate. The PI essentially determines the amount of LL a patient requires for harmonious balance, a value that is quantified as the lumbopelvic mismatch or PI − LL. The PT, measured as the angle between a vertical line passing through the center of the femoral heads and one connecting this to the center of the S1 endplate, represents a measure of pelvic retroversion. Increasing PT (retroversion) is one of the primary mechanisms through which patients compensate for positive sagittal malalignment. These radiographic parameters have been shown to correlate with HRQOL and disability scores in ASD patients and realignment goals established, including SVA <50 mm, PT <22°, and PI−LL <±9° [14–16,25]. These serve as guidelines in planning corrective strategies with the anticipation that achieving such thresholds will help optimize patient outcome.

Although much of the above discussion on spinal alignment focuses on ASD, it is becoming increasingly recognized that many of these concepts apply to the treatment of deformity in children and adolescents [26,27]. The longevity of an instrumented fusion in the latter group is likely influenced by the patient's global alignment and regional alignment in the unfused portions of his/her spine. Thus, surgeons are increasingly incorporating such considerations into their selection of fusion levels and surgical approach for these patients.

Goals of surgery

As mentioned earlier, the goals of deformity surgery differ according to patient age, clinical presentation, and deformity type. In general, they include realignment, correction of deformity, decompression of neural elements as required, achieving solid fusion (bone-bridging all instrumented segments), and minimizing perioperative and delayed complications. For AIS, in particular, the major goal is correcting and stabilizing the curve with appropriate regional alignment to maintain overall balance. In degenerative kyphoscoliosis, the focus is usually on restoring the pathological loss of LL, performing an adequate central and foraminal decompression (usually in the lower lumbar spine) to relieve neural compromise, and reducing positive sagittal malalignment. An additional goal unique to the treatment of deformity in skeletally immature patients with significant growth potential is to permit and guide further growth of the spine without arresting it [6]. Several new and innovative technologies are used to this effect, each with its own benefits and limitations [28–31].

Approach considerations

Adolescent idiopathic scoliosis

When considering the approach for AIS, anterior correction (via thoracotomy or thoracoabdominal approach) may permit a shorter segment fusion. The difference in required fusion length between anterior and posterior approaches is, however, narrower with the use of pedicle screw instrumentation than it had been prior to their advent [32]. An advantage of posterior pedicle screw instrumentation is the ability to directly manipulate the vertebral body in multiple anatomic planes. This facilitates a higher ability to derotate the spine than with an anterior approach, which can be used to correct chest wall deformity and potentially eliminate the need for thoracoplasty. Both anterior soft tissue releases (discectomy/annulotomy) and posterior osteotomy can be used to increase the flexibility of a stiff deformity and permit a higher correction. Previously, anterior releases might have been necessary prior to posterior correction and fixation for correction of large deformities; however, the use of thoracic pedicle screws has reduced the need for such combined approaches [33].

For AIS, all levels comprising the major curve are generally included in the fusion. Exceptions to this rule include proximal extension in the presence of a structural proximal thoracic curve to allow for shoulder balance and selective fusion of only the thoracic or thoracolumbar/lumbar curve when deemed necessary for maintaining overall balance [6]. Correction of deformity from an anterior approach uses compression on the convex portion of the curve, with or without the use of interbody devices placed in the disk spaces. Through a posterior approach, convex compression with or without concave distraction is combined with derotation to address both the rotational and translational components of the deformity. With anterior, posterior, or even combined approaches, regional corrective maneuvers must be performed with an appreciation of their effect on overall alignment. Intraoperative long-cassette anteroposterior and lateral radiographs are critical to ensure that the surgery results in a satisfactory global alignment.

Adult spinal deformity

Posterior approaches have become increasingly popular in the treatment of ASD because of their versatility, familiarity, and relatively high rates of success with modern instrumentation. Such approaches comprise segmental pedicle screw instrumentation to encompass the deformity and any areas with neural compression. Unlike AIS, where the major curve(s) involve the thoracic or thoracolumbar spine, in ASD, the coronal curvature involves the lumbar and lumbosacral spine. Therefore, surgical treatment of ASD often involves fusion from the thoracic spine to the sacrum. Interbody devices can be placed between vertebral segments by a transforaminal approach, that is, transforaminal lumbar interbody fusion (TLIF) to enhance fusion, aid in decompression by restoring foraminal height, and improve segmental lordosis. Using these techniques, several authors have reported significant improvements in radiographic measures [34–36] and HRQOL outcomes [36]. Selection of osteotomy depends on the flexibility of the deformity, degree of desired correction, and number of segments over which the correction will take place [24,37]. The surgeon must also balance the need for more aggressive maneuvers to achieve realignment goals with their associated increased risk.

Posterior osteotomies range from simple facetectomies to resection of one or more complete spinal segments. The most commonly performed osteotomy from a posterior approach, the Smith-Petersen osteotomy (Fig. 2), involves removal of bilateral facets, spinous process, the inferior lamina,

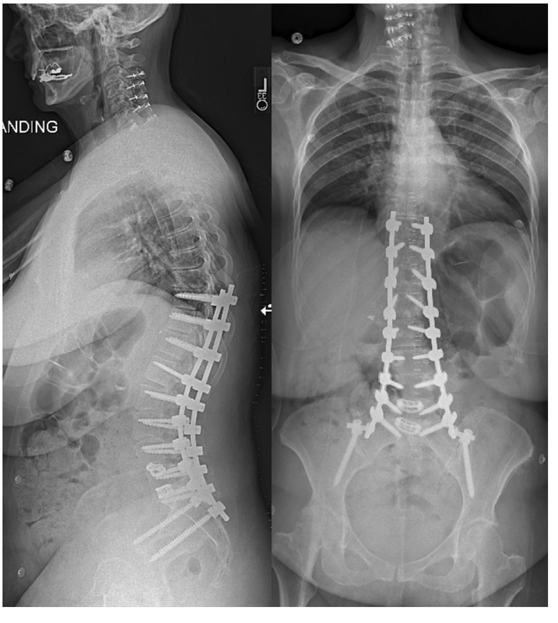

Fig. 2. Lateral (left) and anteroposterior (right) long-cassette radiographs of the same patient described in Fig. 1. Deformity correction surgery comprised posterior instrumented fusion from T10 to S1 with placement of bilateral iliac screws, Smith-Petersen osteotomies from T12/L1 to L5/S1, and transforaminal interbody fusion at L4/5 and L5/S1. Successful realignment to appropriate radiographic parameter thresholds has been achieved.

and interspinous ligament at a single segment. After resection of these elements, the resultant defect is closed (usually by compressing the adjacent pedicle screws) with extension through the disk space and shortening of the posterior column [37]. This osteotomy can be performed at multiple levels and is highly effective for correction of mild to moderate sagittal or coronal malalignment when used in this manner (Fig. 2) More severe malalignment or focal or angular deformity may require a pedicle subtraction osteotomy (PSO) or even a vertebral column resection (VCR). In the former, a wedge of bone including both pedicles is resected, followed by closure of the defect allowing for segmental correction of 20–30° (Fig. 3) [38]. Asymmetric resection of bone can simultaneously correct coronal malalignment. VCR involves removal of an entire vertebral segment (anterior and posterior elements) together with the adjacent disks and is reserved for severe focal deformities that cannot be addressed with more conservative procedures [39]. Both PSO and VCR are technically demanding procedures that are associated with a relatively higher risk of complications even at high-volume centers [37,40–42].

In the treatment of ASD, anterior approaches are typically used in conjunction with posterior instrumentation and fusion. Their advantages include enhanced fusion due to a large surface area, the ability to use large interbody grafts to facilitate sagittal and coronal correction, and indirect neural decompression. They are usually performed in the lower lumbar spine and lumbosacral junction, because of the higher biomechanical stress at these regions following long-segment fusions and the potential to obtain large sagittal correction (particularly at L5-S1). The trade-off is exposure of the patient to an additional procedure with an incremental increase of surgical risk as well as introducing risks unique to the anterior approach itself, such as ileus, significant vascular injury, lumbosacral plexus injury, abdominal hernia, and, in males, retrograde ejaculation [43]. In order to mitigate these risks, several minimally invasive approaches and instrumentation techniques have been developed, most of which entail a lateral or oblique approach to the lumbosacral spine. The lateral transpsoas approach can be performed by a small incision, avoids the need for

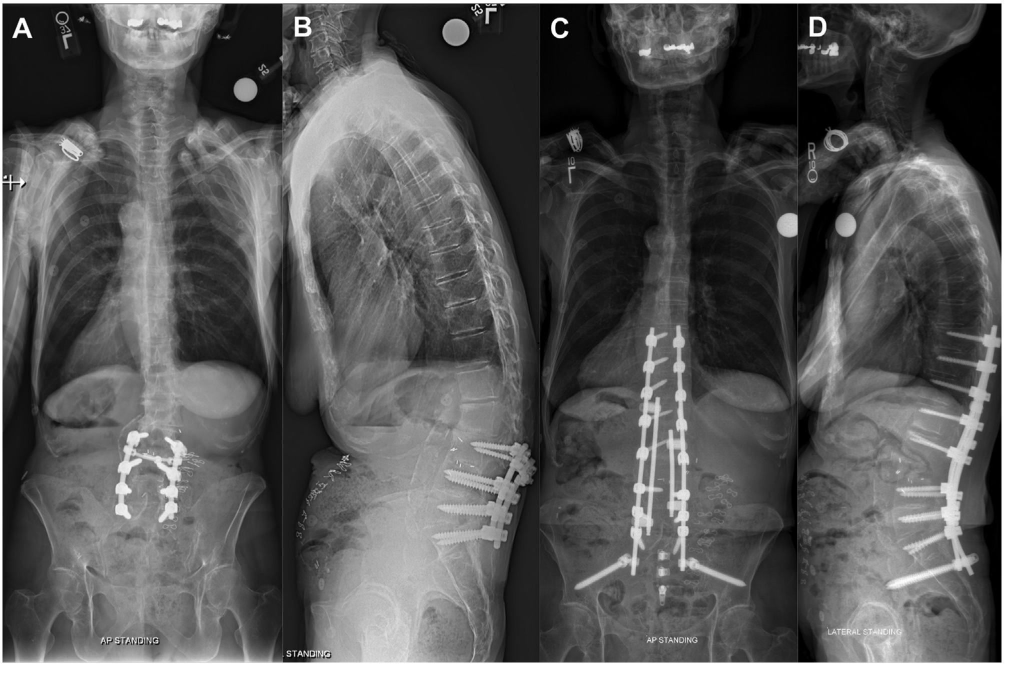

Fig. 3. Patient with previous L3-S1 instrumented fusion, associated iatrogenic flatback deformity and proximal junctional kyphosis resulting in significant positive sagittal malalignment (A and B). C, anteroposterior and D, lateral radiographs following posterior instrumented fusion from T10 to the pelvis with L3 pedicle subtraction osteotomy, T12/L1 and L1/2 Smith-Petersen osteotomies show restoration of lumbar lordosis and successful global realignment.

mobilization of the iliac vessels, and is associated with less intraoperative blood loss and shorter hospital stays [44]. Such techniques will require further research to confirm their safety profile and long-term efficacy in the treatment of ASD.

Surgical adjuncts

Several surgical adjuncts are used to reduce the risk of complications associated with the treatment of spinal deformity. Neurophysiological monitoring is widely used to provide the surgeon with real-time feedback on the functional integrity of the nervous system. Autologous transfusion and anti-fibrinolytics are used to reduce blood loss and the need for perioperative transfusion. These adjuncts are discussed in two separate dedicated articles within this supplement.

Complications

Major spinal deformity surgery, particularly in adults, is associated with high rates of complications [11,41,45]. These include surgical site infection, nerve root or spinal cord injury, major blood loss, cerebrospinal fluid leak, implant failure, junctional failure, adjacent segment degeneration, pseudarthrosis, implant failure, and venous thromboembolism. Complication rates are higher for revision procedures, particularly in those who were performed three-column osteotomies (PSO or VCR) and combined anterior/posterior procedures [46,47]. For a more detailed discussion on complications of major spinal deformity surgery, the reader is referred to the chapter "Postoperative Complications" in this edition.

In adults, complications increase significantly with age, although interestingly, in older individuals, the higher rate of complications is somewhat compensated by a higher improvement in HRQOL and disability than their younger counterparts [11]. Measures to reduce the risk of these complex procedures include performing them at high-volume centers [48,49] with adequate anesthetic and intensive care support, diligent preoperative medical optimization of surgical parameters, and appropriate use of surgical adjuncts.

Conclusions

Spinal deformity comprises a spectrum of disease processes that individually or in combination produces an abnormality in spinal alignment. The characteristic clinical presentation and radiographic appearance differ according to patient age: adolescents and young adults typically present with concerns of deformity and curve progression, whereas older adults complain of pain and disability. Although the specific goals differ between patients, the broad aims include restoration of regional and global alignment, decompression of neural elements as necessary, and establishment of a solid fusion. Surgeons perform deformity correction by various approaches and techniques to achieve the desired correction while minimizing perioperative risk.

Practice points

- Spinal deformity is caused by a spectrum of disease processes that results in an abnormality in regional or global spinal alignment.
- The clinical presentation and radiographic appearance of spinal deformity differ according to patient age.
- The most common deformity in the pediatric population is adolescent idiopathic scoliosis, and in adults, degenerative (kypho) scoliosis.
- Surgery for idiopathic scoliosis focuses on correcting and halting progression of the curve and maintaining global alignment.
- Adult spinal deformity surgery aims to relieve pain and disability by restoring global alignment – often by reestablishing lumbar lordosis – and decompressing neural elements.
- Several techniques and approaches are used judiciously to achieve realignment goals while minimizing surgical risk.

Research agenda

- We need further prospective evidence on outcomes after surgical treatment of pediatric and adult spinal deformity.
- Studies are needed to assess evidence-based interventions to reduce perioperative complications.
- We need further prospective data on the safety and efficacy of minimally invasive techniques for treating spinal deformity.

Conflict of interest statement

None.

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