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Anterior Instrumented Arthrodesis for Adult Idiopathic Scoliosis

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Idiopathic scoliosis has a heterogeneous phenotype that may involve abnormal curvature of the thoracic, thoracolumbar, and lumbar spine. The deformity is complex, involving pathologic curvature in the coronal and sagittal planes and rotation in the axial plane [1]. The onset of idiopathic scoliosis is usually before skeletal maturity, with persistence and possible worsening of the deformity after skeletal maturity. Thoracolumbar and lumbar curves are less prevalent than thoracic deformity in the adolescent population. Adult scoliosis encompasses the adult sequelae of adolescent idiopathic scoliosis and de novo scoliosis. Thoracolumbar and lumbar deformities are more prevalent in adults presenting for management of spinal deformity than in adolescents. The prevalence of scoliosis in adults has been reported variably, and estimates range from approximately 6% in the population older than 50 years of age to nearly 50% of elderly women presenting with back pain and osteoporosis [2,3].

As deformity progresses into adulthood, curve patterns are characterized by a variable amount of secondary degeneration, intervertebral subluxation, and truncal imbalance. These characteristic changes are correlated with several factors, including age, degree of curvature, location of apex, and rate of progression. Asymmetric degeneration perpetuates uneven loading in a cycle that leads to further asymmetric degeneration and progression of deformity. With significant degeneration, it can be difficult to determine the primary classification of a curve. Primary or de novo degenerative curves typically have less frontal plane deformity than adolescent idiopathic deformity with superimposed degeneration, however [4–6]. With increasing age, osteoporosis is another factor that may further contribute to deformity progression, and this comorbidity has an important bearing on operative management and strategies [7,8]. The presence of osteoarthritis in the facet joints leads to more rigid deformity, and associated central canal stenosis may lead to neurogenic symptoms, a complexity rarely seen in the adolescent period of idiopathic scoliosis [9].

Clinical presentation/indications for intervention

The clinical presentation of the adult patient with idiopathic scoliosis is distinct from that of the adolescent [10]. Pain is a presenting complaint in patients with adult idiopathic scoliosis, whereas most adolescents with scoliosis do not have back pain. Deviren and colleagues [9] demonstrated that axial pain has a strong positive correlation to age ($r = 0.63$). Other predictors of pain are predominant lumbar curves and thoracolumbar curves greater than 45° with apical rotation and coronal imbalance [7,11–14]. Schwab and colleagues [15] performed a prospective analysis to determine the predictors of pain in 95 patients with adolescent idiopathic scoliosis of the adult or de novo degenerative scoliosis. This study showed that ''lateral vertebral olisthy, L3 and L4 endplate obliquity angles, lumbar lordosis, and thoracolumbar kyphosis were significantly correlated with pain'' [15].

Pain in adult idiopathic scoliosis is secondary to degenerative changes in discs, facet joints, or

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evoked paraspinal muscle pathologic findings. Later manifestations of the associated arthropathy and spinal stenosis are leg pain and neurogenic claudication. Spinal stenosis is more commonly seen in primary degenerative scoliosis. Patients often notice progression of curvature, decompensation in truncal balance, pelvic or shoulder asymmetry, and height loss before presentation.

Indications for surgery in adults with scoliosis include the following [7]:

1. Progressive deformity
2. Neural symptoms
3. Pain that is unresponsive to nonoperative care

Surgical planning and technical considerations

Treatment for spinal deformity in the adult patient is rigid instrumented fusion with additional decompressive surgery if it is necessary. Anterior, posterior, and combined anterior-posterior instrumentation has been used to achieve arthrodesis in select patients. There are excellent reviews on selection of fusion levels by King and colleagues [16], Bridwell [17], and Lenke and colleagues [18,19] as well as by Mok and Hu in the current issue. The decision of which approach to use is complex and is only discussed in terms of appropriateness of anterior fusion in the current review. The remainder of this work addresses the technical considerations, biomechanical analyses, outcomes, and complications of anterior surgery for thoracolumbar and lumbar adult idiopathic scoliosis.

Anterior spinal fusion (ASF) with instrumentation has been shown to be an effective treatment option for idiopathic scoliosis. It was first used in 1964 by Dwyer and colleagues [20] with a cable and screw system that provided only compressive forces across the convexity. The limitation of this system was that it led to a tendency toward kyphosis [21] as well as loss of coronal plane correction and up to a 33% nonunion rate. Zielke and colleagues [22] modified this technique, changing the longitudinal member from a cable to a semirigid rod. The semirigid rod allowed a derotation maneuver and compression while providing more rigid fixation. Although fusion rates were increased and loss of correction was improved with Zielke instrumentation, semirigid instrumentation systems have had unpredictable clinical results [23–26].

More rigid anterior instrumentation systems have been introduced, including the Dunn system, the Cotrel-Dubousset system, the Kaneda system, the Texas Scottish Rite Hospital system, and the Isola system [27–30]. Recent reports with rigid systems have shown excellent deformity correction and high patient satisfaction in well-selected patients in adolescent and adult populations [9,30–33]. Despite improvements in instrumentation and technique, literature on rigid anterior instrumented fusion for adult idiopathic scoliosis is sparse, and there is no such review of this type to the authors' knowledge.

An anterior solid rod construct has been used most often for thoracolumbar and lumbar scoliosis. The preoperative selection of fusion levels for the anterior approach is based on the standing posteroanterior (PA) film and the right and left lateral bending films, the latter of which assess the flexibility of the primary curve and any compensatory curves [34,35]. Compensatory deformities may include the cephalad thoracic curve and the caudal fractional lumbosacral curve. In the anterior approach to thoracolumbar deformity, only the structural component of the curve is instrumented, as identified on the side-bending radiograph, from end vertebra to end vertebra. In contrast, in the posterior approach, fusion levels are more likely to extend to neutral and stable vertebrae, and therefore encompass more mobile segments. Segments with more than 10° of disc space wedging and greater than 20° of rotation are usually included in the fusion, but fusion can be shortened at the caudal end by one vertebra if bending films show horizontalization of the end vertebra or if the disc space above this vertebra opened with side bending toward the concavity. To prevent decompensation, the adjacent disc space to the instrumented segment should open on both sides on the bending films, the fractional lumbosacral curve should be correctable, and a compensatory thoracic curve should correct to less than 30° to be left out of the instrumentation [36].

The decision to use an anterior approach may provide benefits, such as preservation of additional motion segments [33]. Several variables must be taken into account when making this decision, however. Adult scoliosis can be associated with marked degeneration; thus, it is paramount to consider the condition of the segments above and below the planned fusion and to adjust fusion levels accordingly to attain a balanced stable fusion. When addressing the correctability of a curve, the sagittal, coronal, and axial alignments must be considered. Essential to the correction are balance in the coronal and sagittal planes, factors

that are more important than the absolute degree of correction [37]. If it is deemed that anterior instrumentation cannot achieve trunk balance, the approach should be supplemented by posterior instrumentation or abandoned for a posterior-only approach. The anterior approach allows for multiple levels of discectomy, which can augment correction in the coronal and axial planes. Sanders and colleagues [38] studied the predictors of noninstrumented correction of minor thoracic curves in patients with idiopathic scoliosis who underwent selective anterior fusion of their major thoracolumbar or lumbar curves. They obtained a satisfactory spontaneous correction of thoracic curves in 42 of 44 patients who had thoracic curves less than 55° and a thoracolumbar/lumbar-to-thoracic ratio of 1.25 or greater or a thoracic curve that reduced to less than 20° on preoperative bending films. This study emphasizes that skeletal maturity, as evidenced by closure of the triradiate cartilages, is a favorable predictor of satisfactory outcome. Caution should be used when extrapolating these adolescent outcome data to adults, however, because degenerative changes and associated loss of flexibility may confound the findings.

The authors have shown that curve magnitude and patient age are the main predictors of structural flexibility. Every 10° of increase in curve magnitude greater than 40° results in a 10% decrease in flexibility, and every 10-year increase in age decreases flexibility of the structural curve by 5% and the lumbosacral fractional curve by 10%. Curve magnitude and age of patients are significant predictors of curve flexibility. The demonstration of this association offers useful information in estimating how surgical options for deformity correction may change over time [9]. There is a strong inverse major curve flexibility and curve magnitude ($r = -0.7$; $P < .001$). The authors have deduced an equation to predict curve flexibility in idiopathic thoracolumbar and lumbar scoliosis [9]:

$$\text{FSC} \approx 130 - (\text{Cobb} + \text{age}/2)$$

where FSC is flexibility of the structural curve.

Satake and colleagues [39] determined the preoperative radiographic predictors of postoperative position of the lowest instrumented vertebra (LIV) and wedging of the subjacent intervertebral disc after surgery for thoracolumbar deformity in adolescents. This study of 61 patients with thoracolumbar or lumbar curves demonstrated a correlation between the change of the disc angle and the LIV level relative to the preoperative lower end vertebra (LEV) ($P < .006$). Regression analysis revealed several correlative parameters to the postoperative disc angle: preoperative upright disc angle, preoperative apex-LIV distance, and preoperative T12-to-LIV lordosis ($P < .0001$; $r^2 = 0.51$). These data may be useful in planning surgical levels in adults who may be less tolerant of residual end vertebral tilt and obliquity of the subjacent disc.

Osteoporosis is an important concern when treating the patient with adult deformity. The presence of osteoporosis in patients who are candidates for spinal surgery can affect preoperative planning. These patients may need instrumentation for a successful surgical result; because of instability or deformity, however, certain principles should be observed. These include using multiple sites of fixation, accepting lesser degrees of deformity correction, and avoiding ending the instrumentation within kyphotic segments. Bone quality is an important consideration in evaluation of the anterior or posterior approach to a patient with thoracolumbar deformity. Whereas posterior implants can generally gain good cortical purchase in the pedicle or transverse process with hooks, anterior screws must rely on anchorage into the cancellous vertebral body. Thus, in osteoporotic or osteopenic patients, anterior surgery may provide a less stable option than posterior constructs [40–43]. Bone mineral density must be adequate if anterior surgery is planned. Some authors have advocated using a bicortical screw for all anterior vertebral body implants [28,43,44]. Advances in perioperative medical management as well as improved instrumentation systems may also contribute to improving patient outcomes in patients with osteoporosis [8].

Thoracoplasty is a powerful technique to reduce rib prominence and improve a patient's appearance, as demonstrated by Geissele and colleagues [45]. Lenke [46] has shown that adults who undergo thoracoplasty experience a 27% decline in pulmonary function by 3 months after surgery, however, which, in contrast to adolescents, does not improve appreciably after 2 years of follow-up. Thus, an adult patient with borderline pulmonary function may not tolerate thoracoplasty.

Complications and mechanics

In general, adult patients have an increased risk of experiencing surgical complications

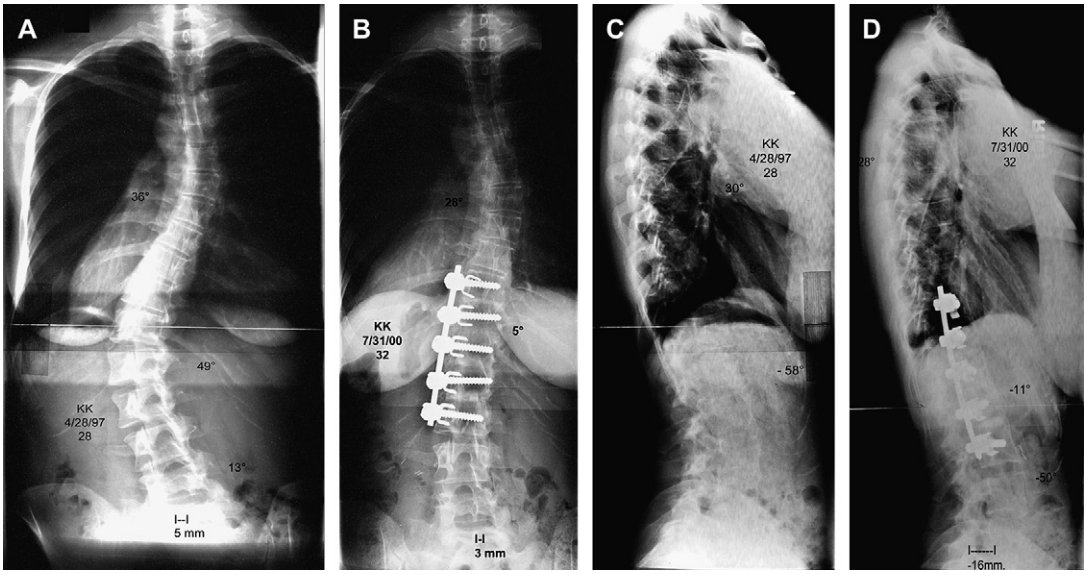

Fig. 1. Preoperative (*A–C*) and postoperative (*B, D*) radiographs of a 28-year-old woman with adult thoracolumbar scoliosis treated with anterior instrumented fusion.

compared with adolescents. Major complications include pseudarthrosis (5%–27%), residual pain (5%–15%), neural injury (1%–5%), infection (0.5%–5%), and thromboembolism (1%–20%) [47]. Complications that are specifically problematic in anterior deformity surgery include pseudarthrosis, kyphosis, approach-related morbidity, and implant failure.

The authors previously reported on complications and outcomes in anterior surgery in 15 patients with adult idiopathic scoliosis (average age of 37.5 years) who had undergone single rod

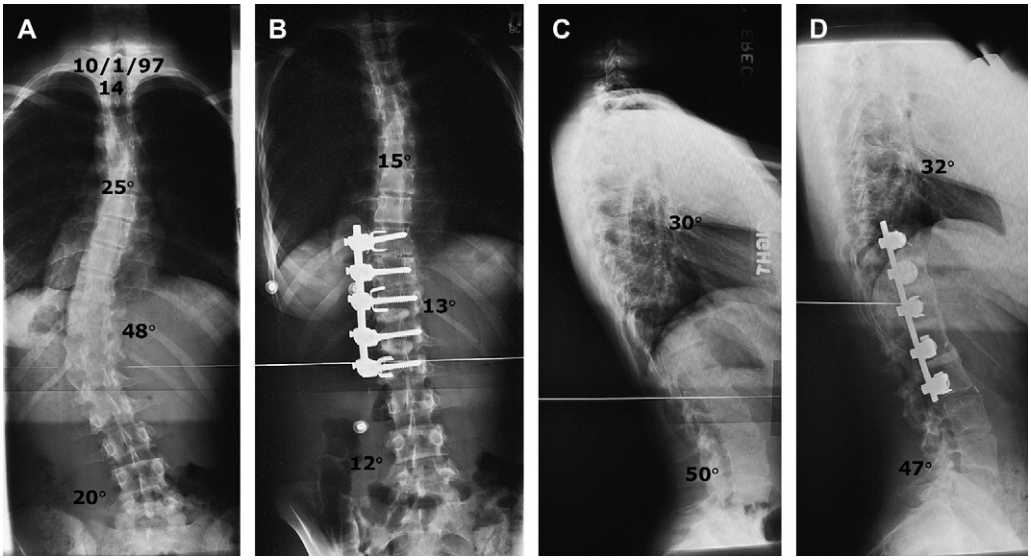

Fig. 2. Preoperative (*A, C*) and postoperative (*B, D*) radiographs of a 14-year-old girl with an adolescent thoracolumbar scoliosis treated with anterior instrumented fusion.

Table 1
Pre- and postoperative mean coronal plane values for adults and adolescents

	Age (years)	Follow-up (months)	Preoperative major curve	Curve flexibility	Postoperative major curve	Correction
Adult	37	47	51°	63%	17°	67%
Adolescent	16	46	49°	79%	10°	80%
Total	27	47	50°	70%	14°	73%
P	$<.05$	$>.05$	$>.05$	$<.05$	$<.05$	$<.05$

anterior instrumented fusions and were followed for an average of 61 months. In this retrospective study, it was found that average curvature correction was 66% (from 50° before surgery to 16° after surgery) after an average of 44 months of radiographic follow-up. Average upper compensatory thoracic curve correction was 40%, which is comparable to data from adolescent patients [33,48]. Notably, sagittal alignment was maintained or improved in all patients, and there was no case of increased kyphosis across the fused segments after surgery. On average, 0.9 levels were spared from fusion compared with levels that would have been chosen in a posterior approach, and there were no occurrences of pseudarthrosis or implant failure. This study demonstrates the efficacy and safety of anterior instrumented fusion in carefully selected patients [33].

Despite the authors' findings indicating the safety of rigid anterior instrumentation, the concerns regarding kyphosis and adjacent segment obliquity are important and cause the authors to pay particular attention to patient selection and technique during operative planning. The thoracic spine in adults with thoracolumbar deformity is generally less flexible than in adolescents, and therefore experiences more biomechanical strain at the vertebral level subjacent to the superior fused level. Obliquity and strain on the subjacent motion segment may promote degeneration and kyphosis in the unfused thoracic spine. This concern is especially important after anterior fusion, in which case the caudal end of the instrumentation generally stops at least one level above the equivalent posterior fusion [33]. The risk of kyphosis seems to have been strongly linked to nonrigid instrumentation, such as the Dwyer and Zielke systems, which primarily use compression across the convexity of the major curve to achieve the correction and were generally used without structural interbody support to promote lordosis.

Rigid fixation and interbody structural support are critical to obtain and maintain deformity correction. Oda and colleagues [49] compared three types of anterior instrumentation to investigate the biomechanical effects of rod number and rod diameter on anterior L1-L4 instrumentation in a fresh calf spine model. Specifically, they compared single 4.75-mm rod, single 6.35-mm rod, and dual 4.75-mm rod configurations in nondestructive torsion, compression, and strain conditions. They concluded that dual-rod instrumentation provides the highest construct stiffness and the lowest rod-screw strain. Increasing the diameter of a single rod construct also increased construct stiffness under torsion. Shimamoto and colleagues [50] demonstrated that a two-rod system may have the potential to minimize the risk of loss of correction.

Interbody structural support is a functional adjunct to anterior instrumentation, acting as fulcrum to augment the compressive correction [51]. Spiegel and colleagues [36] confirmed that the highest strain is observed at the bone-screw interface at both end screws of an anterior construct during lateral bending. This finding correlates with the clinically observed failure locations. He also showed that disc space augmentation with solid implants decreased strain at the end levels in lateral bending away from the implant. Lowe

Table 2
Postoperative Scoliosis Research Society Outcomes Instrument results for adults and adolescents

	Pain	Image	Function	Mental	Satisfaction	Total
Adult	4.08	4.14	4.13	4.02	4.54	82%
Adolescent	4.44	4.44	4.44	4.18	4.83	88%
Total	4.26	4.29	4.29	4.10	4.69	85%
P	$>.05$	$>.05$	$>.05$	$>.05$	$>.05$	$>.05$

and colleagues [51] demonstrated that using more rigid 6.0- to 6.5-mm solid rod anterior instrumentation obviates the need for interbody structural support with regard to maintenance of sagittal profile and prevention of kyphosis. Despite the findings of Lowe and colleagues [51], decreasing strain at end screws is an important strategy when considering the adult female patient in whom bone density may be low.

Outcomes

The authors' group conducted a retrospective study comparing clinical outcomes between adults (mean age of 37.5 years) and adolescents (mean age of 16.5 years) who had undergone anterior spinal arthrodesis for thoracolumbar scoliosis (Figs. 1 and 2). Patients were sent the Scoliosis Research Society (SRS) Outcomes Instrument, charts were reviewed, and pre- and postoperative long standing films of the entire spine were evaluated by independent reviewers not involved in the care of the patients.

Fifteen adult patients with an average age of 37.5 years and 15 adolescent patients with an average age of 16.5 years who had undergone anterior spinal arthrodesis with a single rigid rod were included in this study, and the average lengths of follow-up were 47 and 46 months (1 adult and 1 adolescent were lost to follow-up), respectively. Adult curve flexibility (63%) was less than that of adolescents (79%; $P < .05$). The average preoperative major curves for the adults and adolescents (51° and 49°, respectively) improved less for adults than for adolescents (17° and 10°, respectively, after surgery) ($P < .05$). Sagittal plane alignment and balance were maintained or improved in all patients. On average, 0.9 levels in adults and 1.2 levels in adolescents were saved with anterior surgery (Table 1). All patients achieved a solid fusion. The most common presenting symptom for adults was pain. In adolescents, deformity was the presenting complaint in most patients. The SRS Outcomes Instrument results show similar high satisfaction follow-up results in adults and adolescents. Adolescent outcomes did trend toward higher scores, although the difference was not statistically significant (Table 2).

Anterior surgery for scoliosis correction is a useful surgical approach in select adolescents and adults with thoracolumbar and lumbar deformity. This technique is appropriate for adolescent and adult patients with flexible moderate thoracolumbar or lumbar curves. Flexibility significantly decreases with increased age and curve magnitude and significantly affects postoperative curve correction. Adult patients may develop early degeneration at primary and compensatory curves, and these curves should be evaluated carefully before surgery and monitored closely after surgery. Following these rules, anterior fusion with rigid instrumentation and anterior placement of structural grafts can provide effective correction of deformity, maintenance of sagittal balance, reliable fusion, and potentially save motion segments compared with posterior surgery.

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