Adolescent idiopathic scoliosis: current concepts of surgical management
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Purpose of review
The operative treatment of adolescent idiopathic scoliosis has been rapidly evolving. This review evaluates recent advances in the surgical management of this disease over the past year.

Recent findings
Modern posterior spinal segmental instrumentation and corrective techniques for spinal deformity have led to recent questioning of the need for preliminary anterior release for large curves. Several comparative studies have analyzed the safety and efficacy of various posterior anchors such as pedicle screws, apical sublaminar wires, and hybrid techniques. Thorascopic anterior spine instrumentation for scoliosis, despite its steep learning curve, has been shown to be an effective method for the correction of thoracic scoliosis. Proponents of this technique suggest that potentially fewer vertebrae are fused compared with posterior only techniques, and there is less blood loss, limited pulmonary morbidity, and preservation of posterior spinal musculature.

Summary
Several trends in surgical management of adolescent idiopathic scoliosis have been identified. These include the increasing use of pedicle screw segmental fixation in the thoracic spine for correction of large scoliosis curves greater than 70°. Minimizing or avoiding violation of the chest wall cavity by eliminating the need for a preliminary anterior release and a concomitant thoracoplasty with these powerful posterior techniques of segmental instrumentation appears to preserve maximum long-term pulmonary function.

Keywords
adolescent idiopathic scoliosis, anterior spine instrumentation, pedicle screws, posterior spine fusion, pulmonary function

Introduction
‘Scoliosis has always been one of the interesting and difficult problems in orthopaedics. André probably had it in mind when he devised his symbol for orthopaedics. . . . It is stimulating and encouraging but can be confusing to those who have to treat scoliosis patients and do not know which new trend to follow.’ John R. Cobb [1] wrote this almost half a century ago, and though much has evolved in the treatment of adolescent idiopathic scoliosis (AIS), his words still hold true today. The goal of this review is to evaluate the recent advances in the surgical management of AIS over the past year.

Surgical treatment
Significant advances have occurred at a rapid pace over the past several years in the operative management of AIS. The forces driving this progress include segmental motion preservation of the spine, the three-dimensional nature of the deformity and its correction, and patient-oriented outcome measures. The indications and the goals of surgical treatment for AIS have not changed, however, despite the evolving concepts, techniques, and approaches for scoliosis. Paramount to treatment is achieving a solid arthrodesis and preventing progression of the spinal deformity. Attention to the time-honored concepts of complete facetectomies, decortication, and bone grafting are important to achieve a fusion.

The analysis and management of AIS as a three-dimensional spinal deformity has progressed since the concepts of derotation and multiplanar correction were introduced by Cotrel et al. [2]. The comprehensive framework of the Lenke classification system re-focuses our attention on preserving motion of the spine, to identify scoliosis patterns amenable for selective thoracic fusion within the context of newer approaches and techniques for the correction of deformities seen with AIS [3,4].
Posterior instrumentation

Pedicle screw fixation, initially used in the lumbar spine for scoliosis, demonstrated significant advantages for the correction of deformity, rotation, and ability to save motion segments compared with hook fixation. Pedicle screw instrumentation in the thoracic spine using both translation correction or direct vertebral rotation techniques [5] are being used with increasing frequency in North America. Proponents of thoracic pedicle screw instrumentation cite several advantages for their use. It is a significantly more rigid instrumentation system which addresses all three columns of the spine, can achieve greater three plane deformity correction, and has lower rates of implant failure and pseudoarthrosis. The free hand technique for pedicle screw insertion has been shown to be quite safe at one major spine center [6]. Critics of thoracic pedicle screw fixation for spinal deformity point out the potential neurologic, vascular, and visceral risks of improperly placed pedicle screws. The small size and orientation of the thoracic pedicles, in particular on the concave side of the scoliosis deformity, can be technically challenging and requires precise placement to avoid penetration and potential complications. Lateral penetration of the pedicle screw places the tip in close proximity to the aorta, and medial penetration within the spinal canal. Kuklo et al. [7] evaluated the accuracy of thoracic pedicle screws in severe spinal deformities (>90°) in a retrospective study of 20 patients. Of the 352 pedicle screws placed in the thoracic spine, the overall screw accuracy determined by computed tomography (CT) scans was 96%. When evaluating the preoperative plan for placement of thoracic pedicle screws, 94% of the planned screws were successfully placed. On average, one planned pedicle screw per patient could not be safely inserted. The authors concluded that thoracic pedicle screws could be safely and accurately placed in severe spinal deformities.

Suk and coauthors [8] evaluated their results with selective thoracic fusion using pedicle screw fixation. They had a minimum follow-up of 5 years to evaluate the safety of the pedicle screw fixation. The fusion was carried out from one level proximal to the upper end vertebra to one level distal to the lower end vertebra. They had a correction of 69% of the preoperative thoracic curve at most recent follow-up and the noninstrumented lumbar curve had a correction of 66%. The thoracic and lumbar curve correction was well maintained and showed no significant changes at last follow-up. When safety of pedicle screws was evaluated, the authors noted that 1.5% of the screws were misplaced on postoperative CT scans. No adverse clinical consequences occurred, however, as a result of the misplaced thoracic pedicle screws. Selective thoracic fusion with segmental pedicle screw fixation for thoracic idiopathic scoliosis had satisfactory radiographic and clinical outcomes, and was a safe and effective method for preserving lumbar motion segments as well as restoring and maintaining coronal and sagittal alignment.

Two papers questioned the need for preliminary anterior release for large curves greater than 70°. No specific guidelines exist on the magnitude and rigidity of a curve to warrant preliminary anterior surgery. Burton and coauthors [9*] evaluated their results of AIS patients with curves between 70 and 90°. In a retrospective review, 47 patients were evaluated using hybrid posterior segmental techniques. In their series, the flexibility of the spinal deformities had a mean of 37%, and the average scoliosis measured 75°. At a minimum follow-up of 2 years, the authors achieved correction of 64%. Twenty-four concomitant concave or convex thoracoplasties were performed. The Scoliosis Research Society (SRS) 22/24 scores were 4.4. The authors noted that their results compared favorably with other studies that used a preliminary anterior release and concluded that curves between 70 and 90° do not need an anterior release to achieve good results.

Luhmann et al. [10] evaluated 84 patients in a retrospective study comparing combined anterior and posterior surgery with posterior only for severe spinal deformities between 70 and 100°. Twenty-two patients had a preliminary anterior release and 62 patients had a posterior arthrodesis and spine instrumentation only using three different constructs (hooks, hooks and pedicle screws/hybrid, and pedicle screws). For the entire group, the combined anterior and posterior group had a greater degree and percentage of correction. When the posterior only group was separately evaluated, the pedicle screw group had an equivalent degree of correction to the combined anterior and posterior group. For both groups the preoperative curve flexibility was equal. The authors found that posterior instrumentation only using thoracic pedicle screws was a safe and reproducible technique. The authors concluded that although the implant cost after thoracic pedicle screws is greater, in severe curves the total cost of the procedure may be more equivalent due to less operative time, no chest wall violation, one less procedure, and less total anesthetic time.

Storer and coauthors [11] retrospectively compared hybrid techniques of posterior segmental instrumentation with thoracic pedicle screw fixation. The authors found no difference in curve correction between the two constructs for moderately sized curves. Outcome scores for the two systems using the Children’s Health Questionnaire (CHQ) were similar. The cost of thoracic pedicle fixation was increased. The authors postulated that the biomechanical properties of thoracic pedicle screw fixation may be best reserved for cases involving larger more rigid curves. They could not find measurable...
improvement in clinical outcomes using thoracic pedicle screw fixation and the additional cost and increased risk of neurologic injury lacked clear clinical benefit using thoracic pedicle screws. As noted in an earlier debate on the use of pedicle screws for a 55° curve in AIS [12], the cost–benefit ratio of pedicle screw instrumentation (compared with hook/wire anchors) has not been demonstrated to date. The expense of thoracic pedicle screws at multiple levels almost doubles the cost of hook implants for a standard scoliosis construct. Despite demonstrating improvement in the degree of deformity correction, it is still unclear whether or not this correlates with a measurable improvement in clinical outcomes. Acknowledging the cost and safety concerns of thoracic pedicle screw fixation, this powerful technique for deformity correction offers many potential advantages in the hands of experienced spinal surgeons. Long-term studies hopefully will provide answers to the efficacy of this technique.

Cheng et al. [13] compared apical sublaminar wires with pedicle screws in the correction of AIS. Patients were prospectively matched into two groups of 25 patients each. In the apical sublaminar group, five patients had a preliminary anterior release, seven had a concomitant thoracoplasty, and 6.35 mm rods were used. In the thoracic pedicle screw group, 11 patients had a thoracoplasty, five had a preliminary anterior release, and 5.5 mm rods were used. Coronal plane correction and maintenance were equivalent for both major and secondary curves, and both techniques were able to achieve acceptable global balance without neurological complications. There was a trend towards increased proximal junctional kyphosis after thoracic pedicle screw fixation, but there were no differences in the SRS scores. The cost of implants was significantly greater for the thoracic pedicle screw group, but blood loss was less.

Kim and coauthors [14] compared hybrid fixation with pedicle screw fixation for AIS. In the hybrid system only hooks were used, and there was a minimum 2-year follow-up. Greater curve correction and maintenance were found after pedicle screw fixation for both primary and secondary curves, and both techniques were able to achieve global balance. The authors found no difference in the SRS-24 scores, junctional changes, lower instrumented vertebra (LIV), or operative time. The pedicle screw fixation group of patients had less perioperative blood loss and improved pulmonary function postoperatively. Pulmonary function tests [using percentage predicted value of forced expiratory volume in 1 s (FEV$_1$)] were statistically greater for the pedicle screw group compared with the hybrid instrumentation group. The authors proposed that improved chest wall mechanic, curve correction, and stabilization with the use of thoracic pedicle screws resulted in the improved pulmonary function testing.

**Anterior instrumentation**

Anterior instrumentation is indicated for primary thoracic curves and thoracolumbar curves, with the goal to save two or more levels compared with that predicted for posterior instrumentation [15]. Fusion levels tend to extend from the proximal to the distal end vertebrae measured in the Cobb angle. The potential advantages of the anterior approach are avoiding disruption of the posterior extensor musculature and decreased risk of junctional problems, superior long-term correction of the compensatory non-instrumented curves with less postoperative coronal decompensation, improved ability to derotate the spine in the transverse plane, and better correction of thoracic hypokyphosis. The anterior approach is also indicated for skeletally immature patients (open tri-radiate cartilage) at risk for crankshaft phenomenon. The contraindications for this anterior approach include significant preoperative kyphosis (>40°), curves greater than 75–80°, impaired respiratory function (vital capacity <50%), and double or triple structural curves. Historical problems with anterior instrumentation included rod breakage, pull-out of the proximal screw, pseudoarthrosis, and kyphosis. These problems have been addressed with the use of larger rods, structural grafts and spacers to provide anterior column reconstruction, and maintaining lordosis for thoracolumbar curves.

The role of minimally invasive video-assisted thorascopic surgery (VATS) for anterior release and instrumentation of single thoracic curves continues to progress. The technique is technically challenging, has a steep learning curve, but is thought to result in decreased chest wall and pulmonary function morbidity [16]. Patients are traditionally positioned in the lateral position for thorascopic procedures. Prone positioning is gaining favor since it eliminates the need to change patient positioning if an anterior release is performed before a posterior instrumentation, and the prone position avoids the potential problems with single lung ventilation [17].

Newton et al. [18*] evaluated 112 consecutive patients undergoing preliminary thorascopic anterior release or fusion with subsequent posterior instrumentation, to analyze the ‘success’ of anterior arthrodesis and outcomes at two or more years of follow-up. Twenty-three of these patients had AIS. Fourteen percent of the patients had perioperative respiratory complications, but no long-term complications occurred with the anterior surgery. Evidence of solid anterior arthrodesis was documented in 75% of the disc spaces evaluated. There were fewer complications in the idiopathic subgroup compared with neuromuscular patients. The rate of fusion was greater in AIS, and the underlying diagnosis had a significant effect on fusion rates. The authors concluded that VATS for anterior release and fusion was safe and effective for patients with spinal deformity.
In another study from the same institution, Newton and coauthors [19] prospectively evaluated the experience of a single surgeon with an initial series of 50 scoliosis patients with anterior thoracic instrumentation. There were three implant failures early in the series, using a smaller 4.0 mm stainless steel rod system (switched to 4.75 mm Ti rods later in the series). These results match those of other open thoracotomy and thoroscopic series. The procedure is technically challenging, and a distinct learning curve was evident. The procedure requires an early anterior arthrodesis to prevent implant failure. The authors had a 4% rate of revision surgery, and a 16% rate of technical complications which did not substantially change the clinical outcome (more than half involved improper selection of distal levels of instrumentation). Proper patient selection is also critical to the success of the procedure.

Lonner et al. [20] compared the results of posterior arthrodesis and instrumentation compared with anterior thoracoscopic fusion and instrumentation for thoracic AIS in 51 patients (23 posterior and 28 thoracic). Several of the patients in the posterior group had an associated thoracoplasty. The thoroscopic group compared favorably with the posterior group in terms of coronal plane correction and balance, sagittal contour, complication rate, pulmonary function, and patient-based outcomes (SRS-22 form). The advantages of the thorascopic procedure included decreased number of vertebrae fused, less blood loss, and decreased transfusion requirements. The length of hospitalization was shorter by 1–1.5 days. The thorascopic group demonstrated no significant deleterious effects on pulmonary function, and the patients were not significantly different compared with the posterior group. The authors discussed the increased operative time, which in part reflected the steep learning curve of the procedure.

A potential concern with anterior thoracic instrumentation is the close proximity of the vertebral screws to vital structures such as the aorta. Postoperative CT scans were evaluated in one study to evaluate the location of the screws to the spinal canal and the aorta [21]. The screws were thought to create a contour deformity of the aorta in 12% of the screws, and an additional 14% were adjacent to the aorta. In a related study from the same institution, the position of the aorta relative to the spine was compared in patients with a right thoracic scoliosis and normal patients using magnetic resonance imaging and plain radiographs [22]. The aorta was found to be positioned more laterally and posterior relative to the vertebral body at the T5–T12 levels in patients with scoliosis compared with normal patients. This was more distinct near the apical regions of the curve, with increasing coronal Cobb angles, and with increased apical vertebral rotation. More recent studies have also evaluated the relationship of anterior vertebral screws to the aorta and other intrathoracic structures. Kuklo et al. [23] evaluated 20 consecutive patients with right thoracic curves with pre and postoperative CT scans following open anterior single rod instrumentation. The screw–spinal canal distance measured 5.3 mm, and the screw tip extrusion measured 2.8 mm. Structures such as the trachea, azygous vein, esophagus, lungs and pleura were not found to be at risk. Due to the course of the descending aorta in patients with spinal deformity compared with matched controls, the relationship of the descending aorta to the position of the screws varied by vertebral level. The peri-apical and the distal screws were found to be closer to the aorta. Overall, 15% of the screw tips were positioned 2 mm or less to the aorta.

Bullmann and coauthors [24] evaluated CT scans in 20 consecutive patients for AIS and anterior correction using a dual rod system. Eighty-eight percent of the screws had bi-cortical purchase, and 6% of the screws were within 1–3 mm of the aorta. All other screws were more than 3 mm away from the aorta. The closest proximity of the screw tips to the aorta was found at the upper end vertebra from T5 to T7. The authors concluded that a correction of right thoracic scoliosis using dual rod anterior instrumentation could be achieved safely with a standard open approach. These findings highlight the need for careful placement of anterior vertebral screws or concave posterior pedicle screws in patients with a right thoracic idiopathic scoliosis to minimize the risk of vascular, neurological, or visceral complications.

**Pulmonary function**

Numerous recent papers have focused on the deleterious effects of open anterior thoracotomy approaches and thoracoplasty for scoliosis on long-term pulmonary function. Kim et al. [25] prospectively studied 118 patients, evaluating pulmonary function following modern techniques and approaches for AIS. Pulmonary function was assessed by the absolute and predicted values for forced expiratory vital capacity (FVC) and FEV1 at 5 or more years of follow-up. Significant negative correlations were noted between the preoperative Cobb angles and the percentage predicted pulmonary function, and between the number of vertebrae within the major curve and the percentage predicted pulmonary function. The number of fused vertebrae did not demonstrate any correlation with changes in pulmonary function values. Patients with a posterior spine fusion only had significant increases in absolute pulmonary function, and the change in percentage predicted pulmonary function was not significant. The authors proposed that posterior fusion stabilizes pulmonary function during the remainder of adolescent growth.

Patients having a concomitant thoracoplasty demonstrated a significant decrease in the percentage predicted
pulmonary function at more than 6-year follow-up, suggesting that the regenerated ribs did not allow proper functioning of the chest cage. There was a significant decrease in the percentage predicted pulmonary function at 5 years after open anterior fusion and instrumentation, suggesting that open thoracotomies result in deleterious effects on pulmonary function for as long as 5 years postoperatively. The authors recommended that preservation of maximal pulmonary function is important following scoliosis surgery. A 10–20% decrease in pulmonary function after thoracotomy or thoracoplasty may have long-term implications, especially when the ‘normal’ loss of pulmonary function secondary to the aging process, the effects of smoking and other pulmonary problems are considered.

Faro and coauthors [26] evaluated pulmonary function after thorascopic compared with open anterior scoliosis instrumentation. Fifty-four patients were treated at two different institutions. Pulmonary function was evaluated by measuring FVC and FEV1 percentage predicted values preoperatively, at 3 months postoperatively, and at 1 year. At 3 months the thorascopic group had a significantly smaller decline in FVC than the thoracotomy group. At 1 year, pulmonary function in the thorascopic group recovered, while the FVC remained reduced in the open anterior group. The decline in FEV1 was similar for both groups at 3 months; but at 1 year, the thoracotomy group had better recovery of pulmonary flow. These results suggest that pulmonary function declines for both groups at 3 months; but at 1 year, the minimally invasive thorascopic group returns to its preoperative value, while the open thoracotomy group has a persistent deficit in pulmonary function.

In an interesting prospective study, Yuan et al. [27] evaluated pulmonary function in the immediate postoperative period. Twenty-four patients undergoing scoliosis surgery for numerous etiologies had their pulmonary function evaluated for the first several months following surgery. Forty-six percent of the patients in the study had AIS. The authors found that pulmonary function testing, using percentage predicted values, declined up to 60% after surgery. The nadir was at 3 days. Pulmonary function remained significantly decreased at 1 week and near preoperative baseline by 1–2 months postoperatively. No statistical differences were noted between the decline in pulmonary function and the etiology of scoliosis or type of surgery performed. The authors recommended that postoperative decrease in pulmonary function should be considered during the preoperative prediction of postoperative risks.

Complications

Coe and coauthors [28] reviewed the complications in the treatment of AIS using data derived from the SRS database from 2001 to 2003. A complication rate of 3.7% was recorded in 6334 patients in their series. The complication rates were similar for both anterior and posterior approaches (5%). Combined anterior and posterior procedures had a higher complication rate (10%). The combined group also had a higher rate of neurological complications (1.75%). The most common complications for the anterior and combined groups were pulmonary. Wound infections were the most common complication for the posterior group. The authors pointed out several limitations of the study, including the inability to assess long-term complications. The rate of neurological complications for the anterior and posterior groups was 0.26% and 0.32%, respectively. In the earlier study by MacEwen et al. [29], an initial SRS report in which the majority of scoliosis patients were treated with posterior Harrington rod distraction technique, the rate of neurological complications was 0.72%.

Conclusion

Several trends in the surgical management of AIS have been identified. These include the increasing use of pedicle screw segmental fixation in the thoracic spine for the correction of large scoliosis curves greater than 70°. Minimizing or avoiding violation of the chest wall cavity by eliminating the need for a preliminary anterior release and a concomitant thoracoplasty with these powerful posterior only techniques of segmental instrumentation appears to preserve maximum long-term pulmonary function. From a recent SRS report, the risk of neurological complications using modern anterior and posterior spinal segmental techniques for AIS has decreased more than 50% compared with the figure initially reported in 1975.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 579–580).


Richards BS. Debate: Resolved, a 55 degrees right thoracic adolescent idiopathic scoliotic curve should be treated by posterior spinal fusion and segmental instrumentation using thoracic pedicle screws: Con: Thoracic pedicle screws are not needed to treat a 55 degrees right thoracic adolescent idiopathic scoliosis. J Ped Orthop 2004; 24:334–337.


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