

## Adolescent Idiopathic Scoliosis: Selective Thoracolumbar/Lumbar Fusion (Review Article)

### Abstract

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity causing physical/psychological burdens. Optimal preoperative planning enhances appearance while preserving spinal function. Corrective surgery restores spinal mobility and balance. In dual-curve cases, selective fusion corrects one curve, inducing spontaneous correction of the other—preserving spinal motion and attracting surgical interest. However, limited adoption persists due to insufficient data. This study evaluates selective thoracolumbar/lumbar fusion, detailing surgical outcomes and complications to guide surgeons in procedure selection. Evidence confirms selective thoracic fusion is effective and safe for AIS, offering significant correction, improved quality of life, and fewer complications versus extensive approaches. Future research should refine patient criteria and assess long-term effects.

**Keywords:** Scoliosis, Kyphosis, Spine.

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### Introduction

AIS refers to a spinal disorder considered by a three-dimensional structural deformity that affects both the spine and the trunk. While AIS can progress during growth and result in cosmetic concerns, it is usually asymptomatic. Several classification systems have been proposed for AIS<sup>(1,2)</sup>; however, each has its limitations, and none is entirely comprehensive.

Determining the appropriate levels for spinal fusion remains one of the most challenging aspects of AIS management. Although the foundational principles of fusion described by Moe and colleagues<sup>(3)</sup> have stayed largely unchanged, advances in instrumentation systems have necessitated refinements in surgical technique. Corrective surgery in AIS seeks to achieve spinal balance, prevent curve progression, and preserve mobility. As a result, selective fusion (SF), which shows only structural curves while sparing non-structural curves to maintain motion, has recently garnered increased interest among spine surgeons<sup>(4-10)</sup>.

King et al. (1983)<sup>(2)</sup> presented selective fusion in the context of selective thoracic fusion (STF) for King type II scoliosis. Moreover, selective fusion in adolescents with combined thoracic and thoracolumbar/lumbar (TL/L) curves is defined as performing fusion on only one curve, with the anticipation that the other curve will instinctively accurate<sup>(11-15)</sup>.

To date, the definitive advantages of this approach remain debated. Some surgeons argue that complete fusion provides greater spinal stability, reduces treatment failure, and improves surgical outcomes. In contrast, proponents of SF contend that preserving spinal mobility enhances patients' activity levels and postoperative quality of life<sup>(6-8)</sup>. Importantly, TL fusion, unlike ranging fusion from the thoracic to the lumbar spine, does not necessarily result in significant motion restriction. Therefore, choosing the TL/L fusion levels demands thorough assessment to obtain optimal radiographic and clinical results while reducing the risk of complications.

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Additionally, identifying suitable patients and deciding which vertebrae to incorporate into the fusion process are the primary challenges in selective TL/L fusion.

### Selective Thoracolumbar/Lumbar (TL /L) Fusion Criteria

The Lenke category f in 2001, or AIS was proposed, focusing on the impact of selective fusion on treatment results. This method suggests that only including the structural curves in the fusion, and non-structural curves excluded from the treatment strategy. Selective TL / L fusion applies specifically to Lenke types 5C and 6C<sup>(9)</sup>.

According to the Lenke category system, when the amount of the TL/L curve surpasses that of the thoracic curve, it is categorized as either Lenke 5C or 6C. In Lenke type 5, the thoracic curve usually reduces to under 25 degrees on lateral bending films, and the T10–L2 kyphosis measures less than 20 degrees, which generally makes selective fusion straightforward. However, in type 6, challenges may arise, though selective TL/L fusion might yet be possible in certain situations<sup>(15–17)</sup>.

Selective TL/L fusion should only be carried out if the thoracic curve is elastic and near to reach skeletal maturity<sup>(10)</sup>. If not, the thoracic curve may continue to progress, potentially causing complications in the instrumented upper or lower spinal segments. Clinical observations suggest that performing selective TL/L fusion in females before menarche is related with an increased probability of complications or failure of surgery.

### Early Studies and Initial Criteria for TL/L Selective Fusion

- Dwyer and Schafer<sup>(11)</sup> performed this procedure and emphasized that only the lumbar curve need fusion, provided the thoracic curve fully corrected on lateral bending films.
- Ogilvie (1988)<sup>(12)</sup> outlined initial criteria for selective TL/L fusion, including:
  - Compensatory main thoracic (MT) curve less than 40 degrees
  - Adequate flexibility
- Absence of significant appearance deformity.
- Deviren et al.<sup>(13)</sup> demonstrated that the patient's age and the size of the curve are key factors influencing the flexibility of structural

curves; patients with larger curves and those who are older tend to exhibit reduced flexibility.

- Hiewtma et al.<sup>(14)</sup> observed that the amount of correction of the TL/L curve diminishes as the age increases.
- According to Majd et al.<sup>(15)</sup>, if the TL/L curve correction is under 50% of the original curvature or below 40 degrees, it might also be necessary to perform fusion on the compensatory thoracic curve.

### Lenke Radiographic Criteria for TL/L Selective Fusion

Lenke et al.<sup>(16)</sup> established the following criteria in radiography for performing selective anterior s thoracolumbar/lumbar fusion:

1. The ratio of apical vertebral translation (AVT) in the main thoracic (MT) curve compared to the thoracolumbar/lumbar (TL/L) curve should exceed 1.25.
2. The ratio of apical vertebral rotation (AVR) in the MT curve to the TL/L curve should also be greater than 1.25.
3. The flexibility of the MT curve should be more than that of the TL/L curve, ideally with a Cobb angle of less than 25° observed during lateral bending.
4. The kyphosis at the thoracolumbar junction (T10–L2) should be below 20°.

Additional clinical criteria are as follows:

- Shoulders are even, or the left shoulder is slightly elevated.
- The trunk shift in the TL/L position is more significant than the MT shift.
- The scoliometer reading for TL/L is greater than that for MT, with a ratio exceeding 1.2.
- The thoracic rib hump is considered acceptable by the patient, their parents, and the surgeon, as any postoperative rib alterations are expected to be minimal.

### Final Outcomes and Patient Selection Criteria

In a 2-year review of 49 patients undergoing anterior selective TL/L fusion, Sanders et al.<sup>(17)</sup> concluded that:

- Thoracic curves less than 40° yielded acceptable outcomes
- Skeletal maturity (tri-radiate cartilage closure) was the best predictor of success

- TL/L-to-MT Cobb ratio >1.25
- TL/L angle is less than 55°
- Or thoracic Cobb angle less than 25° on bending films were predictive of successful surgery

These criteria, initially developed for anterior TL/L fusion, are generally applicable to posterior approaches as well.

## Key Indicators for TL/L Selective Fusion

### Ideal Candidates

Lenke types 5C and 6C

### Clinical Criteria

- Level of shoulders or higher left shoulder
- TL/L trunk shift should be more pronounced than the thoracic shift.
- TL/L scoliometer reading exceeds the measurement of the thoracic curve.

### Radiographic Criteria

- AVT TL/L to MT ratio >1.25
- AVR TL/L to MT ratio >1.25
- Cobb angle TL/L to MT ratio >1.25

### Additional Criteria

- MT curve <40°
- TL/L curve <55°
- MT curve more flexible than TL/L
- No thoracolumbar junction kyphosis (T10–L2 <20°)

## Anterior vs. Posterior Approach

Selective TL/L fusion can be accomplished through both anterior or posterior approaches. Utilizing an anterior approach for correction and fusion with instrument provides various benefits compared to the posterior method, including:

1. Correction forces are applied farther from the curve's apex in both lateral translation and rotation, resulting in greater corrective control<sup>(15,18–20)</sup>.
2. The anterior approach results in a shorter spine, thereby lowering the likelihood of traction injuries to the spinal cord compared to the posterior approach<sup>(3,18)</sup>.
3. Greater preservation of spinal motion is possible due to shorter fused levels<sup>(4,20,21)</sup>.
4. Prevention of the "crankshaft phenomenon" in children<sup>(18)</sup>, which is facilitated by improved

visualization, intervertebral fusion, and less technical dependency<sup>(22–24)</sup>.

Additional reported benefits include correction of vertebral rotation and reduction of deformity in adjacent regions<sup>(25)</sup>. Complications associated with anterior fusion include implant failure, pseudoarthrosis, pulmonary dysfunction, inability to range the fusion levels, and a kyphotic loading mechanism<sup>(25–27)</sup>. Nevertheless, just 23 study groups (38%) conducted anterior procedures, likely because of the surgeons' limited experience with them<sup>(28)</sup>. Moreover, improved correction with fewer drawbacks than posterior fusion has become more feasible with the introduction of pedicle screws, which enhance construct stability.

The typical rate of correction for the fused TL/L curve in Lenke type 5C, whether using anterior or posterior surgical approaches, has been documented to be between 70% and 85%<sup>(14,29,30)</sup>. For the non-fused MT curve, the correction rate ranges from 40–55%, with 1–10° loss of correction associated with the fused or non-fused curve at ultimate follow-up. Right after the surgery, coronal and shoulder imbalances were noted in as many as 50% of the patients, although most of them attained balance during the follow-up period<sup>(31,32)</sup>.

Several risk factors have been linked to postoperative coronal imbalance (CIB), including: a preoperative L5 tilt greater than 10° observed in bending films, a higher lowest instrumented vertebra (LIV), a younger age at the time of surgery, a larger TL/L curve, thoracolumbar/lumbar apical vertebral translation (AVT) measured seven days after surgery, a less flexible TL/L curve, increased thoracolumbar kyphosis, larger end-vertebra angles, a preoperative LIV tilt of less than 25°, the inability to achieve a LIV tilt of less than 8°, and a preoperative upper instrumented vertebra (UIV) displacement of 25 mm or more.

Coronal imbalance (CIB) is characterized by a lateral deviation of the trunk in the frontal plane, as estimated radiographically by a horizontal displacement of more than 2 cm between the C7 plumb line and the center of the sacrum. CIB is a recognized complication following spinal deformity surgery, often causing cosmetic concerns and functional impairment, although its relationship with low back pain remains inconclusive in short-term follow-ups<sup>(31–35)</sup>. Although there have been few studies investigating the factors influencing CIB after surgery, the majority of cases with early CIB and

shoulder imbalance reach coronal and shoulder stability at the final evaluation. Furthermore, CIB has no significant impact on back pain or clinical outcomes, in short term<sup>(32,36,37)</sup>.

### Comparison of Anterior and Posterior Methods

Comparisons between anterior and posterior surgical approaches indicate that the rates of correction for the fused TL/L curve, the non-fused thoracic curve, and the occurrence of complications are comparable<sup>(24,38)</sup>. However, the posterior approach tends to have a lower failure rate of implant and pseudoarthrosis, although it is associated with a higher rate of proximal junctional kyphosis (PJK). This may be attributed to increased construct rigidity and extended fusion levels<sup>(28,39,40)</sup>.

A shorter fusion level will be able to retain more motion in the lumbar area, because the majority of spine motion occurs in this area. Li et al.<sup>(40)</sup> found that posterior TL/L fusion is more effective than anterior fusion in restoration and preservation of the lumbar lordosis (LL) in instrumented segments during both short-term and long-term postoperative assessments in the sagittal plane. Additionally, their research indicated that even with modern anterior instrumentation using structural cages, it is not possible to completely prevent the potential for kyphosis in the instrumented segment over time.

Additionally, TK showed good restoration in the two groups. Nonetheless, TK was marginally greater in the posterior group at the ultimate follow-up, though this discrepancy was not statistically significant. Lin et al. confirmed the same results in their meta-analysis<sup>(38)</sup>.

### Selective TL/L Fusion in Lenke Type 6

Several studies have examined the outcomes of the non-fused structural thoracic curve after selective thoracolumbar/lumbar fusion in patients with Lenke type 6C AIS. In research conducted by Chang et al.<sup>(41)</sup>, the results of radiography in 18 patients with Lenke type 5C AIS were compared to those of 13 patients with type 6C. The findings indicated 32.2% correction rate after posterior selective TL/L fusion in the type 6C group. Nevertheless, the rate of correction for fused TL/L curve and non-fused thoracic curve were consistently lower than those observed in the type 5C group at all assessment points in the research. Similarly, in a study involving ten patients with Lenke type 6C AIS, Direito-Santos and colleagues<sup>(42)</sup> found

that there was a 22.4% correction in the non-fused thoracic curve after performing an anterior selective TL/L fusion. This result aligns with what previous research has shown. One important thing to consider is that if a patient still has growth remaining at the time of their surgery, there is a chance that the curve could worsen after the operation<sup>(17,43)</sup>. For younger patients, the compensatory thoracic curve tends to be flexible and may even correct itself after the selective fusion. However, it's important to note that some cases have shown continuing progression, highlighting the need for focused long-term studies in this group of patients.

Chang et al. demonstrated that there were no differences in thoracolumbar/lumbar AVT evaluated at any time, which might account for the comparable SRS-22 scores observed in both groups. For patients with AIS, the primary goal of treatment is to improve spinal advent and balance while limiting the extent of fusion, which makes selective TL/L fusion a worthwhile choice for managing Lenke type 6C.

### Selection of the Lowest Instrumented Vertebra (LIV)

A key challenge in selection of TL/L fusion is determining the lowest instrumented vertebra (LIV). While fusing additional levels may improve spinal correction, it can also lead to decreased spinal mobility. Thus, the choice of LIV should optimize both mobility and correction.

Wang et al.<sup>(44)</sup> suggested two equations for determining the LIV and forecasting the ultimate correction and equilibrium:

1. The ultimate measurement of the lumbar apical vertebra (AV) subtracted from the central sacral vertical line (CSVL) is 14.1, increased by 1.2 times the distance between the preoperative LIV and CSVL.
2. The ultimate AV–CSVL distance in the thoracic spine equals 36.2 plus 0.5 times the preoperative thoracic AV–CSVL distance, plus 0.7 times the preoperative LIV–CSVL distance.

The selection criteria for the LIV included a lateral displacement of up to 28 mm and a tilt of up to 25°. For instance, achieving an ultimate distance of 25 mm between the lumbar AV and CSVL could indicate that the preoperative distance between LIV and CSVL was less than 9.1 mm.

Zhuang et al.<sup>(45)</sup> outlined the criteria for selecting LIV in the following manner:

1. The highest vertebra contacting the CSVL,
2. Rotation of grade 1 or less on the Nash–Moe grading system in standing AP radiographs,
3. The CSVL crosses between the two pedicles of the LIV on radiographs taken during concave-side bending,
4. Absence of placement at the apex of kyphosis.

According to the King classification, the CSVL is characterized as a line that is perpendicular to the iliac crest. Research by Ilharreborde et al. demonstrated that in patients who display the adding-on phenomenon (where there is an increase of more than 5° in the anterior tilt of the LIV), the LIV in 62.5% was situated above the last-touching vertebra (LTV) and in 87.5% above the stable vertebra. Consequently, when determining the LIV, it is essential to consider both the stable vertebra and the LTV.

### Sagittal Alignment

Limited research has focused on the sagittal plane in selective thoracolumbar/lumbar fusion, while the coronal plane has received more attention. In this study, 39 Lenke type 5C AIS who received selective posterior thoracolumbar/lumbar fusion<sup>(46,47)</sup> were examined and categorized into two groups based on their T5–T12 kyphosis (sagittal modifier): group N (10–40°) and group M (<10°).

In summary, there were significant changes in several measurements from values before surgery to the ultimate follow-up. These include the main thoracic/lumbar curve, the minor thoracic curve, global thoracic kyphosis (TK, T1–12), lower thoracic kyphosis (LTK, T5–12), thoracolumbar kyphosis (TLK, T10–L2), cervical lordosis (CL), T1 slope, C7 sagittal vertical axis, and the apex of thoracic kyphosis. In contrast, lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), and the location of the apex did not show significant changes after the surgery.

Concerning the Lenke sagittal modifier groups, there were notable differences in preoperative TK (T1–12), TK (T5–12), TLK, and CL between the two groups, but no significant differences were found after surgery. These results align with the research conducted by Okubo et al.<sup>(48)</sup>, which indicated that selective TL/L fusion predominantly influences the M group in terms of sagittal alignment compared to the N group. In this regard, Karadimr et al.<sup>(49)</sup> recommended that selective fusion should be reserved for patients

classified as Lenke sagittal modifier N and not advised for those with T5–T12 kyphosis exceeding 40°. Conversely, LL and spinopelvic measurements are affected following selective TL/L fusion<sup>(50-52)</sup>, suggesting that the mean length of fusion is extended and the last instrumented vertebra (LIV) is placed further down, impacting lumbosacral alignment. Wang et al. (2017)<sup>(53)</sup> conducted a study examining the relationship between posterior selective thoracolumbar/lumbar fusion and cervical sagittal alignment (CSA) in a group of 30 cases diagnosed with Lenke type 5C adolescent idiopathic scoliosis (AIS). Their findings indicated that while postoperative changes in lumbar curvature do not have a direct impact on CSA, excessive indirect adjustments to the thoracolumbar/lumbar curve can cause increased thoracic sagittal alignment (TSA). This, in turn, can elevate the T1 sagittal slope and subsequently affect the CSA in these patients.

Additionally, T1 slope was found to correlate before and after surgery with C2–C7 lordosis, proximal thoracic kyphosis (proximal-TK), and global thoracic kyphosis (global-TK). In some patients, increased TSA resulted in the development of cervical lordosis (CL) to maintain horizontal gaze. However, some patients experienced a recurrence of reduced cervical lordosis due to intrinsic cervical spine stiffness<sup>(44-48)</sup>.

### Long-term Outcomes

Evaluating long-term outcomes, patient satisfaction, and complications associated with selective TL/L fusion is crucial. In a research conducted by Etemadifar et al.<sup>(54)</sup> that focused on patients with selective fusion (SF) for adolescent idiopathic scoliosis (AIS), significant improvements were noted post-surgery. There was a marked enhancement in the ratio of apical vertebral translation (AVT) between the thoracic curve and the TL/L curve. Furthermore, worsening of deformity, the adding-on phenomenon, coronal decompensation, or needed revision operation was happened in any patients. The analysis of patient satisfaction indicated that 85.8% of participants were content with the results, while 9.2% expressed dissatisfaction.

Lower et al.<sup>(55)</sup> differentiated between patients receiving selective thoracic fusion and those undergoing TL/L fusion, analyzing each group independently. The average preoperative coronal Cobb angle for the TL/L group was 45 ± 8°, which improved to 16 ± 7° at the first standing follow-up, resulting in a 64% correction rate. This level of

correction remained consistent in mid-term and 10-year follow-ups, with corrections of 62% and 60% of the preoperative values, respectively ( $P > 0.05$ ).

The compensatory MT curve that underwent fusion measured on average  $25 \pm 8^\circ$  preoperatively,  $20 \pm 8^\circ$  (21% correction) on the first standing follow-up, and  $16 \pm 7^\circ$  (60% correction relative to preoperative) at the 10-year follow-up. CB showed significant improvement, increasing from 3.1 cm before surgery to 0.9 cm at the 10-year follow-up ( $P < 0.001$ ), demonstrating notable progress in patients who underwent selective TL/L fusion.

Thoracic kyphosis (TK) did not change significantly postoperatively, and lumbar lordosis (LL) remained normal, despite temporary hypolordosis in the first standing follow-up<sup>(28)</sup>.

Delfino et al.<sup>(56)</sup> reported 35 patients with adolescent idiopathic scoliosis (AIS) who had anterior selective thoracolumbar/lumbar fusion were tracked for a minimum of 12 years. The average preoperative thoracolumbar/lumbar Cobb angle was  $49.5 \pm 9^\circ$ , with postoperative and final follow-up corrections achieving  $79 \pm 13\%$  and  $72 \pm 18\%$ , respectively. The mean preoperative thoracic Cobb angle was  $31.4 \pm 14.2^\circ$ , which enhanced to  $18.4 \pm 11.9^\circ$  after surgery and reached  $17.8 \pm 10.8^\circ$  by the final follow-up. Rotation of the apical vertebral from  $25.8 \pm 7.8^\circ$  significantly enhanced to  $9.2 \pm 5.5^\circ$  and ultimately to  $8 \pm 5.2^\circ$  ( $P = 0.001$ ). Sagittal parameters (T5–T12 =  $27.2^\circ$ , L1–S1 =  $56.9^\circ$ ) remained relatively unchanged throughout the study. Coronal balance from 2.4 cm changed to 1.6 cm after fusion and 0.8 cm at the final visit ( $P = 0.006$ ). There were no reports of reconsideration operations or infections, though one patient did require lumbar surgery because of symptomatic disc degeneration.

In the study by Direito-Santos et al.<sup>(42)</sup>, anterior selective TL/L fusion was assessed in a total of 65 patients classified as Lenke 5C and 10 patients classified as Lenke 6C, with an average follow-up period of 9 years. For those with Lenke 5C, there was an average correction of  $85.1 \pm 10.5\%$  in the fused TL/L curve, which remained stable at the ultimate follow-up ( $P > 0.05$ ). The unfused thoracic curve exhibited an initial postoperative correction of  $59.9 \pm 30.5\%$ , which improved to  $66.3 \pm 28.9\%$  by the time of the ultimate evaluation ( $P < 0.018$ ). Additionally, the Cobb angle improved significantly from  $28.9 \pm 14$  mm to  $5.7 \pm 6.7$  mm ( $P < 0.001$ ) and stayed consistent. However, the thoracic kyphosis (TK) and lumbar

lordosis (LL) measurements did not show any significant changes after surgery.

In the Lenke 6C cases, the mean TL/L Cobb angle before surgery measured  $58.6 \pm 13.9^\circ$ , which decreased to  $22.6 \pm 14.5^\circ$  after surgery ( $P < 0.001$ ), indicating a correction of  $62.5 \pm 20.6\%$  that remained stable at the last radiographs ( $P > 0.05$ ). The thoracic Cobb angle reduced from  $39 \pm 7.6^\circ$  to  $30.6 \pm 10.1^\circ$  post-surgery ( $P < 0.008$ ), achieving a correction of  $22.4 \pm 17.5\%$ . The thoracic Cobb angle at the final follow-up was  $29.3 \pm 10.7^\circ$ , showing no significant change from the postoperative measurements. Additionally, the CB improved from  $20.9 \pm 14.5$  mm preoperatively to  $16.6 \pm 14.2$  mm at the final follow-up ( $P = 0.086$ ). In this group, 10 cases (15.4%) from the 5C group and 2 cases (20%) from the 6C group experienced asymptomatic nonunion at the distal level. There were no significant degenerative alterations during the ultimate radiographical assessment.

Chen et al.<sup>(57)</sup> performed a research involving patients with Lenke type 5 AIS, which had  $11.26 \pm 0.85$  years follow-up period of, for evaluation the outcomes of posterior selective TL/L fusion. The average Cobb angles before surgery were  $24.0 \pm 9.0^\circ$  for the thoracic curve and  $45.4 \pm 6.3^\circ$  for the TL/L curve, which reduced to  $12.2^\circ$  and  $12.4^\circ$  three months after the operation. By the ten-year follow-up, the correction was lost  $2.2^\circ$  for the thoracic and  $1.5^\circ$  for the TL/L curve.

They indicated that out of 37 patients, 20 exhibited preoperative coronal imbalance (CIB), but the majority achieved normal levels within the first three months and maintained balance during follow-up. The TK and proximal junctional angle (PJA) showed a gradual rise over time. Proximal junctional kyphosis (PJK) was reported in one out of 37 patients (2.7%) at the three-month mark, and this figure rose to 12 out of 37 patients (32.4%) by the ten-year follow-up. There were no significant differences between the M and N sagittal modifier groups or between those initially imbalanced and those balanced. PJK continues to be viewed as a multifactorial occurrence and a dynamic compensatory response that aids in keeping body equilibrium and decreasing energy expenditure while standing or walking.

The “adding-on phenomenon” and the decompensating of the unfused thoracic curve are acknowledged complications associated with selective fusion (SF), which may deter some surgeons from utilizing this approach. The adding-on sensation

manifests as a gradual failure of correction, a progressive shift in lumbar vertebrae, or alterations in disc angles beneath the lowest fused vertebra (LIV). Reported incidence rates for adding-on and thoracic decompensation reach as high as 36% and 29%, respectively<sup>(6)</sup>. Nevertheless, in most cases, revision surgery was not required, and patients did not have clinical complaints<sup>(6,45)</sup>.

## Conclusion

Overall, the discussion section of this study emphasizes the efficacy and safety of TL/L fusion for AIS. The article highlights the importance of appropriate patient selection, the benefits of this approach on quality of life, and the need for further research to address gaps in the existing literature. These findings can serve as a guide for clinicians in making informed decisions regarding treatment options for adolescents with scoliosis.

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