Posterior Scoliosis Correction Indications, Planning, and Operative Techniques

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Highlights

- Scoliosis surgery aims to provide deformity correction, achieve overall balance, and, most importantly, arrest the progression of the curve.
- Fusion is a time-tested solution to achieve these major goals, but maintaining spinal flexibility through nonfusion techniques is gaining momentum.
- An all-posterior approach for scoliosis surgery gives good outcomes; hence, anterior surgery presently has limited indications.
- Identifying the various curve types by classification helps in documenting and analyzing outcomes but not in the planning of fusion levels.
- Fusion level selection is based on analyzing the behavior of each curve on bending radiographs, photographic parameters, and overall balance measures.
- Careful LIV selection avoids decompensation by providing a horizontal platform while retaining adequate lumbar mobility.
- UIV selection to achieve balanced shoulders consistently has been a challenge and an area of continuing research.
- Instrumenting the strategic vertebrae and reducing the screw density gives an optimal correction of scoliosis along with an increased fusion bed area.
- Combining different correction maneuvers during surgery distributes the forces in various planes, which reduces the risk of neurological complications.

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1 A Brief History of Posterior Surgery

From only fusion without correction to gradual correction with nonfusion techniques, scoliosis surgery has come a long way in the last century. Hibbs [1] should be given the credit for taking the first substantial step to finding a solution to the complex problem of spinal deformity correction. He suggested the fusion of the spine without instrumentation in 1915. Prolonged immobilization, lack of curve correction, high incidence of pseudoarthrosis, and infection were major perils with this technique. Subsequently, no progress was made due to a society heavily invested in world wars until 1950, when Harrington came up with a hook-based distraction system. The strategy was "concave distraction" and "convex compression" due to the prevailing philosophy that scoliosis was a two-dimensional deformity. Consequently, flatback syndrome [2] due to obliteration of thoracic kyphosis leads to pain and disability. For severe curves, Pierre Stagnara [3] improvized by using preoperative traction followed by Harrington instrumentation. Harrington instrumentation also did not provide good stability, which was reflected in the high pseudoarthrosis rates. In the 1970s, Eduardo Luque [4] introduced a combination of sublaminar wires connected to an L-shaped rod (Luque trolley). Essentially, this was the first attempt at the segmental correction of scoliosis, where each vertebra was individually subjected to corrective forces. Translation and mild derotation forces against the distraction forces of the Harrington rod meant that there were fewer chances of flatback. However, the major concern was the risk of neurologic injury while using sublaminar wires. A new era in posterior instrumentation was ushered by the Universal Spine System (USS) and the Cotrel-Dubousset (CD) instrumentation system. The USS used the concept of sideloading anchors in the form of hooks and screws at appropriate sites, which were translated to the rod by a strong persuader. The CD school gave the concept of instrumenting "strategic vertebra" [5] with a combination of hooks (at thoracic level) and screws (at thoracolumbar/lumbar level). In addition, an additional maneuver of rod rotation was added to the correction. A concave rod contoured to the deformity was fixed to anchors and rotated 90° to bring the rod in the sagittal plane to translate the apex toward the center. A convex rod under contoured was fixed to the anchors in a cantilever bending maneuver to push the rib hump down. The axial plane correction in this system was poor [6], and hence, selective thoracic fusions failed due to increased rotation of the unfused lumbar vertebrae. Pedicle screws were introduced by Roy-Camille [7]. All pedicle screw constructs gained popularity in the late 1990s. The advantage of pedicle screw constructs was the three-dimensional correction due to a strong three-column hold on the vertebrae. There was an initial learning curve in instrumenting the concave thoracic pedicles that were dysplastic in severe curves. In due course, the complications of instrumentation were significantly reduced enough to warrant this method as a standard of care. The pedicle screws offered a wide range of maneuvers to be performed in scoliosis correction, such as rod rotation, rod translation, direct vertebral rotation, convex cantilever bending, segmental distraction-compression, and in situ bending. This meant that the corrective forces could be distributed across different steps to reduce the neurological compromise (incidence reduced to 0.7%) due to acute correction. Additionally, each maneuver can be undone at any stage if neuromonitoring shows an alert. For the first time in scoliosis correction, direct vertebral manipulation was possible with pedicle screws, which allowed axial plane correction. This stronger force of correction allowed the substitution of anterior releases with posterior releases only. The intraoperative neurologic status was assessed by Stagnara's wake up [8] test until the 1990s. This was tedious and time-consuming. Additionally, in the event of neurologic compromise, there was no way of determining the cause. Multiple wake-up tests had to be performed to end the surgery with a safe correction. The advent of multimodal spinal cord monitoring allowed real-time assessment of the neurology during the surgery and corrections performed as needed. After a century-long effort to fuse the spine to correct and arrest the deformity, the world is slowly trying to move toward a nonfusion technique. Growth modulation to correct the deformity and allow growth in a controlled manner that can give a balanced mobile spine is an ideal outcome. Vertebral body tethering is an effort to achieve the same. However, these methods are still evolving, and the next decade will see a major effort going toward this.

2 Cases Optimal for the Approach

Regarding idiopathic scoliosis, the posterior approach is the workhorse for all curve types. The advantages of the posterior approach are as follows:

1. Strong three-column fixation with pedicle screws.
2. Posterior osteotomies can be combined with an anterior approach (extracavitary) if needed.
3. Cord visualization and protection are possible in the case of osteotomies for severe curves.

3 Preop Planning

Step 1: Classify/Identify Structural Curves

The first classification system for scoliosis was given by John Cobb [9] in 1948. It was descriptive and tried to group patterns of curves. The Kings classification [10] was the first attempt to group curves and make recommendations for fusion levels based on the Harrington Rod system. The two-dimensional model of scoliosis clubbed with a predominant distraction correction philosophy led to inconsistent results. Nevertheless, the Kings classification gave some key concepts, such as stable vertebra and structural curves, which have held the test of time. To improve the interobserver reliability in identifying various curve patterns, Lenke [11] introduced a classification system with 42 curve patterns. Although this classification system has greatly improved the interobserver reliability in identifying curve patterns, the fusion level selection based on this has not been consistently followed. The subsequent 3D classification systems have only increased the complexity in an attempt to be comprehensive. Scoliosis classification systems have tried to balance the identification of various curve patterns with simultaneous utility in making discrete surgical decisions. This effort has always been fraught with partial success because every curve pattern being seemingly like others in the scheme of classification behaves differently when fused at the same levels. In a study [12], 32 experienced spine surgeons were asked to plan five cases of idiopathic scoliosis. The screw numbers varied from as much as 8 to 30, and levels of fusion varied up to 6 levels. In a similar study [13], the authors concluded that this inconsistency was due to a lack of clear-cut guidelines backed by biomechanical principles with present-day instrumentation systems. Hence, a consistent process to identify a possible behavior of each curve separately by bending radiographs, photographic parameters, and overall balance measures should guide the selection of fusion levels. The authors [14] recommend identifying the structural curves on bending radiographs and choosing fusion levels after studying the behavior of each one of them on bending radiographs.

Step 2: Selection of Fusion Levels (Upper and Lower Instrumented Vertebra)

Broadly speaking, the process of fusion level selection ensures that the fused spine will balance over the unfused spine while making the best effort to save as many lumbar motion segments as possible. The selection of the lower instrumented vertebra (LIV) makes a platform for the fusion tower to stand erect over the horizontal pelvis, and the upper instrumented vertebra (UIV) must be parallel to the T1 vertebra while correcting the shoulder balance. There are several philosophies for achieving this goal, which will be discussed here.

Selection of LIV

Harrington's concept of the stable zone: Harrington defined the stable zone as the area between the lumbosacral facets [15] and recommended the LIV as the most caudal vertebra of the structural curve to fall within this zone. King et al. [10] added a new dimension of the "stable vertebra," defined as the most proximal vertebra to be bisected by the central sacral vertical line. With Harrington distraction instrumentation, they recommended the stable vertebra to be the LIV.

Goldstein's method [16]: The authors recommended going 1–3 vertebrae below the lower end vertebra of the main curve.

Moe's method: Moe [17] was the first to identify rotation of the LIV as an important factor and recommended fusing to the neutral vertebra (NV) with a major thoracic curve and a flexible lumbar curve.

Suk's concept: Suk [18] stressed the concept of rotation and gave some clear guidelines. If the NV was at or one level below the lower end vertebra, then the LIV should be the neutral vertebra (LIV = NV). If the NV was more than one level distal to the lower end vertebra, then the LIV had to be one level proximal to the NV (LIV = NV-1). This was based on the premise that derotation of the LIV would bring it to the stable zone.

Keith Luk et al. [19]: Based on fulcrum bending radiographs, the authors suggested the following approach:

1. Draw a line parallel to the inferior endplate of the proposed LIV.
2. Erect a perpendicular to the above line (CL).
3. Draw a line parallel to the superior endplate of the proposed UIV.
4. Measuring the Cobb angle between the proposed UIV and LIV.
5. Measure the trunk shift by the distance of CL from the center of the proposed UIV.
6. Accept the UIV and LIV, which yield a Cobb angle of fewer than 20° and trunk shift of less than 20 mm.

The Cobb angle improves by adding levels proximally or distally, but trunk shift improves only by adding levels distally.

Fenghua Tao et al. [20]: The authors suggested using the apical vertebra for deciding on the LIV, as the interobserver variability in identifying neutral vertebra was 50%. They suggested the following strategy to choose LIV:

1. D11 as LIV: The apical vertebra at D6 or D6–7 disc.
2. D12 as LIV: The apex is a D7, D8, or D7–8 disc.
3. L1 as LIV: The apex is the D8, D9, D8–9 disc, D9–10 disc.

Hai-Jian Ni et al. [21]: The authors studied Lenke 1A curves and suggested the following method.

1. LIV should not be superior to LEV.
2. On the right side-bending radiographs, the LIV should be derotated to neutral, and the disc immediately below the LIV must open on the left side by at least 5°.
3. On the left side-bending radiographs, the disc immediately below the LIV must open on the right side by at least 0°.

Last touched vertebra (LTV) and last substantially touched vertebra (LSTV) to judge LIV: LTV is defined as the most proximal vertebra to be intersected by the central sacral vertical line (CSVL) in any portion of the vertebral body, including lateral to the pedicle. LSTV is the most proximal vertebra in which the CSVL intersects the pedicle outline or is medial to it. Cho et al. [22] identified two types of curves in Lenke 1A that behaved differently the following fusion at the same levels. If L4 tilted to the right, the curve type was 1AR and 1AL with a tilt to the left. The authors recommended choosing LIV approaching LSTV and NV in 1AR curves, whereas in 1AL curves, they suggested going 1 level distal to the end vertebra. Matsumoto et al. [23] and Cao et al. [24] suggested better results with LIV at or below the LTV. Comparing the LTV with LSTV, Qin et al. [25] found that the LIV at LTV had a higher risk of adding-on compared to LSTV. Hence, they recommended LIV at LSTV or LSTV+1. The first distal uninstrumented vertebra (FDUV) tilt was analyzed in a multicenter study [26], and more than 5° was considered a risk factor for adding-on. The study found that there was a higher incidence (85%) of adding-on in patients with an LIV proximal to LTV.

Selection of UIV

Harrington [15] recommended going one level proximal to the upper-end vertebra, and Goldstein proposed the first neutral vertebra proximal to the upper-end vertebra as the UIV.

Lenke [27, 28] made the following suggestions for UIV in Lenke 1 curves based on shoulder balance:

1. Right shoulder-high: T4
2. Level shoulders: T3
3. Left shoulder-high: T2

For curve types with structural proximal thoracic (PT) curves, they recommended fusing the PT curve by choosing T2 as the UIV. Although there is still controversy, choosing UIV corrects medial shoulder balance and may fail to address lateral balance. The other factor to be considered is not to end the fusion over a kyphotic segment, which may lead to proximal junctional kyphosis.

Determination of Fusion Levels (Authors' Preferred Approach)

Selection for LIV (Lower Instrumented Vertebrae)

According to the authors, an ideal LIV should fulfill the following criteria:

- LIV should be centralized over the pelvis.
- It (the foundation of the construct) should be horizontalizeable over the pelvis.
- The disc distal to the LIV should be mobile enough to allow such self-correction.
- The LIV should be neutrally rotated (axial plane deformities do not compensate well).

These criteria have been listed in the order of priority, and the first two are uncompromisable, while the last two criteria can be modified to save lumbar motion segments.

The following criteria are ascertained on the standing and bending whole spine radiographs by the method outlined below:

- The disc space below the selected LIV should be opened out on both sides on bending radiographs (Fig. 1).
- Perpendicular to the intercristal line drawn from the center of the sacrum, the pedicles of the selected LIV should be closely bisected on one of the two bending X-rays (Fig. 2).
- The lower endplate of the LIV should be parallel to the pelvis on one of the two bending X-rays (Fig. 3).
- The LIV should be neutrally rotated on bending X-rays.
- The selected LIV should not be proximal to the LEV (lower end vertebrae) of the MT (main thoracic) curve.

The most proximal vertebra meeting the criteria distal to the LEV is chosen as the LIV.

Selection for UIV (Upper Instrumented Vertebrae)

The thumb role for selection of UIV is UIV = UEV (upper end vertebra) + 1.

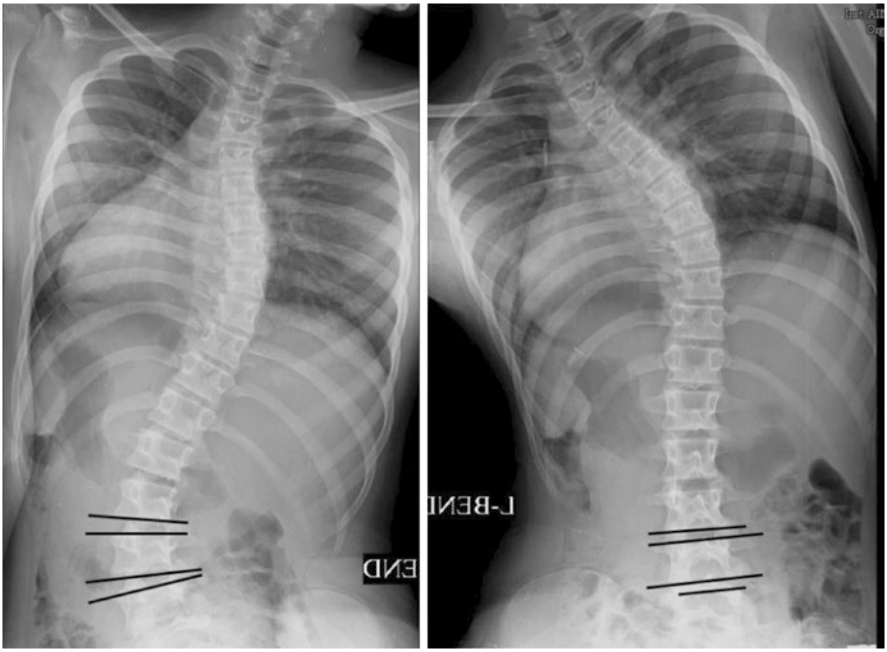

Fig. 1 The disc space below the selected LIV should be opened out on both sides on bending radiographs

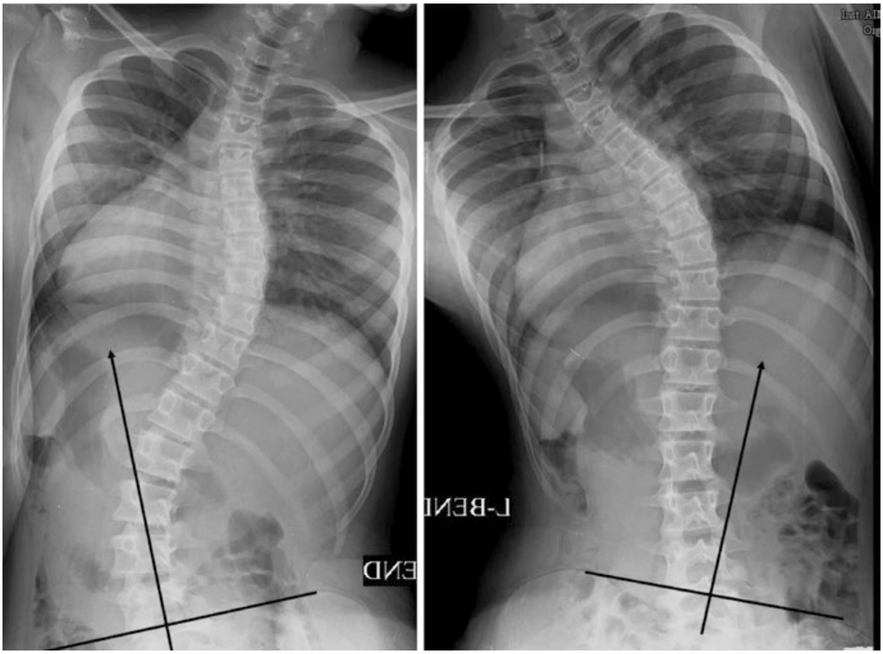

Fig. 2 Perpendicular to the intercristal line drawn from the center of the sacrum, the pedicles of the selected LIV should be closely bisected on one of the two bending X-rays

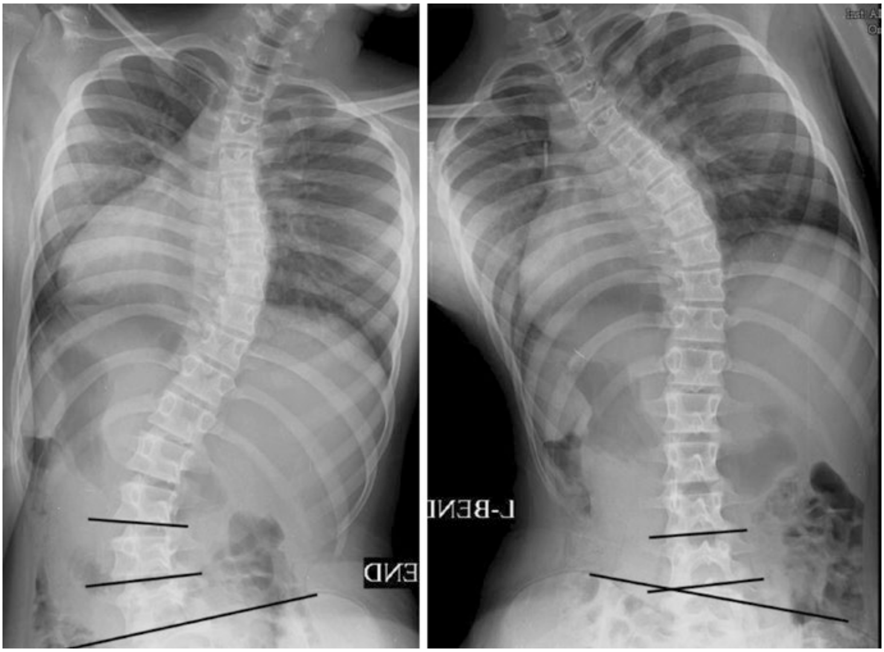

Fig. 3 The lower endplate of the LIV should be parallel to the pelvis on one of the two bending X-rays

When the proximal thoracic curve is structural and the upper-end vertebra is T1 or T2, the authors always prefer to stop at T2 (not T1 or C7) to prevent junctional kyphosis. Once the UIV is decided, shoulder balance is achieved intraoperatively by manipulating the UIV to make it parallel.

Step 3: Selection of Anchors in Various Vertebrae in the Fusion Mass

The options in the anchors on the vertebra are as follows:

1. Pedicle screws: Pedicle screws are the workhorses in scoliosis correction in the present era. The versatility in application, stronger bony hold, and compatibility with every scoliosis maneuver make it the best anchor. There are very few exceptions in which the preference shifts to other anchors.
    (a) Dysplastic pedicles at the concave apex—Pedicle hooks and sublaminar wires are alternatives.
    (b) Pedicle screws at the UIV in certain situations make the construct stiff and lead to proximal junctional kyphosis (PJK)—Transverse process/Laminar hooks are an alternative.
2. Transverse process (TP) hooks: These are offset hooks designed to fit on the superior surface of the transverse process and can be used from D1 to D11. TP hooks are specifically useful at the top of the construct to create a soft transition from the fused to the flexible spine and reduce the chances of PJK.
3. Pedicle hooks: These hooks are designed to capture the pedicle from the inferior aspect. Pedicle hooks are useful at the concave apex with dysplastic pedicles when pedicle screw insertion is not possible.
4. Sublaminar wires and tapes: These wires/tapes are passed under the lamina, and the vertebra is translated medially by gradual tightening over the rod. The sublaminar wires/tapes can be used at every level. They are particularly useful in the following scenarios:
    (a) Osteoporotic bone—Pedicle screw at the concave apex with a poor hold can be augmented by a sublaminar wire during translation to avoid pull out.
    (b) Dysplastic pedicles at the concave apex.
5. Supralaminar and infralaminar hooks: These hooks are made to fit the superior and inferior surface of the lamina. Presently, they are used in the proximal part of the construct, such as the TP hooks.

Step 4: Distribution of Screws Across the Curve on "Strategic Vertebrae" to Obtain Optimal Correction

Once the upper and lower extent of fusion is decided, the next step in planning is to decide the distribution of screws at various levels to obtain an optimum outcome. There have been three predominant approaches in deciding screw distribution/density as follows [29]:

1. 100% high screw density
2. Low-density screw fixation
3. 3/5 zone fixation strategy

The simplest strategy is to use screws bilaterally in every vertebra of the fusion mass (100% density). Although this can achieve an optimal result, the disadvantages are higher cost, clustered screws reducing the total fusion bed area, and overcorrection in flexible curves.

Low-density screw fixation is the approach to securing upper and lower instrumented vertebra while distributing staggered screws in the alternate vertebra. This can be a good strategy in flexible curves but does not work in stiff curves.

3/5 zone fixation strategy [30].

According to this school of thought, there are five zones within the fusion mass, namely, the proximal end, distal end, apical end, upper peri-apical end, and lower peri-apical end (Fig. 4). There can be two constructs based on these zones.

- Three zones only: In this construct, there is 100% screw density in the apical, proximal, and distal ends but no screws in the periapical zones. This is preferred in flexible curves.
- Five zones: In this construct, there is 100% screw density in the apical, proximal, and distal ends but staggered screws (≤50%) in the peri-apical zones. This is the preferred approach in stiff curves.

The following principles are followed by the authors:

1. The concave side of the curve will have more screws when the rod rotation maneuver is the primary correcting maneuver.
2. More screws are stacked around the apex of the curve, which will help in adequate translation toward the midline.
3. The strategic vertebrae, namely, the UIV, LIV, apical vertebra, and neutral vertebra, must be identified. All these vertebrae should have two screws each except the neutral vertebra, which may sometimes be spared.
4. Whenever a direct vertebral rotation maneuver is planned, the vertebrae involved should ideally have screws on both sides.
5. Every other vertebra should have at least one screw.

The attempt here is to reduce the screw density while instrumenting the strategic vertebrae to optimize the outcome. The screw density with this approach ranges

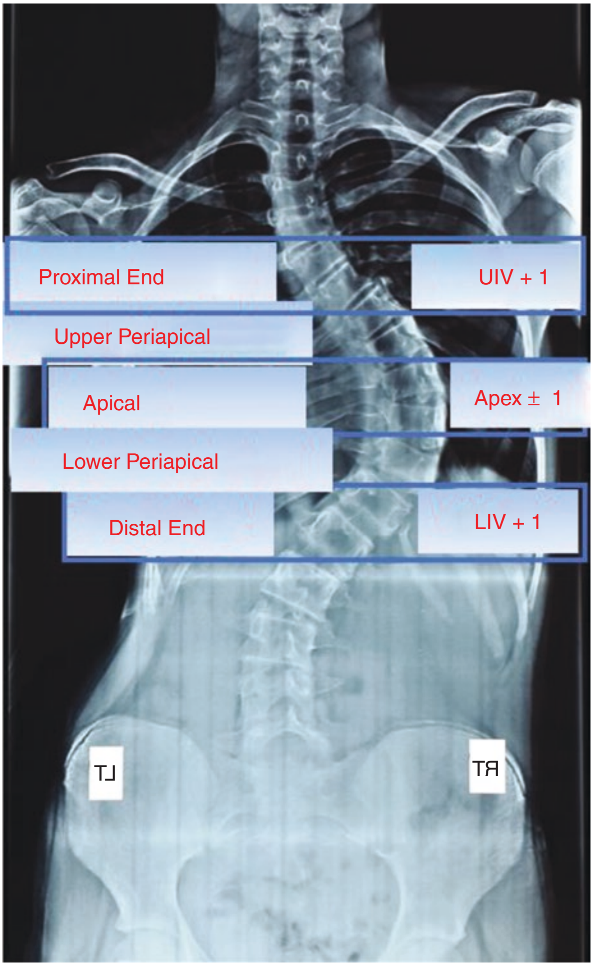

Fig. 4 Five zones in the fusion mass

from 70% in flexible curves to 80% in stiff curves. There is enough evidence to suggest that a higher screw density does not translate to better outcomes. On the other hand, a lower screw density allows for a higher fusion bed.

Step 4: Choosing the Type of Release/Osteotomies Based on the Flexibility of the Curve

Curves with the flexibility of less than 50% are defined as rigid curves. All the curves require inferior facetectomy to improve flexibility and to aid fusion. However, in rigid curves, ponte osteotomy is needed. Ponte osteotomy is a complete posterior osteotomy. The spinous process, inferior aspect of the superior lamina along with the ligamentum flavum, and superior facets on both sides are resected. Vertebral column resection and pedicle subtraction osteotomies are reserved for severely rigid curves.

Step 5: The Maneuvers to Correct the Scoliosis

Once the screws are placed as planned and required releases are done, the next step is to execute different maneuvers utilizing the anchors to achieve correction and balance. The various maneuvers that can be used in different combinations are as follows:

1. Rod rotation: This is one of the primary maneuvers used to correct the curve. The concave rod is contoured according to the anatomical sagittal contour of the region of the spine being instrumented. This rod is placed on the concave side and reduced to the anchors. Once anchored to the screws, the rod is rotated 90° to bring the contouring to the sagittal plane. In this process, the apex is translated medially to correct the curve. One of the problems of this maneuver is that vertebral rotation becomes worse. Therefore, the rib hump and the convex screws must be pushed down while rod rotation is being performed.
2. Rod translation: This is one of the additional maneuvers particularly useful with the side loading screws. The screw is captured to the rod in the coronal plane by translating it medially. Maximum translation occurs at the apex.
3. Convex cantilever bending: After the convex rod is fixed to the most proximal screws, the rod is pushed medially and anteriorly to correct the curve while pushing down on the rib hump.
4. Direct vertebral rotation (DVR): The periapical screws are used to execute this maneuver. Ideally, these vertebrae should have bilateral screws, which are monoaxial. DVR can be performed segmentally or en bloc. During segmental DVR, each vertebra is held by screw extenders bilaterally, and rotation is corrected by turning toward the convex side. The en bloc DVR is performed by connecting all screw extenders into one block and rotating.
5. In situ rod bending: This maneuver can be added to improve correction by bending the rods in situ. It is most useful when scoliosis correction leaves a hypokyphotic spine and in situ bending can restore kyphosis.
6. Compression-distraction: Segmental compression and distraction can also be utilized to improve correction. UIV manipulation can be performed by this maneuver to correct the shoulder balance. The LIV may also be adjusted in this manner to achieve distal balance, which will be elaborated on in the next section.
7. Simultaneous double rod-rotation technique (SDRRT): The concave rod rotation technique as the primary correcting maneuver has the disadvantage of reducing kyphosis in the thoracic spine. The SDRRT technique was described by Ito et al. [31]. The double rod rotation involves the rotation of both concave and convex rods simultaneously. This maneuver creates posterior and lateral translatory

forces on the spinal column and restores thoracic kyphosis as well as satisfactory coronal correction in the authors' study.

8. Vertebral coplanar alignment (VCA): This technique was originally described by Vallespir [32]. Pedicle screws are inserted in every vertebra on the convex side and in the second or third consecutive vertebra on the concave side. Slotted tubes are attached to the convex side screws. With two rigid bars inserted into the slotted tubes, the lower bar is gradually lowered toward the head of the screws, correcting the curve. Spacers are placed between the tubes to restore kyphosis. When satisfactory correction is achieved, a contoured rod is placed on the concave side, and distraction is applied. A contoured convex rod was placed after the removal of the tubes, and compression was applied across the screws to further correct the deformity.

Step 6: Proximal and Distal Balancing

Distal balancing: The manipulation of LIV to assure that the base of the construct is horizontal is called distal balancing. This is needed mostly when the chosen LIV is at or distal to L3 because there are fewer lumbar motion segments to balance. At the end of all correction maneuvers, the LIV is examined for rotation and tilt. After ensuring that both screws in the LIV are at the same level, a balancing rod (long vertical rod with a horizontal base) is placed such that the horizontal base rests on the two LIV screws. The long vertical rod perpendicular to the horizontal base should lie between the concave and convex rods, eventually ending at the C7 spinous process. This is an indirect way of assuring that the fusion mass is perpendicular to the LIV and that the fusion mass is in line with C7, indicating good coronal balance. If the balancing rod sways away from this, compression-distraction is performed at the LIV to achieve the desired balance.

Proximal balancing: The manipulation of UIV to make it horizontal is proximal balancing. Next, the UIV is examined to look for rotation and tilt. The same is corrected by compression-distraction.

4 Our Case Series

The authors studied 92 patients with AIS Lenke 1 ($n = 65$) and 2 ($n = 27$) operated on between 2001 and 2011. There were 73 females and 19 males. The mean age was 14.4 ± 2.1 years. The mean thoracic Cobbs were 59.3 ± 15.7°, with mean preoperative flexibility of 39.5 ± 15.3%. The planning approach and operative strategy elaborated above were applied. The mean postoperative thoracic Cobbs were reduced to 15.6 ± 10.1 at the final follow-up ($p < 0.001$), with a mean correction of 74.5%. The apical vertebral translation of the main thoracic curve was reduced from 4.8 ± 1.5 cm (preop) to 1.4 ± 0.97 cm after surgery ($p < 0.001$). The trunk shift was corrected from 1.6 ± 1.1 cm to 0.02 ± 0.73 cm after surgery ($p < 0.001$) (Table 1).

The strategic vertebral distribution is described in Table 2. L1 was the most chosen LIV (31.5%), and L3 was the most common stable vertebra (29.3%).

One of the important objectives of the study was to assess the effectiveness of the approach in saving lumbar motion segments. With the above approach, the authors could save at least 1 or more lumbar motion segments in 59.8% of patients compared to the stable vertebra method (Fig. 5).

On statistical analysis (paired *t*-test), LIV by the stable zone method was significantly larger than the LIV determined by our strategy ($p < 0.0001$).

Table 1 Results of the authors' study

	Preoperative	One-week postoperative	Final follow-up	*p*
Thoracic Cobbs (°)	59.3 ± 15.7	15.2 ± 9.8 (postoperative correction = 75.1 ± 12.3%)	15.6 ± 10.1 (postoperative correction = 74.5 ± 12.7%)	<0.001
Lumbar Cobbs (°)	28.3 ± 9.9	5.9 ± 5.1	6.6 ± 5.1	<0.001
AVT (cm)	4.8 ± 1.5	1.3 ± 1.03	1.4 ± 0.97	<0.001
Trunk shift (cm)	1.6 ± 1.1	−0.04 ± 0.83	0.02 ± 0.73	<0.001
Thoracic kyphosis (°)	17.5 ± 11.04		22 ± 4.6	<0.001
Lumbar lordosis (°)	−36.5 ± 8.7		−38.7 ± 7.5	<0.001

Table 2 Distribution of strategic vertebra

Location	Lower end vertebra	Neutral vertebra	Stable vertebra	Lowest instrumented vertebra
D9	1 (1.1%)	1 (1.1%)	0	0
D10	6 (6.5%)	1 (1.1%)	0	0
D11	27 (29.3%)	21 (22.8%)	0	2 (2.2%)
D12	30 (32.6%)	21 (22.8%)	1 (1.1%)	1 (1.1%)
L1	25 (27.2%)	18 (19.6%)	13 (14.1%)	29 (31.5%)
L2	3 (3.3%)	12 (13.0%)	17 (18.5%)	25 (27.2%)
L3	0	15 (16.3%)	27 (29.3%)	28 (30.4%)
L4	0	3 (3.3%)	22 (23.9%)	7 (7.6%)
L5	0	0	12 (13.0%)	0

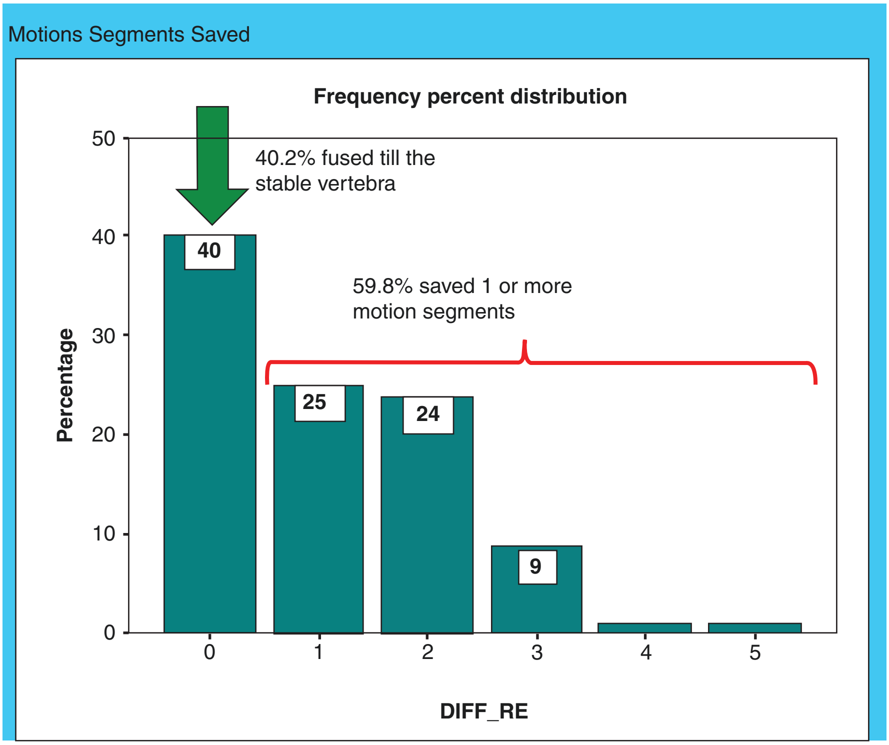

Fig. 5 Lumbar motion segments by the authors' preferred approach

5 Conclusion

Fusion level selection in scoliosis surgery should be guided by analyzing the radiographic, photographic, and balance parameters. Saving lumbar motion segments must be balanced with optimal LIV to prevent decompensation. Screw distribution among strategic vertebrae should take precedence over higher screw density to achieve the same correction while saving cost and improving fusion. Intraoperatively, various maneuvers should be combined to distribute the corrective forces applied across the curve to prevent cord stretching.

References

1. Hibbs RA. An operation for progressive spinal deformities: a preliminary report of three cases from the service of the orthopedic hospital. 1911. Clin Orthop Relat Res. 2007;460:17–20.
2. Aaro S, Dahlborn M. The effect of Harrington instrumentation on the longitudinal axis rotation of the apical vertebra and the spinal and rib-cage deformity in idiopathic scoliosis studied by computer tomography. Spine (Phila Pa 1976). 1982;7:456–62.

3. Stagnara P, Fleury D, Fauchet R, et al. Major scoliosis, over 100 degrees, in adults. 183 surgically treated cases. Rev Chir Orthop Reparatrice Appar Mot. 1975;61:101–22.
4. Luque ER. Segmental spinal instrumentation for correction of scoliosis. Clin Orthop Relat Res. 1982;163:192–8.
5. Cotrel Y, Dubousset J, Guillaumat M. New universal instrumentation in spinal surgery. Clin Orthop Relat Res. 1988;227:10–23.
6. Asghar J, Samdani AF, Pahys JM, et al. Computed tomography evaluation of rotation correction in adolescent idiopathic scoliosis: a comparison of an all pedicle screw construct versus a hook-rod system. Spine (Phila Pa 1976). 2009;34:804–7.
7. Roy-Camille R, Roy-Camille M, Demeulenaere C. Osteosynthesis of dorsal, lumbar, and lumbosacral spine with metallic plates screwed into vertebral pedicles and articular apophyses. Presse Med. 1970;78:1447–8.
8. Dubousset J. A tribute to Pierre Stagnara. Spine (Phila Pa 1976). 1996;21:2176–7.
9. Ovadia D. Classification of adolescent idiopathic scoliosis (AIS). J Child Orthop. 2013;7:25–8.
10. King HA, Moe JH, Bradford DS, Winter RB. The selection of fusion levels in thoracic idiopathic scoliosis. J Bone Joint Surg Am. 1983;65:1302–13.
11. Lenke LG, Betz RR, Harms J, Bridwell KH, Clements DH, Lowe TG, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am. 2001;83:1169–81.
12. Robitaille M, Aubin CE, Labelle H. Intra and interobserver variability of preoperative planning for surgical instrumentation in adolescent idiopathic scoliosis. Eur Spine J. 2007;16(10):1604–14. https://doi.org/10.1007/s00586-007-0431-x.
13. Aubin CE, Labelle H, Ciolofan OC. Variability of spinal instrumentation configurations in adolescent idiopathic scoliosis. Eur Spine J. 2007;16(1):57–64. https://doi.org/10.1007/s00586-006-0063-6.
14. Menon KV. Classification systems in adolescent idiopathic scoliosis revisited: is a three-dimensional classification needed? Indian Spine J. 2020;3:143–50.
15. Harrington PR. Treatment of scoliosis. Correction and internal fixation by spine instrumentation. J Bone Joint Surg Am. 1962;44-A:591–610.
16. Goldstein LA. Surgical management of scoliosis. Clin Orthop Relat Res. 1964;35:95–115.
17. Moe JH. THE CLASSIC: a critical analysis of methods of fusion for scoliosis: an evaluation in two hundred and sixty-six patients. Clin Orthop. 2007;460:21–8.
18. Suk SI. Pedicle screw instrumentation for adolescent idiopathic scoliosis: the insertion technique, the fusion levels and direct vertebral rotation. Clin Orthop Surg. 2011;3:89–100.
19. Luk KD, Don AS, Chong CS, Wong YW, Cheung KM. Selection of fusion levels in adolescent idiopathic scoliosis using fulcrum bending prediction: a prospective study. Spine (Phila Pa 1976). 2008;33(20):2192–8.
20. Tao F, Shi Z, Xie Y, Pan F, Wu Y, Zhang Y, Wang Z, Li M. Determination of lowest instrumented vertebra by the location of apical vertebra in Lenke type 1 adolescent idiopathic scoliosis. Int Orthop. 2011;35(4):561–7.
21. Ni HJ, Su JC, Lu YH, Zhu XD, He SS, Wu DJ, Xu J, Yang CW, Wang CF, Zhao YC, Li M. Using side-bending radiographs to determine the distal fusion level in patients with single thoracic idiopathic scoliosis undergoing posterior correction with pedicle screws. J Spinal Disord Tech. 2011;24(7):437–43.
22. Cho RH, Yaszay B, Bartley CE, Bastrom TP, Newton PO. Which Lenke 1A curves are at the greatest risk for adding-on. In addition, why? Spine (Phila Pa 1976). 2012;37:1384–90.
23. Matsumoto M, Watanabe K, Hosogane N, Kawakami N, Tsuji T, Uno K, et al. Postoperative distal adding-on and related factors in Lenke type 1A curve. Spine (Phila Pa 1976). 2013;38:737–44.
24. Cao K, Watanabe K, Hosogane N, Toyama Y, Yonezawa I, Machida M, et al. Association of postoperative shoulder balance with adding-on in Lenke type II adolescent idiopathic scoliosis. Spine (Phila Pa 1976). 2014;39:E705–12.

25. Qin X, Sun W, Xu L, Qiu Y, Zhu Z. Effectiveness of selective thoracic fusion in the surgical treatment of syringomyelia-associated scoliosis: a case-control study with long-term follow-up. Spine (Phila Pa 1976). 2016;41:E887–92.
26. Clément JL, Solla F, Tran A, Morin C, Lakhal W, Sales de Gauzy J, et al. Five-year outcomes of the first distal uninstrumented vertebra after posterior fusion for adolescent idiopathic scoliosis Lenke 1 or 2. Orthop Traumatol Surg Res. 2017;103:727–31.
27. Roussouly P, Labelle H, Rouissi J, Bodin A. Pre- and postoperative sagittal balance in idiopathic scoliosis: a comparison over the ages of two cohorts of 132 adolescents and 52 adults. Eur Spine J. 2013;22:S203–15.
28. Suk SI, Lee SM, Chung ER, Kim JH, Kim SS. Selective thoracic fusion with segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis: more than 5-year follow-up. Spine (Phila Pa 1976). 2005;30:1602–9.
29. Dumpa SR, Shetty AP, Aiyer SN, Kanna RM, Rajasekaran S. Reciprocal changes in sagittal alignment in adolescent idiopathic scoliosis patients following strategic pedicle screw fixation. Asian Spine J. 2018;12(2):300–8.
30. Le Navéaux F, Aubin CÉ, Larson AN, Polly DW Jr, Baghdadi YM, Labelle H. Implant distribution in surgically instrumented Lenke 1 adolescent idiopathic scoliosis: does it affect curve correction? Spine (Phila Pa 1976). 2015;40(7):462–8. https://doi.org/10.1097/BRS.0000000000000793.
31. Ito M, Abumi K, Kotani Y, et al. Simultaneous double-rod rotation technique in posterior instrumentation surgery for correction of adolescent idiopathic scoliosis. J Neurosurg Spine. 2010;12:293–300.
32. Piza G, Burgos J, Sanpera I, Hevia E, Domenech P, Rodriguez JC, Garcia M, Ramos R, Perez A, Rodriguez B, Gutierrez P, Vicente J, Gonzalez JL, Maruenda JI, Barrios C, Riquelme O. Vertebral coplanar alignment: a standardized technique for three dimensional correction in scoliosis surgery: technical description and preliminary results in Lenke type 1 curves. Spine (Phila Pa 1976). 2008;33:1588–97.