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Preoperative Radiographic Planning of Adolescent Idiopathic Scoliosis: Educational Corner

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Background

Scoliosis is defined as a three-dimensional spinal deformity diagnosed with lateral curvature and axial vertebral rotation (1). The most common type is adolescent idiopathic scoliosis (AIS), which manifests in healthy children at 10 years of age and older, especially in girls (1, 2). Despite advances in the treatment of scoliosis, treatment planning of progressive adolescent scoliosis remains a significant challenge. It is now well known that untreated scoliosis in the adults can lead to painful spinal osteoarthritis, progressive deformity, spinal stenosis with radiculopathy, muscle fatigue from coronal and sagittal plane imbalance, and the psychological effects with the decrease in quality of life (3). This educational corner aims to prepare a simple step-by-step guideline of pre-operation evaluation and planning of AIS for orthopedic surgeons and residents.

Step 1

What Is a Standard Scoliosis Radiographic Evaluation?

There are many examination techniques for screening and diagnosis of scoliosis. The Adam's test with level plane and ruler or a scoliometer is used to diagnose scoliosis and evaluation of the curves (4). These tests are clinician-dependent; therefore, measurements are difficult to standardize (5, 6). Despite the enormous advances in imaging, plane radiography remains the best way of diagnosis and evaluation of scoliosis (7). The best point of radiography is the ability to image the whole spine in the standing patient while giving the surgeon the three-dimensional rotatory nature of the scoliotic deformity (7).

It is necessary to have a strict adherence to the standard techniques and prevent errors and variations in radiographic analysis.

Radiographs should be in standing and weight-bearing position. They present a more reliable view of the curvature, truncal imbalance, and the measurements that are important for surgical decision-making (7). Besides, scoliosis radiographs should include cervical spine and pelvis (7).

A surgeon needs at least three different radiographic views to obtain measurements for evaluation to surgical decision-making: 1) posteroanterior (PA) view, 2) lateral view, and 3) sideward-bending view (Figure 1).

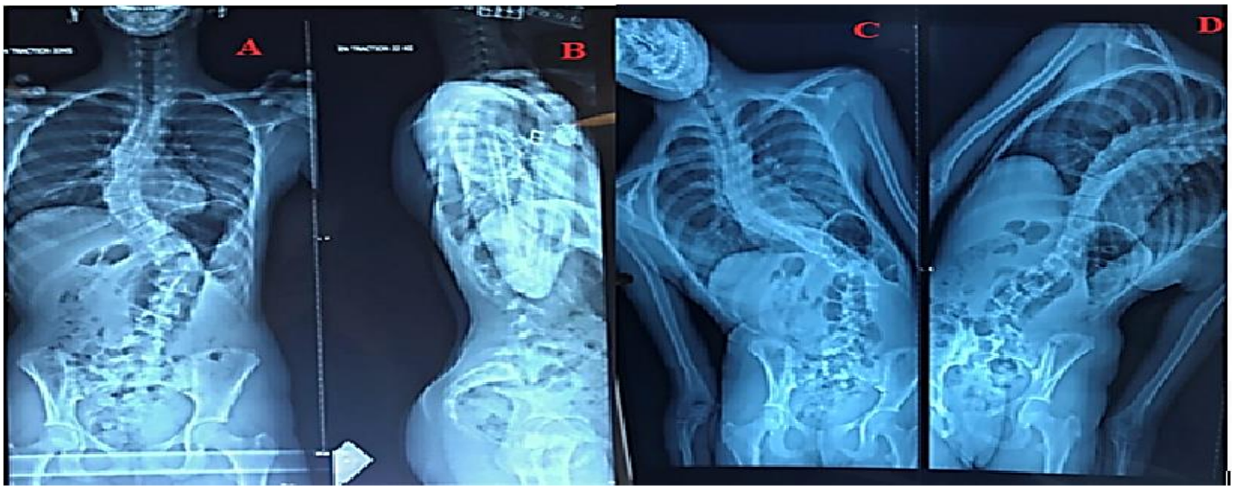

Figure 1. A: Posteroanterior (PA) view; B: Lateral view; C and D: Right and left bending

For standardized radiographic views, the patient is positioned with the feet a shoulder-width apart and knees extended. The distance to the radiation source should be about 183 cm (72 inches). PA views minimize the radiation to the breast (4). The patient flexes the elbows for the lateral view, places the hands over the clavicles, and looks straight ahead. Sideward-bending views are obtained upright, with the patient leaning maximally to one side or the other (7).

Step 2

How to Distinguish Radiographic Landmarks in Scoliosis Plane Radiography?

2.1. Apical Vertebra: The vertebra or disk with the greatest rotation or farthest deviation is the apical vertebra. It is generally found at the curve's apex (Figure 2) (8).

2.2. End or Terminal Vertebra: The vertebrae with the maximal tilt toward the apex of the curve are the end vertebrae (EV), and they are used to measure the Cobb angle (Figure 2) (8).

2*.3. The Neutral Vertebra (NV):* The NV are the vertebrae that show no evidence of rotation on PA radiographs; their pedicles are in the standard, symmetric position. The NV may be at the same level as the EV or above or below the curve but are never nearer to the apex than the EV (Figure 2) (8).

2.4. The Central Sacral Vertical Line (CSVL): The line which is vertically drawn across the top of iliac crests and passes through the center of the sacrum on the radiographs is called as CSVL (Figure 2) (8).

2*.5. The Plumb Line:* The plumb line is a vertical line drawn from the center of the C7 vertebral body (Figure 2) (8).

2.6. Stable Vertebrae: Stable vertebrae are the vertebrae that CSVL bisected or nearly bisected at the below level of the EV of the distal curve (Figure 2) (8).

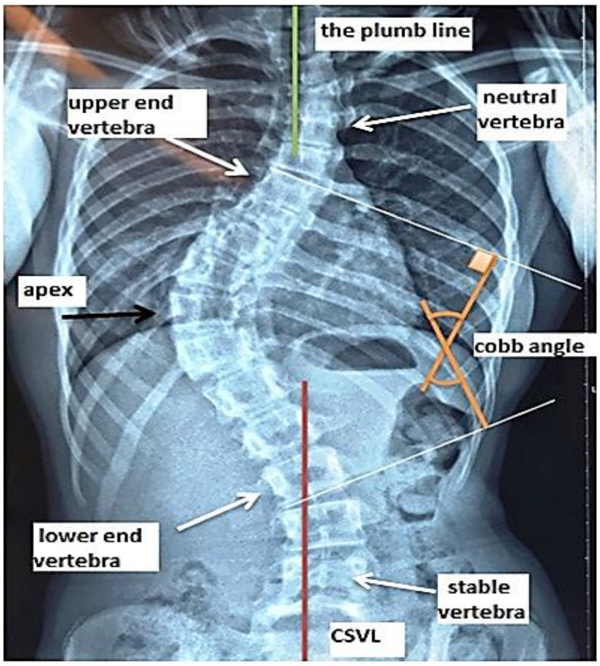

Figure 2. Whole spinal posteroanterior (PA) radiograph of a patient with adolescent idiopathic scoliosis (AIS)

Step 3

How to Define Scoliosis Curves?

3.1. Cobb Angle: The Cobb angle of a scoliotic curve is the maximal angle formed by the junction of two lines, one is the superior endplate of the superior EV, and another is the inferior endplate of the inferior EV. First, We have to keep in mind that there is a diurnal variation of Cobb angle about 5 degrees, especially in the afternoon (9). Second, because of vertebral rotation associated with scoliosis, we have a problem in the positioning of patients, and the actual Cobb angle can be greater than 20 degrees than that plotted at radiographs (10). The patient's position at follow-up imaging must be similar to the initial radiography. Cobb angle decreases in prone position because of that loss of correction can occur after standing up position. A total error of 2°-7° in Cobb angle evaluation has been reported due to variations in radiographic acquisitions and measurement error (7).

3.2. Structural and Non-Structural Curves: We need sideward-bending radiographs to identify if a curve is structural or non-structural. Because of the axial rotation and morphologic changes, a structural curve is inflexible and fails to reduce less than 25 degrees in sideward-bending (Figure 3) (11).

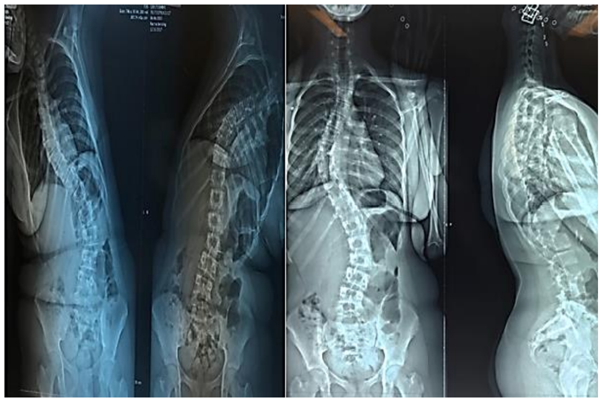

Figure 3. A patient with structural curve

But a flexible, non-structural curve corrects in a sideward-bending position (Figure 4). Non-structural curves are present to compensate for and maintain the truncal balance. Over time, by shortening the ligaments, muscle atrophy, and bony changes, a non-structural curve may progress to a structural curve.

Figure 4. A patient with non-structural curve

Step 4

How to Classify AIS Curves?

4.1. Lenke Classification: Lenke et al. redefined curves with a new classification system to simplify surgical decision-makings (Table 1) (11, 12).

Table 1. Lenke classification

Curve type	PT	MT	TL/L	Description
1	Non-structural	Structural (major)	Non-structural	MT
2	Structural	Structural (major)	Non-structural	DT
3	Non-structural	Structural (major)	Structural	DM
4	Structural	Structural	Structural	TM
5	Non-structural	Non-structural	Structural (major)	TL/L
6	Non-structural	Structural	Structural (major)	TL/L structural MT

PT: Proximal thoracic; MT: Main thoracic; TL/L: Thoracolumbar/lumbar; DT: Double thoracic; DM: Double major; TM: Triple major

We need PA view, lateral view, and right and left sideward bending of the spine radiographs for this two-dimensional classification. It consists of six curve types based on the three regions in the spine column and whether it is a structural or non-structural curve.

Three regions in Lenke classification include:

1. Proximal thoracic (PT): with the apex between T1 and T3
2. Main thoracic (MT): with the apex between T3 and T12
3. Thoracolumbar/lumbar (TL/L): with the apex between T12 and L4

Major curves are always structural, but structural curves are not always major.

Then, these six curves are subdivided ("modified") to A, B, C grading according to the position of the apical vertebrae of the lumbar spine from CSVL. If CSVL lies between the pedicles, lumbar modifier "A" is assigned, if CSVL touches pedicles, lumbar modifier "B" is set, and if CSVL lies medial to the pedicles, lumbar modifier "C" is defined (Table 2) (12).

Table 2. Lenke classification, modifiers

Lumbar spine modifier	CSVL to lumbar apex
A	CSVL between pedicles
B	CSVL touches apical body
C	CSVL completely medial
Sagittal thoracic modifier	
"-" (hypo)	< 10°
"N" (normal)	10°-40°
"+" (hyper)	> 40°

CSVL: Central sacral vertical line

The other modifier is the sagittal profile of the thoracic spine (T5-T12). The normal kyphotic angle is 10°-40°, and if the kyphotic angle is between 10°-40°, the modifier "N" is assigned, if the kyphotic angle is less than 10°, the modifier "-" is given, if the kyphotic angle is greater than 40°, the modifier "+" is defined (Table 3) (11, 12).

Table 3. Suk classification

Thoracic		Lumbar	
A	**B**	**A**	**B**
NV = EV + 1	NV = EV + 3	Crossing CSVL, rotation < G2	Not crossing, rotation > G2
Fused to NV	Fused to NV - 1	Fused to L3	Fused to L4

NV: Neutral vertebra; EV: End vertebra; CSVL: Central sacral vertical line

There are some examples to illustrate this classification (Figure 5).

Step 5

How to Decide between Non-Operative and Operative Management in AIS?

Treatment of AIS can be non-surgical or surgical. Curves less than 15 degrees usually do not need active treatment and can be followed. Patients with moderate curves between 25 to 45 degrees without skeletal maturity used to be treated with bracing. Although much controversy surrounds using bracing, trends in the last 20 years have moved toward no bracing or bracing only significant curves (6, 13, 14).

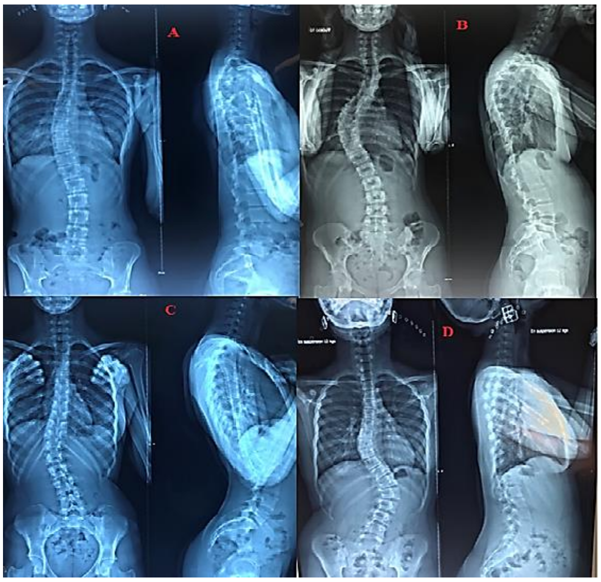

Figure 5. A: An 8-year-old girl with Lenke type 1 adolescent idiopathic scoliosis (AIS); B: A 21-year-old girl with Lenke type 2 scoliosis; C: A 15-year-old girl with Lenke type 5, posteroanterior (PA) and lateral views; D: A 13-year-old girl with Lenke type 6 AIS

In patients with curves exceeding 45 or 50 degrees, surgical treatment is indicated. Moreover, curves with progression even after skeletal maturity or large curves that cause loss of pulmonary function (15) or respiratory failure need surgery. Besides, larger curves are harder to correct. Sometimes patients prefer to straighten their spine with surgery, especially in the borderline degrees (40-45 degrees) (16).

5.1. Surgical Correction: Surgical decision and approach, choosing appropriate technique, fusion level, and hardware options are always challenging for spine surgeons. There are two different approaches to AIS surgical treatment: selective or non-selective fusions (17). Studies show that patients suffer from rigidity in their spine, lower back pain, and degenerative disc disease in previous surgery techniques in long-term follow-up. Nowadays, selective fusion has developed to reduce these problems by minimizing the fused segments (18).

Step 6

How to Decide between Selective and Non-Selective Fusion?

The selective fusion method is based on leaving a small flexible curve to save the motion, instead of a rigid and straight spine (17). There is no definite guideline for surgical decision-making; we try to sum up the evidence to help surgeons in the surgical approach. Lenke et al. presented a new classification system to determine selecting fusion levels (11). The first step is identifying the major and structural curves. The major curves must be included in the fusion surgery, but including non-structural curves in the fusion differs individually. Up to 70% of non-structural curves are corrected spontaneously following structural curve correction.

6.1. Suk Classification: Pedicle screw instrumentation is a surgical technique for patients with AIS that preserves more motion segments and proposes three-dimensional correction of the spine deformity (19-21). Pedicle screws are inserted in the concave side which is the correction side and every two or three vertebrae on the convex side which is called supportive side. An over-bent rod is inserted on the correction side then rotated 90 degrees counterclockwise. The coronal and sagittal curves will be corrected with this maneuver. Vertebral rotation deformity is corrected with direct vertebral rotation (DVR) opposite to the vertebra's rotation (22).

The important step in this method is to determine the right and exact fusion level and vertebra to prevent complications. Suk et al. introduced a simple classification with only four curve patterns: single thoracic, double thoracic, double major, and TL/L curves. Then each curve has two types (A or B) (22).

Single thoracic curve is defined as a thoracic curve of more than 40 degrees without any lumbar curve more than 40 degrees. If there is a lumbar curve more than 40°, the thoracic curve must be more than five degrees larger.

It is important to determine whether the proximal curve needs fusing or not in double thoracic curves. Double thoracic curves, needing both curve fusion, consist of two proximal and distal curves. The proximal curve must be more than 30 degrees, and the distal one must be more than 40 degrees. In addition, level or left elevated shoulder and T1 tilted with double thoracic curve should be treated by fusing both curves.

There are two types of A and B curves defined by the relation between NV and EV for thoracic curves. If NV and EV are the same or one-level gap difference, it is type A. For type A curves in both single or double thoracic curves, fusion could stop at EV (when NV = EV) or could be down to the NV (when NV = EV + 1). If the NV is located two or three vertebrae distally to the EV, it is type B curve.

When the lumbar curve (> 40 degrees) is larger than the thoracic curve (> 30 degrees) or the thoracic curve is less than five degrees larger than the lumbar curve, it is called the double major curve in Suk classification. If the apical vertebra rotation of the lumbar curve is more than grade two, both thoracic and lumbar curves have to be fused.

The definition of TL/L curve in Suk classification is when the lumbar curve is more than 40 degrees but the thoracic curve is less than 30 degrees.

A and B types for the lumbar curves depend on two factors in right and left bending views (Table 3). The first is the position of the L3 and CSVL in the right bending radiograph, and the second is L3 rotation grading in the left bending (Figure 6). Type A curve is specified when L3 crosses CSVL and its rotation is less than grade two. It must be fused to the EV, which is L3. Type B is when L3 does not cross the line in right bending and has more than grade two rotation according to Nash-Moe method. Distal fusion in type B has to be EV + 1 which is L4 (22).

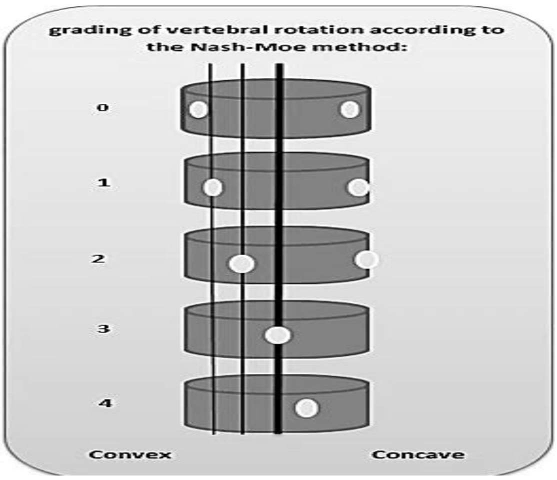

Figure 6. Vertebral rotation grading

There is an example for Suk classification and its management according to it (Figure 7).

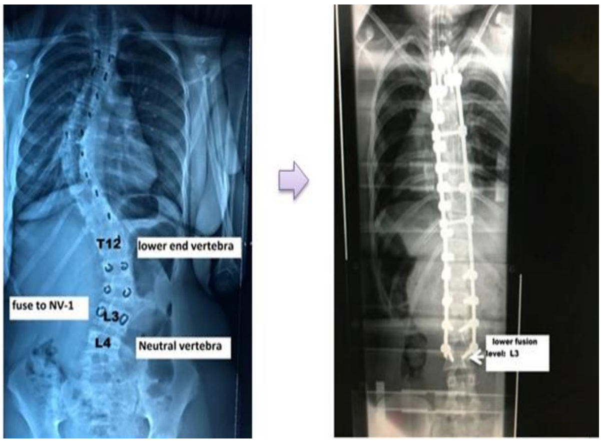

Figure 7. A 20-year-old girl with thoracic adolescent idiopathic scoliosis (AIS), type B, in which the neutral vertebra (NV) (L4) is located at the end vertebra (EV) (T12) + 3. The distal fusion level is the NV - 1 (L3)

Step 7

How to Select Upper Instrumented Vertebra (UIV) and Lower Instrumented Vertebra (LIV)?

According to the latest reviews about fusion levels, we defined patients as selective thoracic fusion (STF) for thoracic curves and selective TL/L fusion for thoracolumbar and lumbar curves (18). The surgeon has to determine two fusion levels: upper instrumented and lower instrumented levels.

7.1. STF

7.1.1. UIV: Motion is not an important factor for choosing the fusion level in the thoracic spine, because the rib cage and sternum are rigid and do not have so much mobility. The limiting element in the thoracic spine is the shoulder balance. Many studies discussed how to determine appropriate UIV in STF, and there is no specific guideline. Some studies recommended that PT curve fusion was unnecessary in all double curves (23, 24). A review article evaluated 26 articles and summarized the most common approaches (18). In conclusion, if the PT curve is structural, we notice the shoulder position preoperatively. UIV is T2 for left shoulder elevation, T3 for level shoulders, and T4 for right shoulder elevation. If the PT is non-structural, we can use the following formula: upper EV (UEV) of the major curve + 2 (2 vertebrae proximal) for left shoulder elevation, UEV + 1 vertebra proximal for level shoulders, and UEV for right shoulder elevation.

7.1.2. LIV: Selecting the right LIV is vital to prevent adding-on phenomenon and distal junctional kyphosis (DJK) (18). Besides, it is accepted that the fusion area should be as short as possible. Many studies suggested different approaches. Earlier, they recommended an end-to-end vertebrae fusion (upper end and lower end). With developing the instrumentation methods especially after starting using pedicle screws, several authors discussed that which vertebra could be LIV. Trobisch et al. reviewed articles, classified them according to the Lenke system, and reported that selecting LIV in Lenke 1 and 2 depended on lumbar modifiers (17). For modifier A curves, LIV is the vertebra touching the CSVL, and in modifiers B and C, LIV is the thoracolumbar stable vertebra. Surgeons also offer that LIV could be the last substantially touched vertebra by CSVL (25-27). So many studies have been conducted to determine appropriate LIV for thoracic curves, but there are many controversies and there is no consensus about it yet.

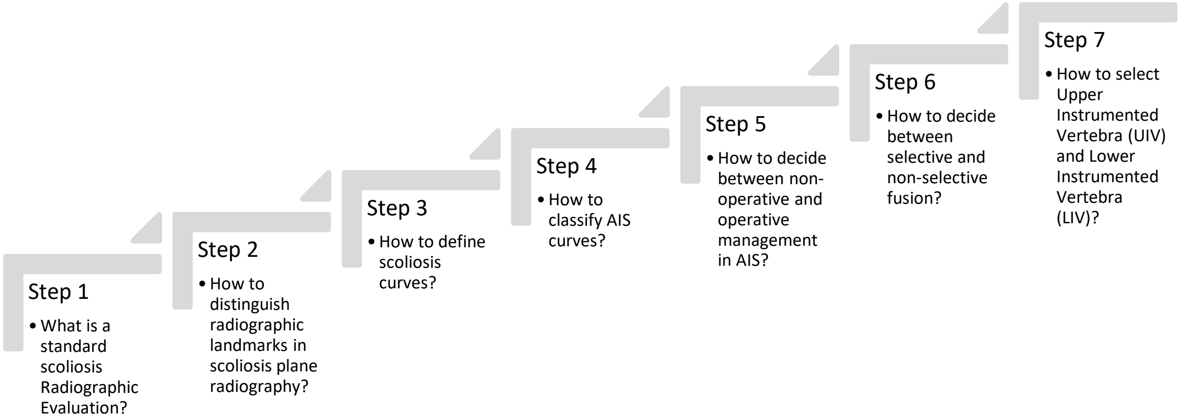

Figure 8. Step by Step approach for preoperative planning of scoliosis

7.2. Selective TL/L Fusion

7.2.1. UIV: Several studies selected UEV as the UIV in lumbar curves (28-30). A review article by Trobisch et al. recommended UEV as the UIV, but it should not be at the apex of the thoracic kyphosis (17). The latest studies mentioned that UIV should be one level caudal to UEV in Lenke type C curves (TL/L curves). Further studies showed no clinical and radiological difference if UIV was UEV or one level caudal to UEV. In summary, according to the shorter fusion strategy, using a level caudal to UEV can be an alternative besides using UEV.

7.2.2. LIV: Shorter fusion strategy in patients with TL/L curve leads to decreased risk of degenerative disc disease and low back pain in the future (18). Most of the studies proposed that LIV should be stopped at L3, and preserving one more mobile segment might be helpful for long-term prognosis.

Eventually, further comparative studies and long-term follow-up studies are required to establish a definite guideline. At last, surgeons should individualize the selection of the fusion levels to achieve the best results for each patient.

In summary, first, we should know the definition of AIS. Examination and imaging are the main tools for diagnosis. Radiography is a simple and valuable tool to diagnose and evaluate curvatures. The surgeon can assess the curves and landmarks using standard radiographs and then decide for operative or non-operative management. Lenke classification is one of the most practical classifications that are used for surgical decision-making. The most critical step for pre-surgical planning is analyzing the spine and determining which vertebra should be fused (Figure 8). There are two approaches for surgery: selective and non-selective fusion. Based on the level of curves, selective fusion can be at thoracic or lumbar spine or both.

There are two approaches for surgery: selective and non-selective fusion. Based on the level of curves, selective fusion can be at thoracic or lumbar spine or both (Figures 9 and 10).

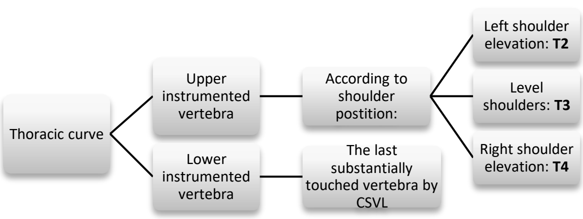

Figure 9. Recommended fusion levels for thorasic curves

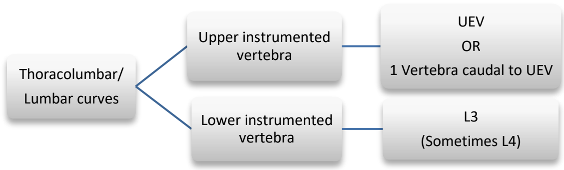

Figure 10. Recommended fusion levels for thoracolumbar/lumbar (TL/L) curves
Lumbar modifier photo: https://hsg.settingscoliosisstraight.org/lenke-calculator/lumbar-modifier/

Conflict of Interest

The authors declare no conflict of interest in this study.

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