

Radiological Evaluation of Spine Deformity in Scoliosis: A Comprehensive Review of Imaging Parameters and Diagnostic Modalities

Mahmoud Mohamed Mahrous Shamloul¹, Mahmoud MostafaTaha¹, Wael Abd Elrahman Elmesallamy¹, Mohamed Salah Mohamed¹

¹Neurosurgery Department, Faculty of Medicine, Zagazig University, Egypt

*Corresponding author:

Mahmoud Mohamed Mahrous Shamloul

Cite this paper as: Mahmoud Mohamed Mahrous Shamloul, Mahmoud MostafaTaha, Wael Abd Elrahman Elmesallamy, Mohamed Salah Mohamed (2024) Radiological Evaluation of Spine Deformity in Scoliosis: A Comprehensive Review of Imaging Parameters and Diagnostic Modalities..Journal of Neonatal Surgery, 13, 2362-2370

ABSTRACT

Background: Scoliosis is a complex three-dimensional spinal deformity that requires accurate radiological assessment for proper diagnosis, classification, treatment planning, and follow-up. Radiological evaluation plays a pivotal role in identifying curve characteristics, vertebral rotation, spinal balance, skeletal maturity, and associated abnormalities. Conventional radiography remains the cornerstone of scoliosis assessment, particularly through measurement of the Cobb angle and evaluation of coronal and sagittal alignment. Additional imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI) provide valuable information in selected cases, especially in patients with congenital anomalies, atypical curve patterns, neurologic manifestations, or preoperative planning. This review discusses the principal radiological parameters used in scoliosis evaluation, including identification of the apex, end vertebrae, stable vertebrae, vertebral rotation, structural versus nonstructural curves, shoulder balance, and skeletal maturity assessment. The indications and roles of advanced cross-sectional imaging techniques are also highlighted.

Keywords: *Scoliosis; Radiological evaluation; Cobb angle; Vertebral rotation; MRI; CT; Spinal deformity; Risser index; Coronal balance; Sagittal balance*

INTRODUCTION

Identification of the Apex and Significant Vertebrae Identification of the curve apex and significant vertebrae is crucial for denoting the curve type, selecting the surgical approach and instrumentation system, and determining the optimal level for fusion (1).

Clear understanding of definitions is mandatory. The apex is the vertebra or disk with the greatest rotation or farthest deviation from the center of the vertebral column. End vertebrae are those with the maximal tilt toward the apex of the curve, and they are used to measure the Cobb angle.

Neutral vertebrae are those that show no evidence of rotation on standing frontal (either posteroanterior [PA] or anteroposterior [AP]) radiographs; their pedicles are in the normal, symmetric positions (2)

Neutral vertebrae may be at the same levels as end vertebrae, either above (proximal to) or below (distal to) the curve, but are never nearer to the apex than end vertebrae are.(2)

Stable vertebrae are the vertebrae farthest cephalad that are bisected or nearly bisected by the central sacral vertical line (CSVL) at a level below the end vertebra of the distal curve (Figure 1) (3).

The CSVL is a roughly vertical line that is drawn perpendicular to an imaginary tangential line drawn across the top of the iliac crests on radiographs. It bisects the sacrum (4)

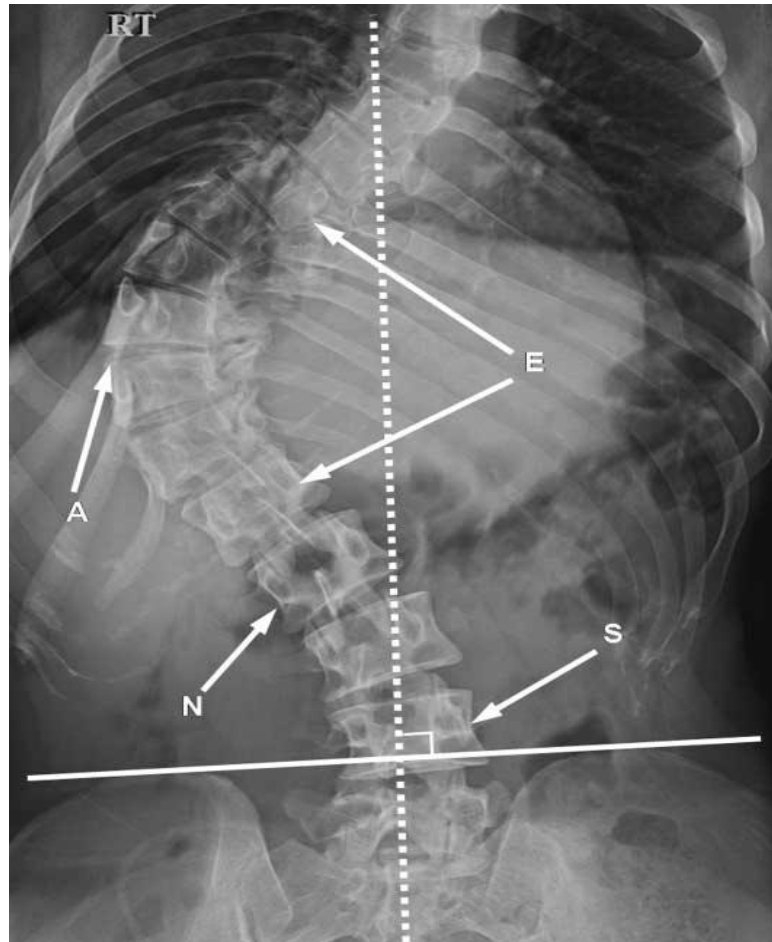


Figure 1 Diagram superimposed on a standing AP radiograph from a patient with scoliosis shows the significant components of the abnormal curvature: The end vertebrae (E) are those most tilted, and the apex (A) is the disk or vertebra deviated farthest from the center of the vertebral column. A neutral vertebra (N) is one that is not rotated, and a stable vertebra (S) is one that is bisected or nearly bisected by the CSVL (dotted line), which is exactly perpendicular to a tangent drawn across the iliac crests (solid line)

Measurement of the Cobb Angle and Its Pitfalls

The Cobb angle of a scoliotic curve is the angle formed by the intersection of two lines, one parallel to the endplate of the superior end vertebra and the other parallel to the endplate of the inferior end vertebra (**Figure 2a**) (5)

The angle may be plotted manually or digitally. Digital Cobb angle measurements obtained by using a software program at the workstation of a picture archiving and communication system were reported to be comparable to manual measurements on radiographs, a finding suggestive of equal reliability of the two measurement methods (**Figure 2**) (6)

When incorporating measurement of the Cobb angle into routine clinical assessments of curvature, especially in monitoring for progression, the following caveats should be kept in mind:

First, a diurnal variation of 5° has been observed in Cobb angle measurements of the same curve over the course of a single day (6).

Second, because of the vertebral rotation associated with scoliosis, it may be difficult to position the patient so as to obtain an accurate frontal view, and the actual Cobb angle might be 20% greater than that plotted on radiographs.

Third, surgeons have reported that a Cobb angle decrease due to prone positioning and anesthesia during surgery (7)

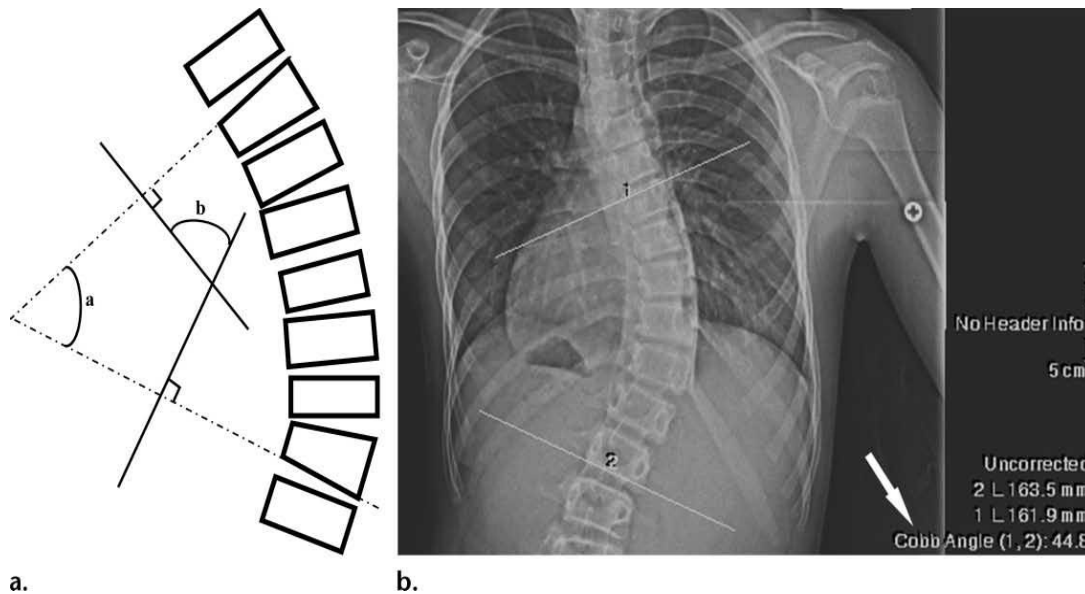
Fourth, a total error of 2° – 7° in Cobb angle assessment has been reported to result from variations in radiographic acquisitions and measurement error (7).

Fifth, intra observer variation by 5° – 10° in Cobb angle measurement has been reported, and the inter observer variation is even greater(8).

Identification of Primary and Secondary Curves

Major curves, also called primary curves, are the largest abnormal curves in the scoliotic spine and the first to develop (9).

Minor curves, also called secondary curves, are smaller and are considered to develop afterward, to compensate for the perturbation of balance that accompanies the progression of major curves by repositioning the head and trunk over the pelvis to maintain balance (9).



The terms major curve and minor curve are sometimes used as synonyms for structural curve and nonstructural curve, respectively, although the definitions of these entities do not correspond exactly because of vertebral morphologic changes

Figure 1 Diagram demonstrates measurement of the Cobb angle. First, tangents (dashed-dotted lines) are drawn along the superior endplate of the superior end vertebra and the inferior endplate of the inferior end vertebra. If the endplates are not reliably visualized, the borders of the pedicles are used instead. The Cobb angle is defined either as the angle between the tangential lines (angle a) or the angle between two lines drawn perpendicular (solid lines) to the tangents (angle b). When correctly measured, the two angles are identical. (b) Screen capture from a picture archiving and communication system workstation shows the use of interactive software to calculate the Cobb angle (arrow) from two tangents drawn on a spinal radiograph.

(e.g, wedging and rotation), a structural curve is not correctable with ipsilateral bending (9).

By contrast, no vertebral morphologic changes take place in a nonstructural curve, which is a mild compensatory curve enabling sagittal and coronal truncal balance; therefore, it is correctable with ipsilateral bending (10).

Differentiation between structural and non-structural curves is important when selecting the appropriate level for fusion. Although some sources express reservations about the best method for determining whether a curve is structural or non-structural, a structural curve may be reliably defined as one with a Cobb angle of 25° or more on ipsilateral side-bending radiographic views (Figure 3) (10).



Figure 2 Structural and nonstructural curves in a 14-year-old girl with scoliosis. (a) Neutral standing AP radiograph shows dextroscoliosis at the upper thoracic level (b) Rightward- bending view shows a Cobb angle of 32° (>25°) for the right-sided curve at the upper thoracic level, a finding indicative of a structural curve. (c) Leftward-bending view shows a Cobb angle of 15° (<25°) for the left-sided curve at the thoracolumbar level, a finding indicative of a nonstructural curve

The plumb line is a vertical line drawn downward from the center of the C7 vertebral body, parallel to the lateral edges of the radiograph. It is used to evaluate coronal balance on standing frontal radiographs and sagittal balance on standing lateral radiographs. Coronal balance is evaluated by measuring the distance between the CSVL and the plumb line, and sagittal balance is evaluated by measuring the distance between the posterosuperior aspect of the S1 vertebral body and the plumb line (11)

For both coronal and sagittal measurements, balance is considered abnormal if the distance is greater than 2 cm (Figure 4). For measurements of coronal balance, a plumb line located to the right of the CSVL is considered to reflect positive coronal balance, whereas a plumb line located to the left of the CSVL is considered to reflect negative coronal balance (11)



Figure 3 Measurement of coronal and sagittal alignment of vertebrae on neutral standing radiographs obtained in an 11-year-old girl

Measurement of Vertebral Rotation

The advent of modern instrumentation systems led to a marked increase in the importance of measuring vertebral rotation in the scoliotic spine (12)

The shortcomings of the Cobb angle for describing vertebral rotation are partly overcome by the so-called Nash-Moe method, in which the pedicle location on frontal radiographs is used as an indicator of the extent of vertebral rotation. With the Nash-Moe method, the half vertebra on the convex side of curvature is divided into three segments, and rotation is quantified on the basis of the pedicle location in regard to the segments (Figure 5) (13)

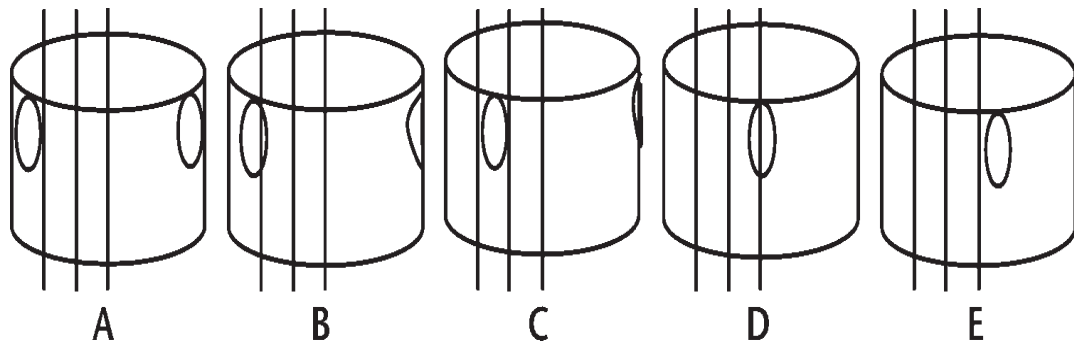


Figure 4 Diagrams show the grading of vertebral rotation according to the Nash-Moe method: A, neutral position (no rotation); B, grade 1; C, grade 2; D, grade 3; and E, grade 4

To estimate the stage of skeletal maturity, the ossification center of the iliac crest is usually assessed radiographically by using the Risser index. Grades 0 through 5 describe the extent of apophyseal ossification, which commences laterally and extends medially (Figure 6) (14)

Complete excursion of the ossified apophysis takes approximately 1 year, and fusion of the ossification center to the iliac crest takes another 2 years

Risser grade 4, which signifies complete excursion of the ossified apophysis of the iliac crest, has been considered to denote the completion of spinal growth and cessation of curve progression in girls (14)

However, the use of Risser grade 4 as an indicator of arrested progression has been criticized. Furthermore, grading of skeletal maturity according to the Risser index is far less reliable in boys, in whom ossification starts at a later age than it does in girls; in boys, growth cannot be considered complete until Risser grade 5 ossification is achieved (14)

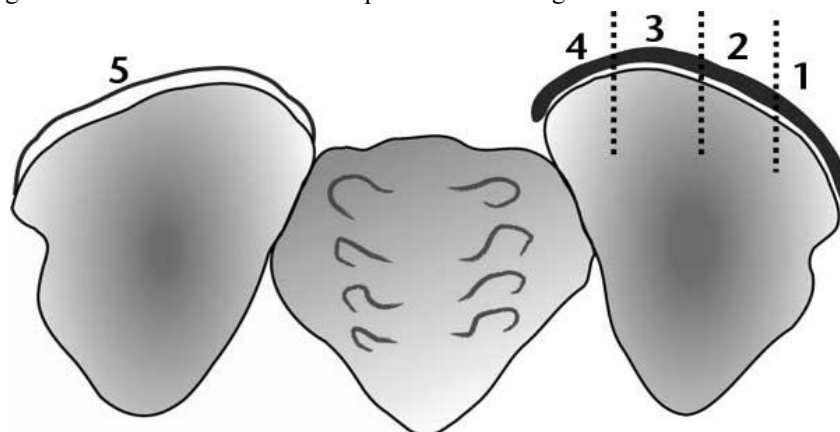


Figure 5 Diagram shows the anatomic appearances that correspond to grades of visible skeletal maturity as defined by the Risser index

Assessment of shoulder balance

It is estimated clinically by comparing the highest point of the Acromion on both shoulders. Radiologically shoulder balance can be assessed as shown in (Figure 7) (15)

A. Clavicle rib cage intersection: (CR1D) The clavicle intersect the outer face of the rib cage to a variable height. At this point, the horizontal line can be marked and the difference between the right and left shoulder can be measured.

B. T1 tilt angle: is measured by the intersection of a line drawn along the T1 cephalad endplate and a line parallel to the horizontal reference line

C. The clavicle angle is measured by the intersection of a line touching the two highest points of the clavicle and a line

parallel to the horizontal reference line

D. The radiographic shoulder height is determined by the difference in the soft tissue shadow directly superior to each acromioclavicular joint on a standing poster anterior radiograph (15)

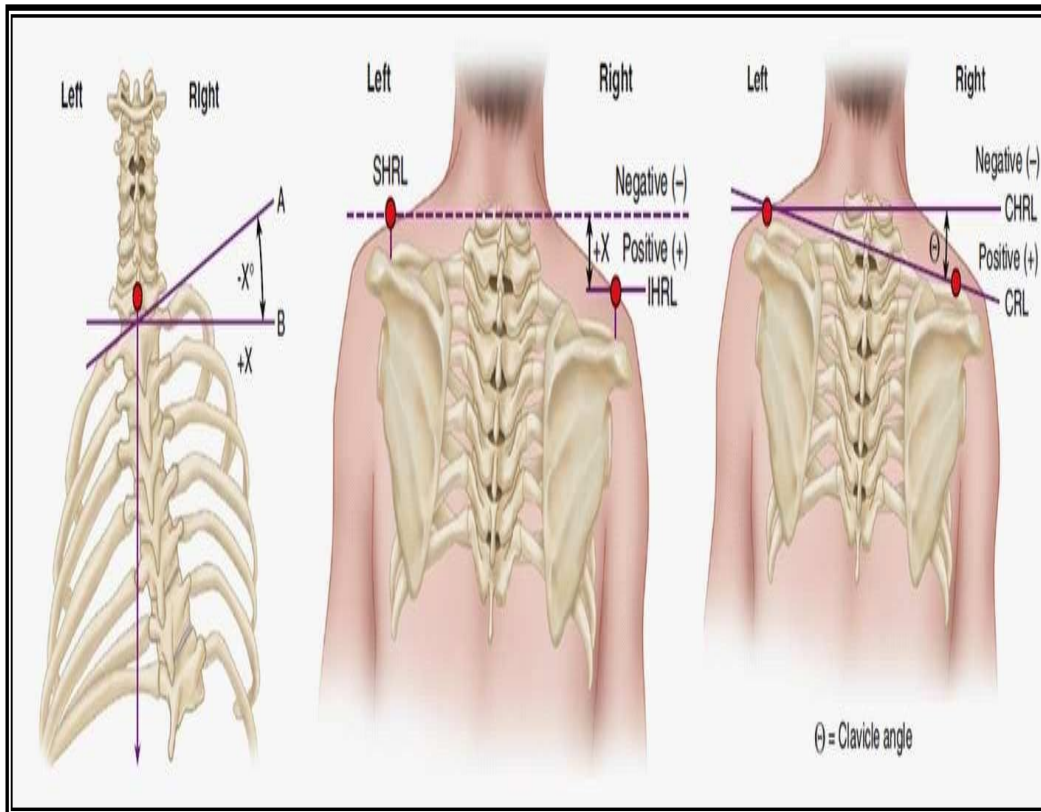


Figure 6 (A) T1 tilt: When right edge of vertebral body is up, tilt angle is defined as negative. When left edge of vertebral body is up, tilt angle is defined as positive. (B) Radiographic shoulder height. IHRL, Inferior horizontal reference line; SHRL, superior horizontal reference line. (C) Clavicular angle. CHRL, Clavicle horizontal reference line; CRL, clavicle reference line

Use of Cross- sectional Imaging Modalities

When to Use CT and MR Imaging

The main purpose of performing CT or MR imaging in a patient with scoliosis is to identify an underlying cause. In addition, the cross-sectional imaging modalities are useful for guiding surgical treatment and evaluating postoperative complications(16)

Radiography is the method of choice for the initial diagnostic imaging evaluation; it is sufficient to exclude most congenital and developmental osseous anomalies, which account for most cases of scoliosis with an underlying pathologic origin (16)

It is noteworthy that congenital and developmental osseous causes tend to produce curvatures that affect a relatively short segment of the spine on radiographs(17)

Neurofibromatosis with dystrophic curvature, although it is uncommon, also may produce a short-segment curve. In cases with a complex osseous deformity, radiography alone is inadequate and the use of CT is mandatory, especially when surgery is planned (17)

MR imaging is used with increasing frequency to evaluate patients with an unusual curve pattern or alarming clinical manifestations (Tables 1, 2)

Table 1 Main Indications for Further Imaging in Patients with Radiographic Findings of Scoliosis
Congenital osseous abnormality (fusion and segmentation anomaly)
Congenital neuropathic abnormality (Arnold- Chiari malformation , tethered cord , dysraphism- related abnormality)
Dysplasia (neurofibromatosis, osteogenesis imperfecta, Marfan syndrome)
Pain suggestive of bone tumor , infection ,or intervertebral disk herniation
Neurologic deterioration with abnormality at electro neurography or evoked electromyography
Pre-operative evaluation of osseous abnormality
Presumed post-operative complication
Idiopathic curvature of spine with specific clinical or radiographic features listed in Table 1

Table2 Indications for MR Imaging in a Patient with Presumed Idiopathic Scoliosis
Clinical features
Age<10years
Signs of neurologic deterioration
Rapid progression
Foot deformity
Back pain , neck pain , headache
Radiographic features
Curve type commonly associated with neuropathy (left thoracic, double thoracic, triple major, short-segment, or long right thoracic curve; severe curvature after skeletal maturity)
Wide spinal canal, thin pedicle, wide neural foramina ,or other features suggestive of a non-osseous lesion

REFERENCES

1. Fatima, J., et al. (2021). "Spinal vertebrae localization and analysis on disproportionality in curvature using radiography—a comprehensive review." EURASIP Journal on Image and Video Processing 2021(1): 23.
2. Roussouly, P. (2019). The standing position: Its principles and spinopelvic relations. Spinal Anatomy: Modern

Concepts, Springer: 113-125.

3. Dubousset, J. (2019). The pelvic vertebra, the cephalic vertebra and the concept of the chain of balance. *Spinal Anatomy: Modern Concepts*, Springer: 171-187.
4. Ross, J. S. and K. R. Moore (2025). *Diagnostic Imaging: Spine-E-Book*, Elsevier Health Sciences.
5. Wang, J., et al. (2018). "Measurement of scoliosis Cobb angle by end vertebra tilt angle method." *Journal of orthopaedic surgery and research* 13(1): 223.
6. Hardesty, C. K., et al. (2013). "Interobserver variability using a commercially available system of archived digital radiography with integrated computer-assisted measurements for scoliosis Cobb angles." *Journal of Pediatric Orthopaedics* 33(2): 163-169.
7. Giannoglou, V. and E. Stylianidis (2016). "Review of advances in Cobb angle calculation and image-based modelling techniques for spinal deformities." *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 3: 129-135.
8. Prestigiacomio, F., et al. (2022). "Intra-and inter-observer reliability of Cobb angle measurements in patients with adolescent idiopathic scoliosis." *Spine deformity* 10(1): 79-86.
9. Khodaei Jalalabadi, M. (2022). "Development of a Detection Model for Curve Progression in Adolescents with Idiopathic Scoliosis."
10. Patel, P. and A. G. King (2013). *Scoliosis. Spine Surgery Basics*, Springer: 261-286.
11. Negrini, A., et al. (2019). "Spinal coronal and sagittal balance in 584 healthy individuals during growth: normal plumb line values and their correlation with radiographic measurements." *Physical Therapy* 99(12): 1712-1718.
12. Boyer, L., et al. (2018). "Accuracy and precision of seven radiography-based measurement methods of vertebral axial rotation in adolescent idiopathic scoliosis." *Spine deformity* 6(4): 351-357.
13. Kim, J. K., et al. (2025). "Deep learning algorithm for the automatic assessment of axial vertebral rotation in patients with scoliosis using the Nash–Moe method." *Scientific Reports* 15(1): 26647.
14. Costa, L., et al. (2021). "Ossification and fusion of the vertebral ring apophysis as an important part of spinal maturation." *Journal of Clinical Medicine* 10(15): 3217.
15. Namikawa, T., et al. (2015). "Radiological assessment of shoulder balance following posterior spinal fusion for thoracic adolescent idiopathic scoliosis." *Scoliosis* 10(Suppl 2): S18.
16. Ng, S.-Y. and J. Bettany-Saltikov (2017). "Imaging in the diagnosis and monitoring of children with idiopathic scoliosis." *The open orthopaedics journal* 11: 1500.
17. Lacroix, M., et al. (2023). *Scoliosis. Seminars in musculoskeletal radiology*, Thieme Medical Publishers, Inc.