

Spine Deformity

Imaging Evaluation

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Contents

Entity (with Alternative Names and Abbreviations)	2
Scoliosis	2
Kyphosis	2
Clinical Scenario and Indications for Imaging	3
Imaging Technique and Recommended Protocol	3
Spinal Canal and Neural Element Assessment	4
Traumatic and Degenerative Deformities	5
Degenerative Spinal Deformity	5
Interpretation Checklist and Structured Reporting	5
Treatment Monitoring: Follow-Up Scheme and Findings/Pitfalls	6
Spondylolisthesis	6
Imaging Technique and Acquisition	7
Imaging Patterns in Low-Grade Spondylolisthesis	7
References	10

Abstract

Spinal deformities comprise a diverse spectrum of conditions affecting both pediatric and adult patients, with scoliosis, kyphosis, and spondylolisthesis representing the most prevalent disorders. Imaging is fundamental throughout the entire patient pathway, supporting diagnosis, deformity characterization, treatment planning, and postoperative surveillance. This chapter provides a comprehensive overview of the neuroradiological approach to spinal deformity, highlighting the complementary roles of conventional radiography, magnetic resonance imaging (MRI), computed tomography (CT), and low-dose



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biplanar EOS imaging. Emphasis is placed on imaging protocols, quantitative assessment of coronal and sagittal alignment, evaluation of spinopelvic balance, and the principles of structured reporting. The imaging characteristics of adolescent idiopathic, congenital, and degenerative scoliosis, Scheuermann's kyphosis, and spondylolisthesis are reviewed, with particular attention to neural axis abnormalities, spinal canal assessment, and associated intraspinal pathology. The chapter also discusses contemporary concepts of sagittal alignment, radiation dose optimization, and advanced three-dimensional imaging techniques. Through illustrative clinical cases and practical reporting guidance, it highlights the pivotal role of neuroradiology within the multidisciplinary management of spinal deformities, enabling accurate diagnosis, risk stratification, surgical planning, and longitudinal follow-up across all age groups.

Keywords

Scoliosis · Scheuermann kyphosis · Clinical neuroradiology · Spine MRI · Degenerative scoliosis

Entity (with Alternative Names and Abbreviations)

Scoliosis is a structural spinal deformity characterized by lateral curvature, vertebral rotation, and disturbance of sagittal alignment.

Alternative names include *spinal curvature* and *spinal deformity*.

Common abbreviation: **AIS** (adolescent idiopathic scoliosis) and **JIA** (juvenile idiopathic scoliosis).

Kyphosis is a spinal deformity exceeding accepted normal value for age in the sagittal plane. Common examples of this condition are Scheuermann's kyphosis and posttraumatic kyphosis as well as kyphosis associated with coronal imbalance in complex adult scoliosis.

Spondylolisthesis refers to sagittal forward translation of a vertebra upon the underlined one and more rarely to lateral translation of the same.

Scoliosis

Scoliosis is defined radiographically as a lateral spinal curvature exceeding 10° on standing posteroanterior radiographs, measured using the Cobb technique. Although traditionally described as a coronal-plane disorder, scoliosis is now recognized as a complex three-dimensional deformity incorporating coronal deviation, sagittal malalignment, and axial rotation.

Adolescent idiopathic scoliosis represents the most prevalent pediatric spinal deformity, affecting approximately 2–3% of children, with a higher risk of progression in females (Weinstein et al. 2008). Congenital and neuromuscular scoliosis, although less frequent, are associated with higher rates of neurological abnormalities. Congenital scoliosis, linked to defective segmentation during vertebral embryogenesis, frequently coexists with intraspinal anomalies (Menezes 2007).

Adult scoliosis may evolve from untreated AIS or de novo degeneration driven by asymmetric disc collapse, facet hypertrophy, and osteophytosis (Aebi 2005). Sagittal balance, measured by SVA and pelvic parameters, strongly correlates with functional outcome (Vialle et al. 2005).

Anatomically, scoliosis involves asymmetric vertebral growth or degeneration, disc wedging, and axial rotation. These changes disrupt spinal biomechanics, producing compensatory curves and pelvic retroversion. In adults, sagittal malalignment—quantified by parameters such as sagittal vertical axis—is strongly correlated with pain and disability (Glassman et al. 2005).

Kyphosis

Scheuermann's disease (Scheuermann 1921) exemplifies developmental kyphosis caused by anterior vertebral wedging, end-plate irregularity, and Schmorl's nodes. The Hueter-Volkman principle explains progressive deformity—growth inhibition under compression and stimulation under tension. Histologically, irregular cartilage and disc herniation into vertebral bodies generate rigid hyperkyphosis (Lowe and Klineberg 2007).

Clinical Scenario and Indications for Imaging

From a clinical neuroradiology perspective, imaging serves not only to confirm diagnosis but also to identify associated neural axis abnormalities, quantify deformity severity, and guide treatment decisions. Pediatric patients are often asymptomatic, whereas adults commonly present with pain, neurological symptoms, and functional impairment related to degenerative changes and sagittal imbalance (Aebi 2005; Glassman et al. 2005).

Imaging is indicated at initial diagnosis, during follow-up to assess progression, prior to intervention, and posttreatment. In pediatric scoliosis, MRI is recommended for early-onset scoliosis, atypical curve patterns (e.g., left thoracic curves), rapid progression, or neurological symptoms to exclude syringomyelia or tethered cord (Menezes 2007).

Adult indications include chronic back pain, radiculopathy, and sagittal imbalance secondary to degenerative scoliosis (Aebi 2005). In Scheuermann's kyphosis, imaging quantifies angular deformity ($>45^\circ$ kyphosis with $\geq 5^\circ$ wedging in three consecutive vertebrae) and monitors for progression (Lowe and Klineberg 2007).

Imaging Technique and Recommended Protocol

Plain Radiography

Standing full-length posteroanterior and lateral radiographs including the pelvis are mandatory. Consistent positioning is essential for longitudinal comparison. Low-dose acquisition should be used whenever available (Vialle et al. 2005, Dubousset et al. 2013).

Radiographs remain the **first-line imaging tool** for spinal deformity assessment.

Key neuroradiologic roles:

- Measurement of **Cobb angle** (coronal deformity)
- Evaluation of **global sagittal balance**
- Detection of vertebral anomalies and alignment changes

Standard views include the following:

- Standing PA and lateral full-spine radiographs
- Flexion-extension views (for suspected instability)
- Supine AP side bending full-spine radiographs to evaluate structural vs nonstructural curves and determine cranial and caudal levels of surgical fusion.

Limitations:

- Poor visualization of neural elements
- Limited assessment of spinal canal compromise

Magnetic Resonance Imaging

Whole-spine MRI is recommended in pediatric patients with red flags and in adults with neurological symptoms. MRI is the modality of choice for detecting syringomyelia, tethered cord, or degenerative stenosis. Sagittal T1/T2 imaging of the full spine with axial cuts through the apex is recommended. In Scheuermann's disease, MRI reveals end-plate irregularity and marrow changes corresponding to Schmorl's nodes.

MRI is the cornerstone of neuroradiological evaluation in spine deformity.

Primary roles:

- Assessment of spinal cord and nerve roots
- Evaluation of disc degeneration and ligamentous structures
- Detection of intramedullary signal abnormalities

Key MRI sequences:

- T1-weighted: anatomy and marrow changes
- T2-weighted: cord compression and myelopathy
- STIR: edema and inflammation
- Gradient echo: hemorrhage
- Contrast-enhanced studies: tumors, infection, and postoperative scarring

MRI is mandatory in:

- Congenital scoliosis
- Rapidly progressive deformity

- Neurological deficits
- Pediatric deformities (to exclude intraspinal anomalies)

MRI is crucial to exclude **intraspinal pathology**, especially in:

- Left thoracic scoliosis
- Early-onset scoliosis
- Rapid curve progression

Common associated findings:

- Syringomyelia
- Tethered cord
- Chiari malformation
- Diastematomyelia

Neuroradiologists must assess:

- Cord position within the canal
- Cord deformation at the apex
- Signal changes suggesting chronic compression

Computed Tomography Imaging

CT is reserved for detailed assessment of osseous anatomy in congenital scoliosis, complex deformities, and postoperative evaluation. Dose optimization is mandatory, particularly in younger patients. CT defines vertebral rotation and bony morphology for preoperative planning. Aid in screw trajectory assessment while maintaining radiation optimization (Aebi 2005).

CT provides high-resolution evaluation of bony anatomy, making it essential in:

- Congenital deformities (hemivertebrae, segmentation failure)
- Post-traumatic deformities
- Pre-operative planning

Neuroradiological advantages:

- Accurate depiction of spinal canal dimensions
- Detection of retropulsed fracture fragments
- Pedicle morphology assessment for instrumentation planning

Three-dimensional CT reconstructions are particularly valuable for preoperative planning providing detailed visualization of vertebral morphology, pedicle anatomy, rotational deformity, and congenital anomalies to facilitate safe instrumentation and surgical strategy.

Low-Dose Biplanar Imaging

EOS imaging allows simultaneous orthogonal acquisition in the standing position, enabling three-dimensional reconstruction with significantly reduced radiation exposure (Dubousset et al. 2013).

EOS is a low-dose biplanar imaging system that captures simultaneous frontal and lateral images in the standing in weight-bearing position; it provides reduced radiation dose (up to 50–85% lower than conventional radiography) allowing three-dimensional spinal reconstruction, improving assessment of complex deformities.

From a neuroradiological standpoint, EOS does not replace MRI or CT but provides **critical biomechanical context** for neural compression seen on cross-sectional imaging (Table 1).

Spinal Canal and Neural Element Assessment

From a neuroradiology perspective, deformity severity does not always correlate with neurological risk—canal morphology and stress distribution are critical.

Key parameters:

Table 1 Recommended imaging protocols in pediatric and adult scoliosis

Modality	Pediatric scoliosis	Adult scoliosis
Radiography	Standing PA + lateral, low dose	Standing PA + lateral
MRI	Whole spine if atypical or early onset	Targeted spine for neurological symptoms
CT	Selective (congenital/postoperative)	Preoperative or postoperative
EOS	Preferred for follow-up	Increasingly used

- Anteroposterior canal diameter
- Cross-sectional canal area
- Relationship of deformity apex to cord level

Posterior vertebral body involvement—particularly fragments projecting toward the spinal canal—poses the greatest neurological risk, especially in traumatic and degenerative deformities.

MRI signs of chronic neural compromise include the following:

- Cord thinning
- Myelomalacia
- Gliosis (T2 hyperintensity with volume loss)

Traumatic and Degenerative Deformities

Neuroradiological priorities:

- Identification of unstable fracture patterns
- Assessment of posterior vertebral wall integrity
- Detection of delayed canal compromise

CT is superior for fracture morphology, while MRI evaluates the following:

- Cord contusion
- Epidural hematoma
- Ligamentous disruption

Degenerative Spinal Deformity

Common MRI findings:

- Disc collapse and vacuum phenomenon
- Facet arthropathy
- Ligamentum flavum hypertrophy
- Multilevel spinal stenosis

Sagittal imbalance often results in compensatory neural compression, particularly in the lumbar spine.

Interpretation Checklist and Structured Reporting

A structured report should systematically address deformity characterization and associated findings. Neuroradiologists must correlate imaging findings with the following:

- Level-specific neurological deficits
- Gait disturbance
- Upper motor neuron signs

Not all deformities with dramatic radiographic appearance cause neurological compromise, while subtle canal distortion may produce significant symptoms.

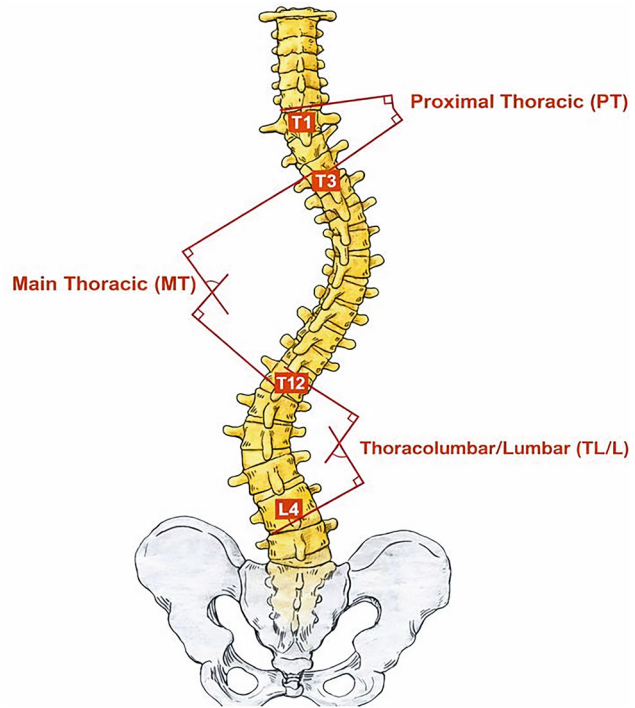
Cobb angle is the standard radiographic measurement used to quantify the magnitude of spinal curvature, particularly in scoliosis. It is defined as the angle between lines drawn parallel to the superior endplate of the upper end vertebra and the inferior endplate of the lower end vertebra of a spinal curve (<https://www.srs.org/Files/Research/Manuals-and-Publications/sdsg-radiographic-measurement-manual.pdf>).

It is typically obtained using standing anteroposterior (AP) or posteroanterior (PA) spine radiographs. Limitations include radiation exposure, magnification errors, patient positioning variability, and interobserver/intraobserver variability (commonly ± 3 – 5°) and the fact that it is a two-dimensional representation of a three-dimensional deformity.

Cobb angles measured on EOS are generally highly correlated with plain films but may show small systematic differences, often 1–3° lower, due to improved positioning, endplate visualization, and measurement precision. Differences between EOS and plain radiographs are usually not clinically significant for routine decision-making (Fig. 1, Table 2).

Fig. 1 Cobb's angle

Coronal plane
demonstrating scoliosis
curve with measurements of
the main angles typically
performed by drawing lines
between most tilted
vertebrae

**Table 2** Structured reporting checklist for scoliosis imaging

Domain	Key elements
Coronal plane	Curve location, direction, Cobb angle
Sagittal plane	Kyphosis, lordosis, sagittal vertical axis
Axial plane	Vertebral rotation
Neural axis	Syrinx, tethered cord, stenosis
Degeneration	Disc disease, facet arthropathy

Treatment Monitoring: Follow-Up Scheme and Findings/Pitfalls

Pediatric patients require serial imaging at 6–12-month intervals during growth, with reduced frequency after skeletal maturity (Weinstein et al. 2008). MRI is warranted if new pain or neurological signs develop. Adult follow-up depends on symptoms or postsurgical evaluation. Contrast-enhanced MRI differentiates scar tissue from recurrent compression.

Common pitfalls include inconsistent positioning, projection errors, and underestimation of sagittal imbalance on supine MRI. Awareness of these limitations is essential for accurate longitudinal assessment.

Neuroradiology plays a key role in the following:

- Assessing decompression adequacy
- Evaluating residual or recurrent canal stenosis
- Differentiating scar tissue from recurrent compression (contrast MRI)

Metal artifact reduction techniques are essential in postoperative patients with instrumentation.

Spondylolisthesis

Spondylolisthesis is no longer considered a purely local vertebral disorder but rather a manifestation of global sagittal spinopelvic imbalance. Advances in imaging analysis over the past two decades have demonstrated that pelvic morphology and compensatory spinal alignment play a central role in the pathophysiology, progression, and clinical expression of the disease. Consequently, comprehensive imaging evaluation, rather than isolated assessment of slip grade, is essential. This section focuses on the

neuroradiological approach to imaging assessment, with emphasis on sagittal alignment parameters and their diagnostic implications.

Imaging Technique and Acquisition

The cornerstone of evaluation is a standing lateral radiograph of the entire spine including the pelvis and proximal femora. Supine imaging underestimates sagittal imbalance and should not be used for alignment analysis. Proper positioning requires visualization of the following:

- The occiput and cervical spine
- The thoracolumbar spine
- The sacrum
- Both femoral heads (to establish pelvic reference points) with 10 cm of proximal femurs

MRI is necessary to confirm the etiology of the condition (pars defects), to rule out neural compression in the lateral recess or foramen, or disc pathology.

CT is reserved to selected cases of uncertain etiology (stress fractures) or to follow up healing after conservative or surgical treatment.

Radiological analysis relies on reproducible angular and linear measurements:

- **Pelvic Incidence (PI)**
A fixed anatomical parameter reflecting pelvic morphology. Increased PI is strongly associated with spondylolisthesis severity.
- **Sacral Slope (SS)**
Describes sacral orientation relative to the horizontal. High SS reflects increased shear forces at L5–S1.
- **Pelvic Tilt (PT)**
Indicates pelvic retroversion and serves as a marker of compensation.
- **Lumbar Lordosis (LL)**
Adaptive spinal response to pelvic morphology.
- **C7 Plumb Line**
Assesses global sagittal balance; anterior displacement indicates decompensation.

Patients with spondylolisthesis exhibit **significantly higher PI, SS, PT, and LL** compared with controls, with progressive deviation as slip grade increases.

Imaging Patterns in Low-Grade Spondylolisthesis

Low-grade slips (<50%) demonstrate three distinct radiological morphotypes based on PI:

1. Low PI (“Nutcracker” Type)

- PI <45°
- Low SS
- Posterior element impingement during extension
- Minimal shear forces

2. Normal PI Type

- PI 45–60°
- Near-physiological sagittal alignment
- Comparable to asymptomatic individuals

3. High PI (“Shear” Type)

- PI ≥60°
- High SS and lordosis
- Increased anterior shear stress at L5–S1
- Greater risk of progression These phenotypes are identifiable on routine lateral radiographs and highlight the importance of pelvic morphology in image interpretation (Fig. 2).

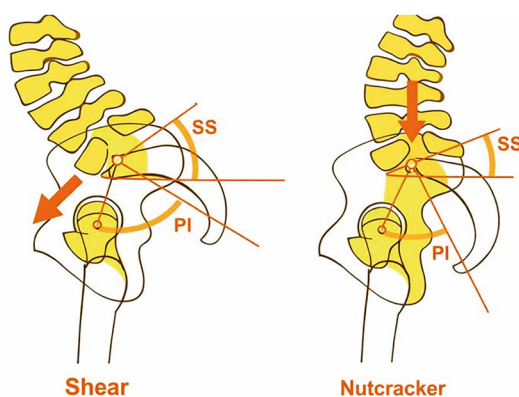


Fig. 2 Diagram illustrating the two described mechanisms of developmental spondylolisthesis

Case Studies

Case 1: Pediatric AIS

A 15-year-old female presented with a right thoracic curve (58° Cobb) 18 months post-menarche and after 12 months of compliant brace treatment. Low-dose biplanar imaging demonstrated vertebral rotation with preserved sagittal balance (a, b). Clinical examination excluded neurological abnormalities, and surgical treatment was discussed. After acceptance, bending films demonstrated (c, d) a structural mid thoracic curve and nonstructural proximal thoracic and lumbar curves. Therefore, selective posterior spinal fusion with apical vertebral derotation was performed and maintained at five years (e, f) (See Fig. 3).

Case 2: Adult Idiopathic Scoliosis

A 56-year-old female with chronic back pain and radiculopathy demonstrated thoracolumbar scoliosis with positive sagittal imbalance on standing radiographs (a, b). Combined anteroposterior surgical correction resulted in proximal junctional failure three months after surgery (c, d), which was corrected with proximal extension of fusion and osteotomies (e, f) (See Fig. 4).

Case 3: Scheuermann's Kyphosis

A 15-year-old male with rigid thoracolumbar kyphosis of 72° . EOS radiographs showed

anterior wedging T9–T1 (a, b), while bending films (c, d) demonstrated flexibility of the lumbar spine. Surgical correction performed from T2 to L3 (sagittal neutral vertebra) with favorable alignment at five-year follow-up (e, f) (See Fig. 5).

Case 4: High-Grade Isthmic Spondylolisthesis

A 12-year-old female premenarche presenting with symptoms of left S1 radiculopathy resistant to pain conservative management. Full-spine EOS (a, b) and MRI (c, d) show high dysplastic L5 lysis with root compression and prolapsed L5–S1 disc. Intraoperative fluoroscopic image demonstrated reduction of L5 slip with pedicle screws and interbody cage performed with EMG monitoring (f arrow). A one-year follow-up EOS demonstrates stability of the constructed and restored spinal balance (g, h) (See Fig. 6).

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Author's Contributions Chiara Zini MD PhD conceived the neuroradiological framework and drafted imaging sections.

Marco Teli MD FEBOT contributed surgical interpretation and case material.

Both authors approved the final version and share equal responsibility for its integrity.

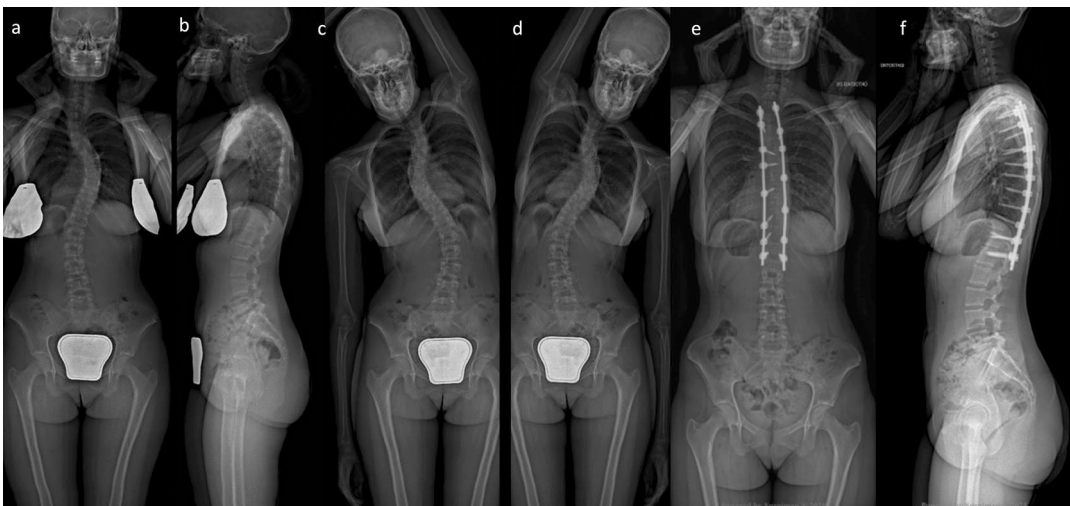


Fig. 3 Case 1: Pediatric AIS

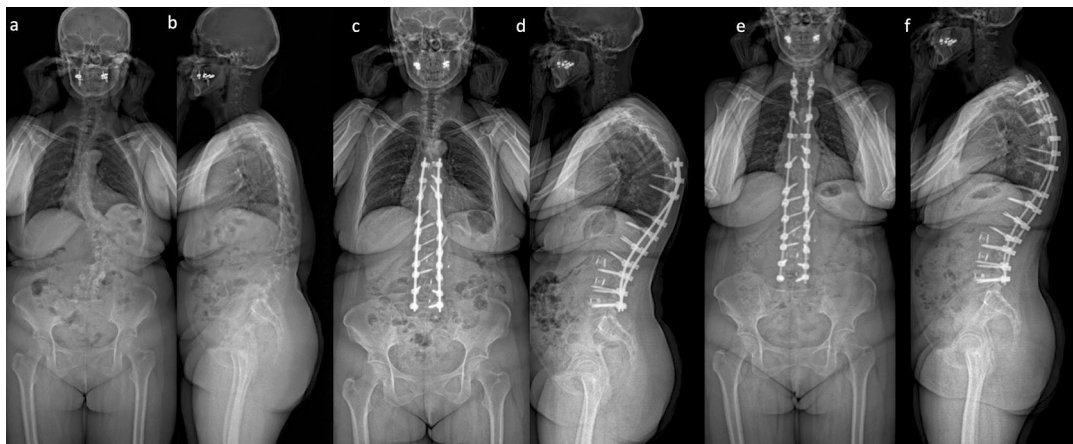


Fig. 4 Case 2: Adult Idiopathic Scoliosis

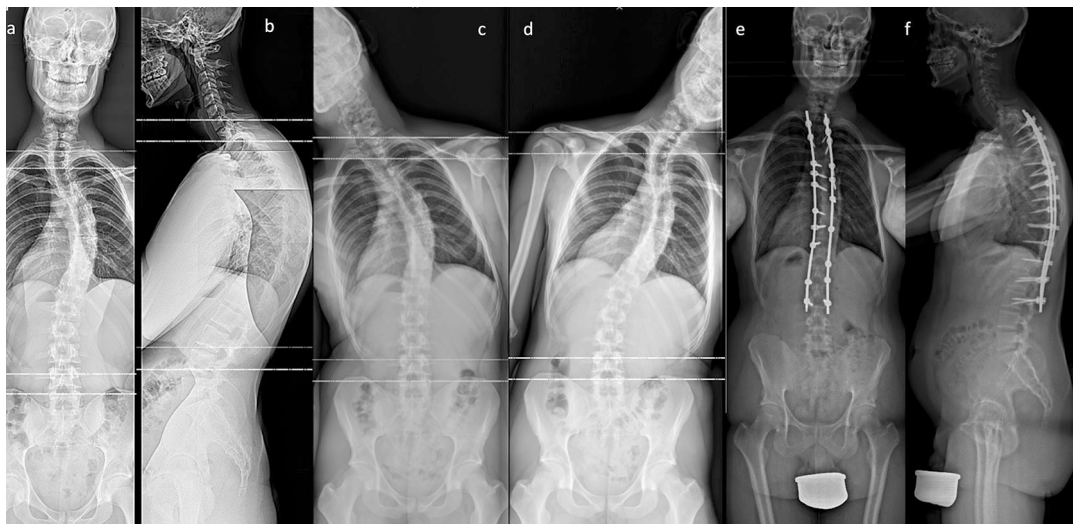


Fig. 5 Case 3: Scheuermann's Kyphosis

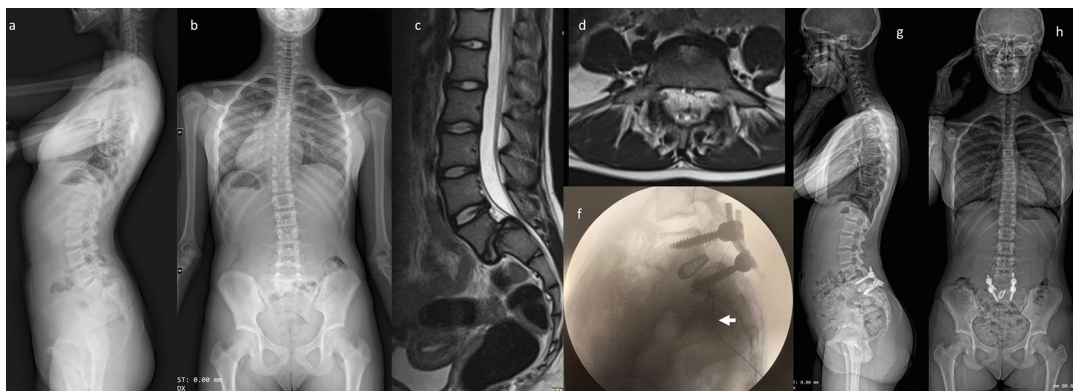


Fig. 6 Case 4: High-Grade Isthmic Spondylolisthesis

Preface Spinal deformities encompass a wide clinical spectrum that challenges neuroradiologists to integrate anatomic and biomechanical perspectives. This chapter bridges pediatric and adult paradigms of spinal-alignment disorders, combining classical radiography with modern cross-sectional and low-dose three-dimensional methods. The multidisciplinary collaboration represented here underscores the role of clinical neuroradiology in comprehensive patient care.

Competing Interest Declaration The author(s) has no competing interests to declare that are relevant to the content of this manuscript.

References

- Aebi M. The adult scoliosis. *Eur Spine J.* 2005;14:925–48.
- Dubousset J, Charpentier A, Dimeglio A. Spinal deformities in paediatric orthopaedics. In: Morrissy RT, Weinstein SL, editors. *Lovell & Winter's paediatric orthopaedics*. Philadelphia: Lippincott Williams & Wilkins; 2013. p. 698–743.
- Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The impact of positive sagittal balance in adult spinal deformity. *Spine.* 2005;30:2024–9.
- Lowe TG, Klineberg E. Scheuermann's kyphosis: diagnosis and management. *J Am Acad Orthop Surg.* 2007;15:646–56.
- Menezes AH. Pathogenesis and treatment of pediatric spinal deformity associated with craniovertebral junction anomalies. *Neurosurg Clin N Am.* 2007;18:535–46.
- Scheuermann HW. Kyphosis dorsalis juvenilis. *Ugeskr Laeger.* 1921;83:385–93.
- Vialle R, Levassor N, Rillardon L, Templier A, Skalli W, Guigui P. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. *J Bone Joint Surg Am.* 2005;87(2):260–7.
- Weinstein SL, Dolan LA, Cheng JC, Danielsson A, Morcuende JA. Adolescent idiopathic scoliosis. *Lancet.* 2008;371:1527–37.
- Further Reading (Web and Reviews, Not Cited)**
- Banno T, et al. Global sagittal alignment and quality of life in adult spinal deformity. *Spine.* 2016;41:E953–8.
- Chiang CY, et al. Artificial intelligence in spinal imaging: current status and future directions. *Eur Radiol.* 2021;31:3945–56.
- Diebo BG, et al. Adult spinal deformity: classification and surgical planning. *Eur Spine J.* 2019;28:1335–42.
- Fardon DF, Williams AL, Dohring EJ, Murtagh FR, Gabriel Rothman SL, Sze GK. Lumbar disc nomenclature: version 2.0. *Spine J.* 2014;14:2525–45.
- Lowe TG. Bracing and fusion in juvenile kyphosis. *Spine Deform.* 2019;7:1020–8.
- Patten SA, et al. Molecular genetics of AIS and Scheuermann's disease. *Orthop Clin N Am.* 2013;44:109–21.
- Risser J. The iliac apophysis: an invaluable sign in the management of scoliosis. *Clin Orthop Relat Res.* 2010;468(3):646–53.
- Scoliosis Research Society. Adult spinal deformity radiographic measurement manual. Milwaukee: Scoliosis Research Society; n.d.. [cited 2026 Jan 23]. Available from: <https://www.srs.org/Files/Research/Manuals-and-Publications/sdsg-radiographic-measurement-manual.pdf>