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CASE SERIES

A new modular radiographic classification of adult idiopathic scoliosis as an extension of the Lenke classification of adolescent idiopathic scoliosis

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Abstract

Purpose To propose and test the reliability of a radiographic classification system for adult idiopathic scoliosis.

Methods A three-component radiographic classification for adult idiopathic scoliosis consisting of curve type, a lumbosacral modifier, and a global alignment modifier is presented. Twelve spine surgeons graded 30 pre-marked cases twice, approximately 1 week apart. Case order was randomized between sessions.

Results The interrater reliability (Fleiss' kappa coefficient) for curve type was 0.660 and 0.798, for the lumbosacral modifier 0.944 and 0.965, and for the global alignment modifier 0.922 and 0.916, for round 1 and 2 respectively. Mean intrarater reliability was 0.807.

Conclusions This new radiographic classification of adult idiopathic scoliosis maintains the curve types from the Lenke classification and introduces the lumbosacral and global alignment modifiers. The reliability of the lumbosacral modifier and global alignment modifier shows near perfect agreement, and sets the foundation for further studies to validate the reliability, utility, and applicability of this classification system.

Keywords Adult · Scoliosis · Idiopathic · Lumbosacral · Arthrodesis · Classification

Introduction

In this paper, we propose a reliable radiographic classification system for adult idiopathic scoliosis (AdIS) that builds upon the Lenke classification for adolescent idiopathic scoliosis (AIS). The Lenke AIS classification is well established [1, 2], and was designed to help determine the appropriate vertebral levels to be included in spinal arthrodesis [1]. However, the Lenke AIS classification was intended for adolescent scoliosis and not applicable to adult idiopathic deformities [1, 3, 4].

While AdIS is the chronological progression of AIS, AdIS and AIS patients differ significantly with respect to symptoms, radiographic findings, and surgical treatment [3, 5]. Adult patients often present with a combination of back or leg pain [5, 6]. Radiographically, coronal and/or sagittal malalignment is more common [5], curves are less flexible, and degeneration of the lumbosacral fractional curve is often present [7]. Moreover, the lumbosacral curve becomes progressively less flexible with age [7]. When surgical treatment is offered for AdIS, fusion constructs often extend to the sacrum/ilium [5]. A radiographic classification system for AdIS should therefore include additional assessment of the lumbosacral curve and global alignment. There is currently no reliable method to communicate the radiographic findings in AdIS.

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To address these differences, we developed a three-component radiographic AdIS classification that is analogous to and extends the Lenke AIS classification to adults. The AdIS classification was developed with three primary goals: (1) to be applicable to adult idiopathic deformities through assessment of the lumbosacral curve and global alignment, (2) to be easily understood and usable by surgeons and trainees by maintaining similarity to the AIS classification, and (3) to have excellent inter- and intrarater reliability by keeping the classification simple and practical. The AdIS classification has three components: curve type (1–6), a lumbosacral modifier (non-structural, structural), and a global alignment modifier (aligned, sagittal malalignment, coronal malalignment, combined sagittal and coronal malalignment) (Fig. 1). The six curve types are maintained from the Lenke AIS classification, with a change in the minor curve structural criteria.

Material and methods

The adult idiopathic scoliosis (AdIS) classification

The AdIS classification is based on the Lenke AIS classification with several modifications: utilization of supine radiographs instead of side-bending radiographs and the creation of the lumbosacral and global alignment modifiers. Three, instead of four, radiographs of the spine (standing long-cassette coronal and lateral, and supine coronal) are used to determine classification. Supine radiographs are predictive of side-bending radiographs [8], and importantly are not effort or operator dependent, thereby increasing reproducibility for classification purposes. Assessment of the lumbosacral curve and global alignment is made through the lumbosacral and global alignment modifiers (Fig. 1).

I. **Curve types (1 through 6)**

The curve type describes the standing and supine radiographic features of the proximal, main thoracic, and thoracolumbar/lumbar curves. Curve types are maintained from the Lenke AIS classification and are determined by the major (largest) curve and structural

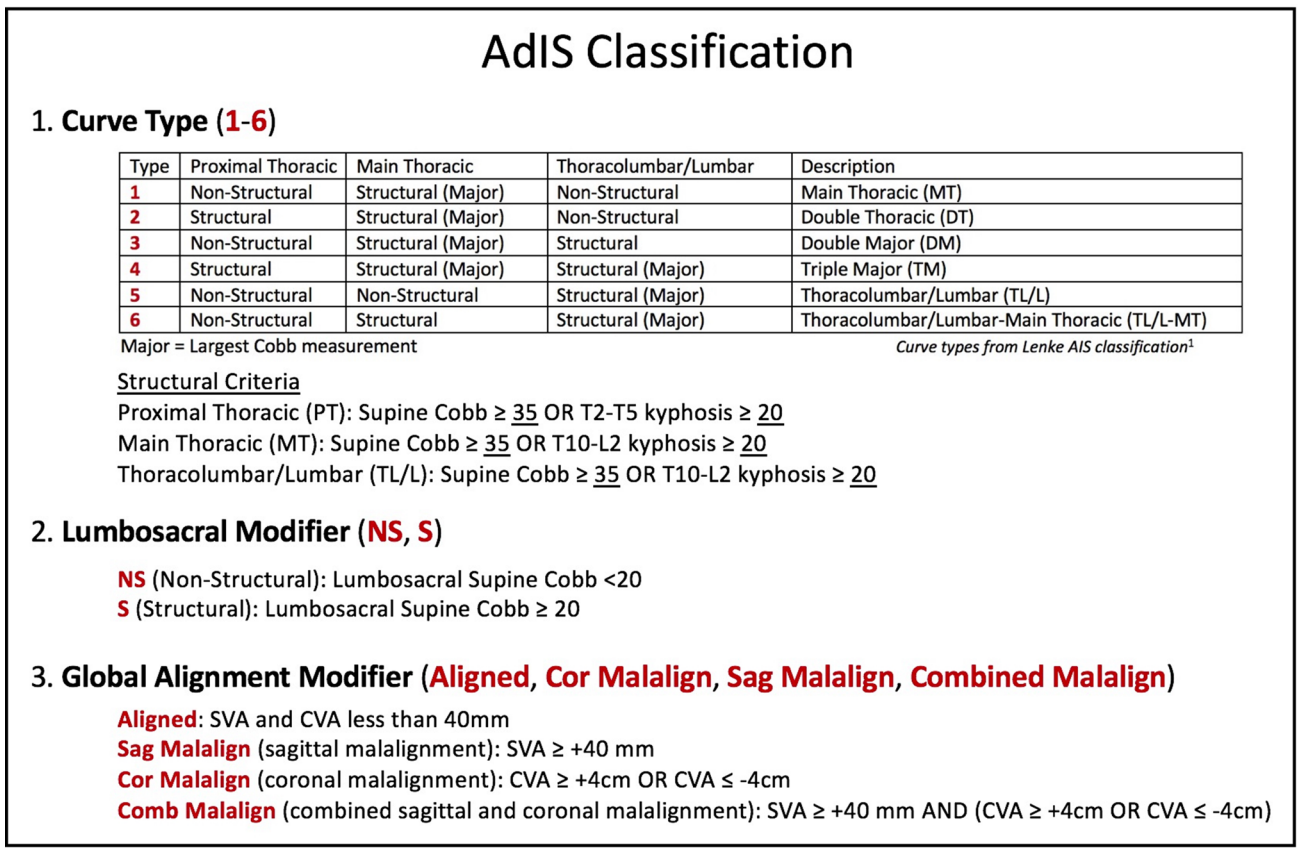

Fig. 1 Overview of the three-component AdIS classification

characteristics of the minor curve [1]. Structural criteria are determined by a single supine radiograph rather than two side-bending radiographs in combination with the standing lateral radiograph. A curve with supine radiograph Cobb angle measurement greater than 35° is structural. The structural criteria of 35° were chosen based on our previous work comparing supine to side-bending films in the assessment of curve flexibility [8, 9]. In addition, proximal thoracic, main thoracic, and thoracolumbar curves also have specific sagittal structural criteria.

Type 1: main thoracic: The main thoracic curve is the major curve, and the proximal thoracic, thoracolumbar/lumbar curves are minor nonstructural curves.

Type 2: double thoracic: The main thoracic curve is the major curve, while the proximal thoracic curve is minor and structural and the thoracolumbar curve/lumbar curve is minor and nonstructural.

Type 3: double major: The main thoracic and thoracolumbar/lumbar curves are structural, while the proximal thoracic curve is nonstructural. The main thoracic curve is the major curve and is greater than, equal to, or no more than 5° less than the Cobb measurement of the thoracolumbar/lumbar curve.

Type 4: triple major: The proximal thoracic, main thoracic, and thoracolumbar/lumbar curves are all structural; either of the two latter curves may be the major curve.

Type 5: thoracolumbar/lumbar: The thoracolumbar/lumbar curve is the major curve and is structural. The proximal thoracic and main thoracic curves are nonstructural.

Type 6: thoracolumbar/lumbar—main thoracic: The thoracolumbar/lumbar curve is the major curve and measures at least 5° more than the main thoracic curve, which is structural. The proximal thoracic curve is nonstructural.

II. **Lumbosacral modifiers (NS or S)**

Assessment of the lumbosacral fractional curve is critical during operative planning for AdIS. While the lumbosacral curve in AIS, if present, is universally compensatory, the lumbosacral curve in AdIS stiffens with age and degeneration [7]. A structural lumbosacral curve is defined as a lumbosacral curve greater than 20 ° on a supine coronal radiograph. The lumbosacral curve measurement is defined as the supine Cobb measurement from the superior endplate of L4 to the superior endplate of S1.

Modifier NS (nonstructural): Modifier NS is used when the Cobb angle of the lumbosacral curve is less than 20°.

Modifier S (structural): Modifier S is used when the Cobb angle of the lumbosacral curve is greater than or equal to 20°.

III. **Global alignment modifiers (Aligned, Sag Malalign, Cor Malalign, or Comb Malalign)**

Global alignment is another critical component of the preoperative evaluation in AdIS. The global alignment modifier further divides the six curve types based on the presence of sagittal, coronal, or combined global malalignment. 40 mm was chosen as the cutoff for sagittal malalignment to be consistent with SRS-Schwab Adult Spinal Deformity Classification [10]. 40 mm was also chosen as the cutoff for coronal malalignment, as it has been shown to be associated with worse scores on the SRS-22 and Owestry Disability Index [11].

Modifier Aligned: SVA and CVA less than 40 mm.

Modifier Sag Malalign: SVA greater than 40 mm.

Modifier Cor Malalign: CVA greater than or less than 40 mm.

Modifier Comb Malalign: SVA greater than 40 mm and CVA greater or less than 40 mm.

Institutional review board approval

Institutional review board approval was obtained.

Reliability testing

30 operative cases were selected from the practice of the senior author. Patients were included based on a reported history of AIS or presence of typical idiopathic curve patterns. Patients with isolated short segment lumbar curves < 4 levels or marked central stenosis were excluded to further select for idiopathic curves. Two reviewers (JDL, LGL) participated in the selection of cases. 12 surgeons graded 30 pre-marked cases twice, approximately 1 week apart. Case order was randomized between sessions. Six reviewers were orthopaedic surgeons and six were neurosurgeons. Eight were attendings and four were fellows. Each case contained three radiographs: standing coronal, standing lateral, and supine coronal. Inter- and intrarater reliability was calculated for each component. Inter- and intrarater reliability was calculated for each component using Fleiss' kappa coefficient with SAS software (SAS Institute, Cary, North Carolina). Kappa values were classified as follows: 0.00–0.20 (slight agreement), 0.21–0.40 (fair agreement), 0.41–0.60 (moderate agreement), 0.61–0.80 (substantial agreement), and 0.81–1.00 (almost perfect agreement) [12].

Results

The interrater reliability (Fleiss' kappa) for curve type was 0.660 and 0.798, for the lumbosacral modifier 0.944 and 0.965, and for the global alignment modifier 0.922 and 0.916, for rounds 1 and 2, respectively. Intrarater reliability was 0.807 (Table 1).

Case examples

Case 1

This patient is a 25-year-old male with a type 1/NS/Aligned curve. He presented with back pain and worsening deformity. Curve type is 1 because the patient has a 66° main thoracic curve, while no other curves meet structural criteria on supine or lateral radiographs. The lumbosacral modifier is "NS" because the lumbosacral curve measures 0° on supine film. The global alignment modifier is "Aligned" because the SVA and CVA do not meet malalignment criteria. Posterior spinal fusion from T3 to L2 was performed (Fig. 2).

Table 1 Interrater reliability (Fleiss' kappa) by curve type, lumbosacral modifier, and global alignment modifier

	Curve type	Lumbosacral modifier	Global alignment modifier
Round 1	0.660	0.944	0.922
Round 2	0.798	0.965	0.916
Total	0.729	0.955	0.919

Case 2

The patient is a 22-year-old female with a type 5/NS/Aligned curve who presented with a long-standing history of scoliosis and mild back pain. Curve type is 5 because the patient had a 76° thoracolumbar curve with no other curves meeting structural criteria on supine or lateral radiographs. The lumbosacral modifier is "NS" because the lumbosacral curve is 17° on supine film. The global alignment modifier is "Aligned", since both the SVA and CVA do not meet malalignment criteria. Posterior spinal fusion from T9 to L4 was performed (Fig. 3).

Case 3

The patient is a 32-year-old female with a type 3/S/Aligned curve. Her scoliosis was diagnosed since the age of 13, but presented with increasing back pain and failure of non-operative

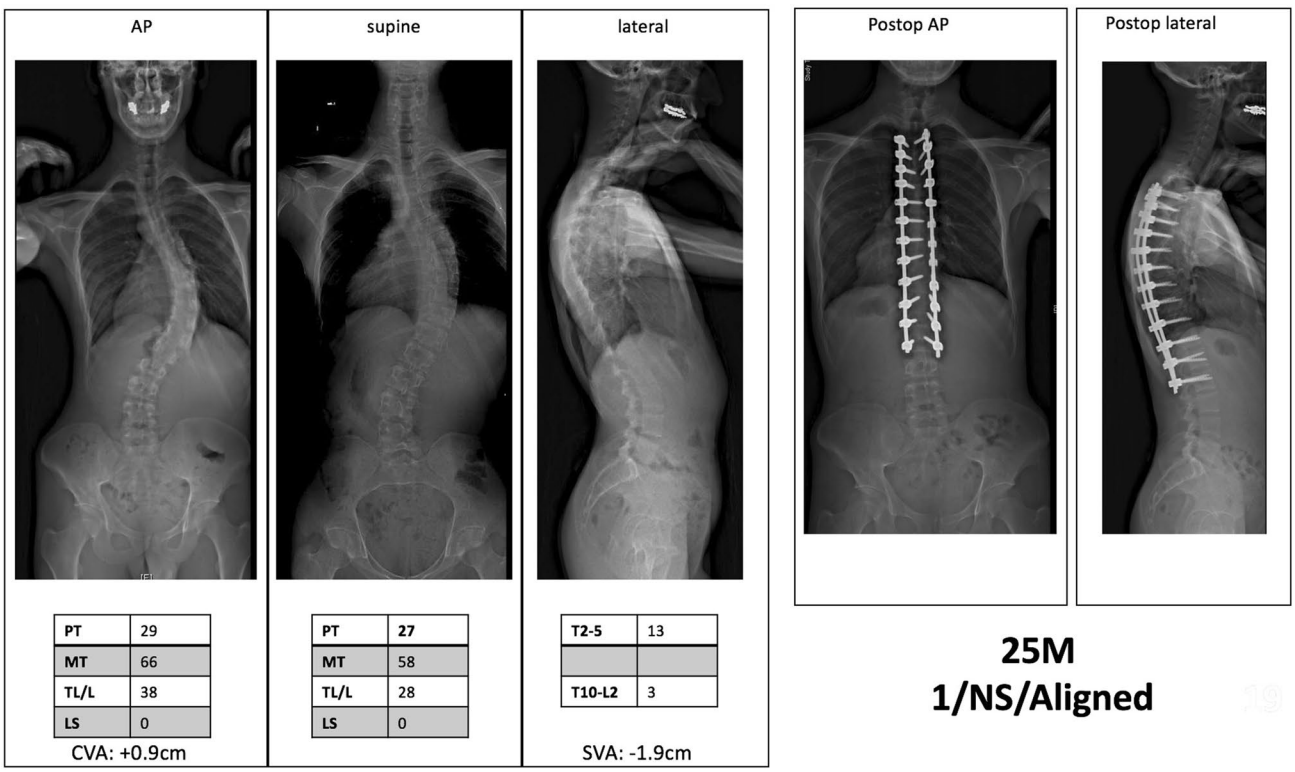

Fig. 2 A 25-year-old male with 1/NS/Aligned curve

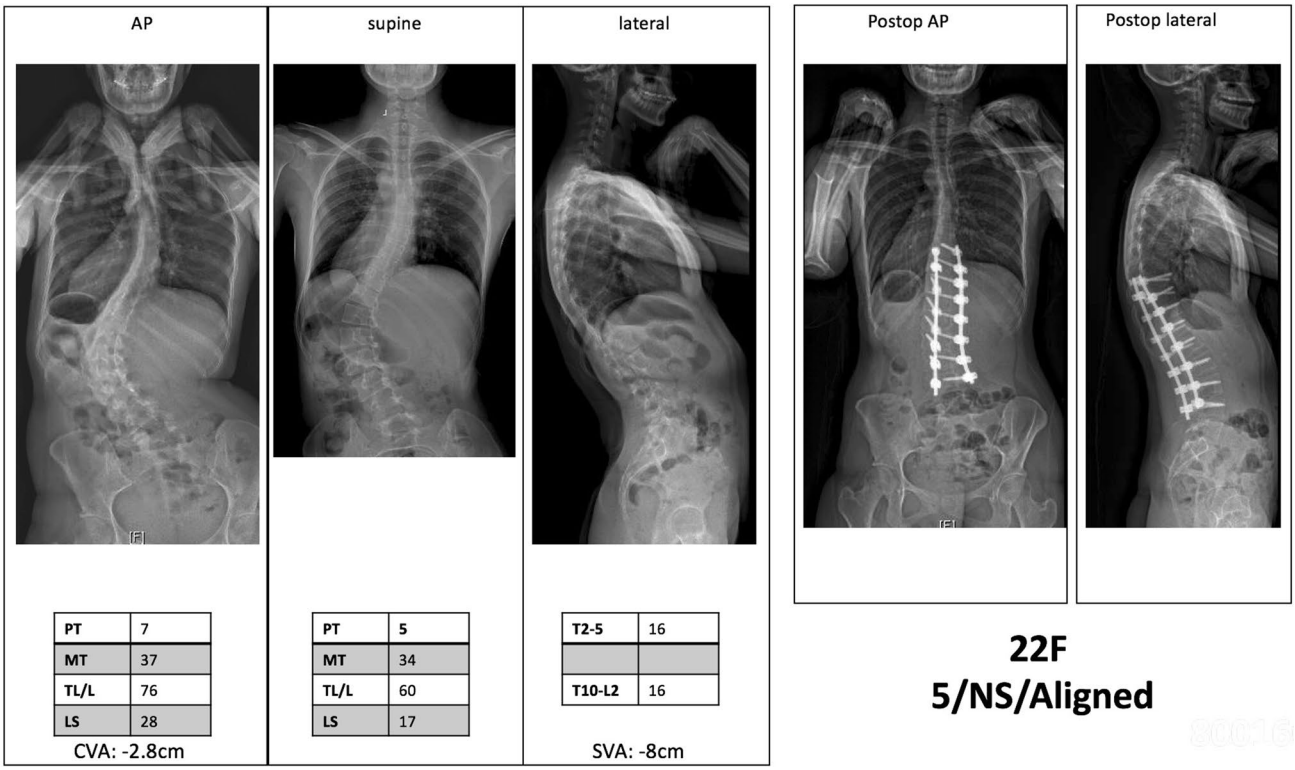

Fig. 3 A 22-year-old female with 5/NS/Aligned curve

treatment. Curve type is 3, because the patient had a 77° main thoracic curve and structural 72° lumbar curve. The lumbosacral modifier is "S" because the lumbosacral curve measures 27° on supine film. Global alignment modifier is "Aligned", since the SVA and CVA do not meet malalignment criteria. Posterior spinal fusion from T3 to sacrum/ilium was performed (Fig. 4).

Case 4

The patient is a 67-year-old male with a type 6/S/Comb Malalign curve. He had a long-standing history of idiopathic scoliosis, but presented with increasing sagittal and coronal imbalance. Curve type is 6 because the patient has a 99° thoracolumbar curve and a structural 93° main thoracic curve. No other curves meet structural criteria on supine and lateral radiographs. Lumbosacral modifier is "S", because the lumbosacral curve measures 31° on supine film. Global alignment modifier is "Comb Malalign" because the SVA is + 12 cm, and the CVA is + 4.2 cm. Posterior spinal fusion from T3 to S1/Ilium was performed (Fig. 5).

Discussion

The original purpose of the of Lenke AIS classification is to provide a radiographic classification to help guide determination of appropriate arthrodesis levels in AIS [1]. As patients with AIS age into adulthood, curves become more rigid, sagittal and coronal malalignment become more common, and the lumbosacral curve degenerates. Spinal fusion constructs for AdIS often extend to the ilium. The Lenke AIS classification does not assess the lumbosacral curve or global alignment, and thus cannot be applied to adult idiopathic deformities. There is currently no accepted radiographic classification system for AdIS [10, 13].

Classification systems are important tools which help clinicians and researchers communicate, define treatment, and analyze outcomes [1, 4, 13–15]. Several attempts have been made to classify and categorize adult spinal deformity in its entirety, highlighting the need to provide organization around this complex diagnosis. These classification

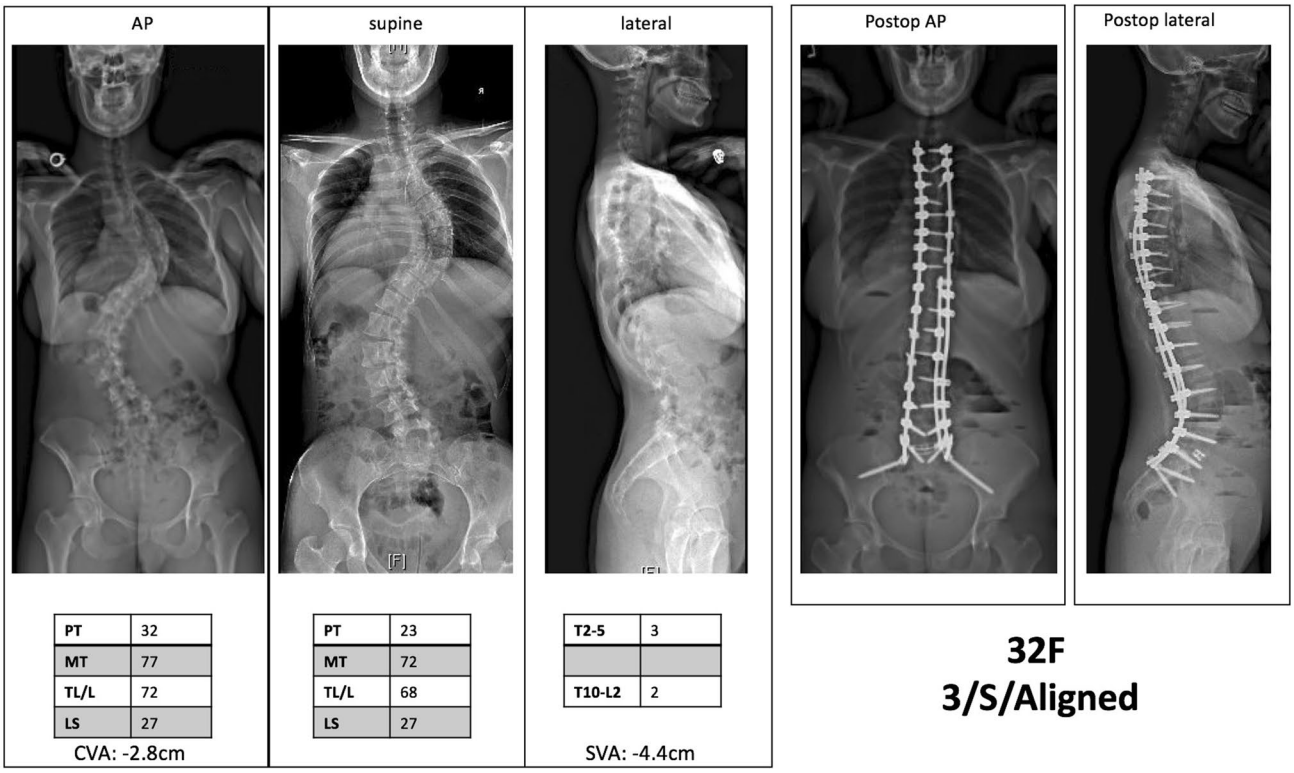

Fig. 4 A 32-year-old female with 3/S/Aligned curve

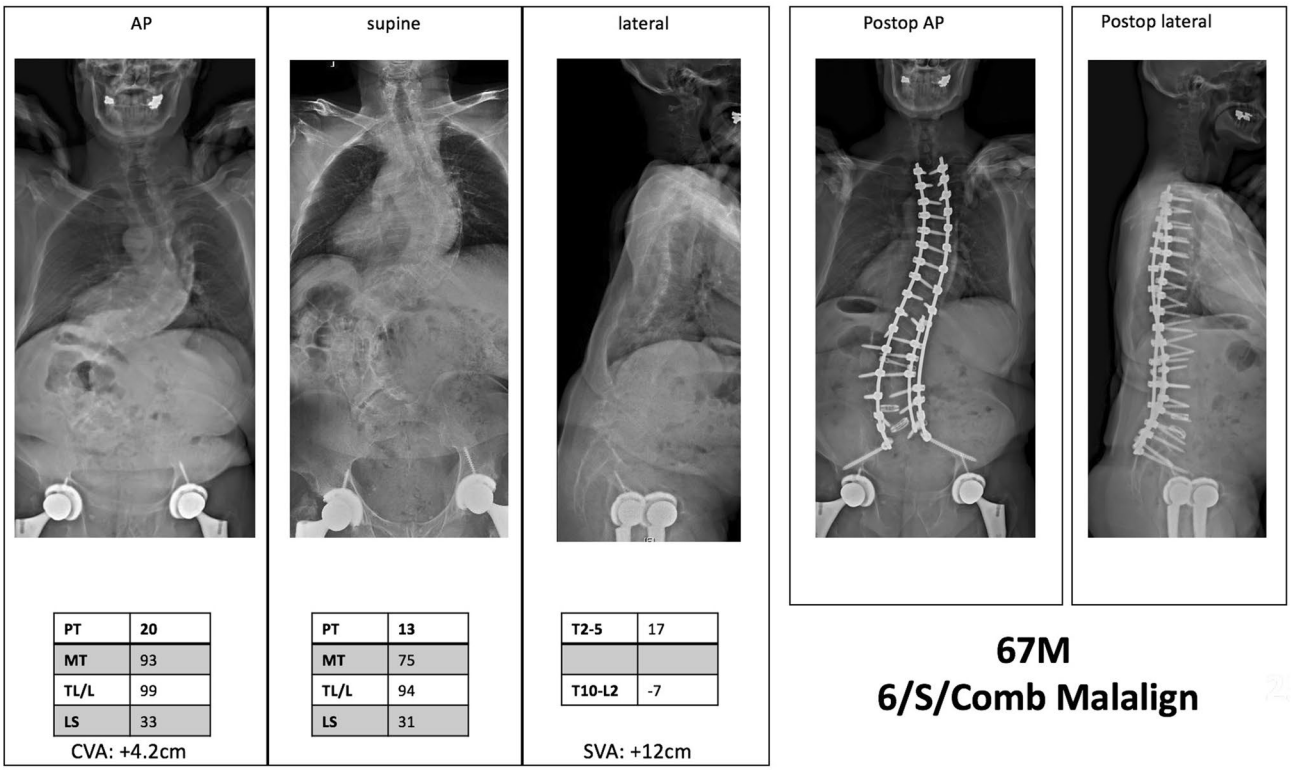

Fig. 5 A 67-year-old male with 6/S/Comb Malalign curve

schemes include the SRS classification [15], Schwab classification [14], and Aebi classification [16]. However, in contrast to AIS, adult spinal deformity is a heterogenous diagnosis with a wide variety in patient age, deformity etiology, and curve pattern, thereby making classifications complex and potentially difficult to apply in a busy clinical practice. Meanwhile, there is no classification system targeted specifically at idiopathic curves in adults.

We have developed a new two-dimensional radiographic classification for adult idiopathic scoliosis, a unique subset of adult spinal deformity. The purpose of this classification is to reliably categorize and communicate the radiographic features of AdIS patients to facilitate clinical treatment and research. The classification was developed with three primary goals: (1) to be applicable to adult idiopathic deformities through assessment of the lumbosacral curve and global alignment, (2) to be easily understood and usable by surgeons and trainees by maintaining similarity to the AIS classification, and (3) to have excellent inter- and intrarater reliability by keeping the classification simple and practical.

We performed a reliability study of the AdIS classification among 12 spine surgeons. 30 cases were graded 1 week apart. The 12 spine surgeons included 6 orthopedic surgeons and 6 neurosurgeons. The AdIS classification demonstrated substantial agreement with respect to the Lenke curve types ($k = 0.660$ and 0.798), and near perfect agreement with respect to the new lumbosacral ($k = 0.944$ and 0.965) and global alignment modifiers (0.922 and 0.916). Overall intrarater reliability was excellent at 0.807.

With respect to curve type, the reliability of the AdIS classification was consistent with the Lenke AIS classification, which is expected because the curve types are largely unchanged. For the curve type, there was substantial agreement among the 12 reviewers of the study ($k = 0.660$ and 0.798), which is similar to the results published by Lenke et al. among a group of seven independent scoliosis surgeons (0.74 and 0.893) [1]. A subsequent independent reliability study of the Lenke AIS classification by Ogon et al. showed similar findings, where kappa coefficient for curve type was 0.75 [17]. In 2003, Richards et al. published their results comparing the reliability of the Lenke vs King classification, and showed the interobserver and intraobserver kappa coefficients for the Lenke curve type were 0.76 and 0.64 [18]. One key difference between the AdIS classification and the Lenke AIS classification is the use of supine radiographs, rather than side-bending radiographs, to determine the flexibility of minor curves. This further enhances the reliability of the classification by removing human effort and variability introduced through side-bending radiographs. Not only are supine films predictive of side-bending radiographs, but also the supine Cobb angle of 35° combined with < 30% supine correction shows high sensitivity and specificity for identifying structural curves [8, 9]. For the purposes of this classification, minor curve structural criteria was set at 35° on supine radiographs.

The reliability of the lumbosacral modifier ($k = 0.944$ and 0.965) and global alignment modifier (0.922 and 0.916) showed near perfect agreement. These results highlight a key goal in design of the AdIS classification, which is to be easily applicable and highly reliable. The results of the lumbosacral and global alignment modifiers can be compared to the reliability of the SRS Classification for Adult Spinal Deformity, which is a classification applicable to both adult idiopathic and degenerative curves. The SRS classification is a four-part classification which includes seven curve types, regional sagittal modifiers, lumbar degenerative modifiers, and global alignment modifiers [15]. The classification was validated by 19 surgeons using 25 cases. Interobserver reliability for curve type was 0.64, sagittal modifier was 0.73, degenerative modifier 0.65, and global alignment modifier was 0.77. The comparatively lower kappa value of the SRS degenerative modifier is likely attributable to the fact that it includes two non-binary radiographic measures: (1) radiographic assessment of disc height loss and facet arthropathy and (2) rotational, lateral, antero, or retro listhesis > = 3 mm.

One potential criticism of this classification is the definition of a structural lumbosacral curve. The grading of the lumbosacral curve as "structural" does not require it to be included in the arthrodesis. Similarly, if a lumbosacral curve is non-structural, this does not require it to be excluded from the arthrodesis. This is analogous to the conclusions from Lenke et al. in the AIS classification, where 31/315 patients had structural curves excluded from the arthrodesis or non-structural curves included [1]. Many other patient characteristics play into the decision of whether to include the lumbosacral curve in the arthrodesis, including the presence of radiculopathy, patient age, bone quality, and presence of significant degeneration on magnetic resonance imaging. Inclusion of all these factors into the classification scheme would create an overly complex and unreliable classification that could not be useful in either clinical or research settings. Ultimately, classification systems serve as a framework to facilitate communication and organize clinical decision making, but clinical assessment of the patient is critical and may override radiographic classification [1].

Another potential criticism is the exclusion of spinopelvic parameters such as pelvic incidence (PI), lumbar lordosis (LL), and pelvic tilt (PT) in the classification scheme, in light of the high correlation these parameters have with pain, disability, and patient-reported outcome measures [19, 20]. While spinopelvic parameters would be a critical component of an outcome-based classification such as the SRS-Schwab Adult Spinal Deformity Classification, the goal of the AdIS classification is to provide a reliable radiographic classification to help determine the appropriate levels of spinal arthrodesis in adult idiopathic scoliosis. Similarly, this classification is

intended specifically for adult deformities with an idiopathic etiology; iatrogenic, neuromuscular, or degenerative deformities often present with significant sagittal plane malalignment that is not addressed with this classification.

Finally, pre-marked radiographs (Case 1–4) were used for the reliability testing, as this is a widely accepted method of perform reliability testing for classifications systems [10, 15, 17, 21]. The real-life reliability may be lower than the results we reported, which further highlights the need for a highly reliable classification system to achieve clinical and research relevance.

We hope this simple and reliable classification provides a new language for the study and treatment of adult idiopathic scoliosis. In the realm of AdIS, many clinical questions remain unanswered, including the role of selective thoracic fusions, the ideal timing of surgery, and clear indications for stopping fusions short of the ilium [22]. A reliable classification system will help us scrutinize our past results and refine future treatment. We invite further additions and modifications to this classification scheme to improve understanding and treatment of AdIS.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by James D. Lin and Meghan Cerpa. The first draft of the manuscript was written by James D. Lin and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Compliance with ethical standards

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IRB approval This research protocol was approved by our local Institutional Review Board.

Informed consent Not applicable. Retrospective radiographic study.

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