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HEALTH SERVICES RESEARCH

Scoliosis Research Society—Schwab Adult Spinal Deformity Classification

A Validation Study

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Study Design. Inter- and intra-rater variability study.

Objective. On the basis of a Scoliosis Research Society effort, this study seeks to determine whether the new adult spinal deformity (ASD) classification system is clear and reliable.

Summary of Background Data. A classification of adult ASD can serve several purposes, including consistent characterization of a clinical entity, a basis for comparing different treatments, and recommended treatments. Although pediatric scoliosis classifications are well established, an ASD classification is still being developed. A previous classification developed by Schwab *et al* has met with clinical relevance but did not include pelvic parameters, which have shown substantial correlation with health-related quality of life measures in recent studies.

Methods. Initiated by the Scoliosis Research Society Adult Deformity Committee, this study revised a previously published classification to include pelvic parameters. Modifier cutoffs were determined using health-related quality of life analysis from a multicenter database of adult deformity patients. Nine readers graded 21 premarked cases twice each, approximately 1 week apart. Inter- and intra-rater variability and agreement were determined for curve type and each modifier separately. Fleiss' kappa was used for reliability measures, with values of 0.00 to 0.20 considered slight, 0.21 to 0.40 fair, 0.41 to 0.60 moderate, 0.61 to 0.80 substantial, and 0.81 to 1.00 almost perfect agreement.

Results. Inter-rater kappa for curve type was 0.80 and 0.87 for the 2 readings, respectively, with modifier kappas of 0.75 and 0.86, 0.97 and 0.98, and 0.96 and 0.96 for pelvic incidence minus lumbar lordosis (PI-LL), pelvic tilt (PT), and sagittal vertical axis (SVA), respectively. By the second reading, curve type was identified by all readers consistently in 66.7%, PI-LL in 71.4%, PT in 95.2%, and SVA in 90.5% of cases. Intra-rater kappa averaged 0.94 for curve type, 0.88 for PI-LL, 0.97 for PT, and 0.97 for SVA across all readers.

Conclusion. Data from this study show that there is excellent inter- and intra-rater reliability and inter-rater agreement for curve type and each modifier. The high degree of reliability demonstrates that applying the classification system is easy and consistent.

Key words: adult deformity, spino-pelvic alignment, classification.
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Adult spinal deformity (ASD) encompasses a complex group of pathologies that cover a broad range of radiographical patterns with various clinical presentations. The prevalence of ASD is difficult to evaluate precisely, but it has been reported as occurring in up to 60% in the older population.[1] In contrast to adolescent idiopathic scoliosis, for which radiographical findings guide therapeutic choices, the most important considerations for adequate management in patients with ASD are pain and disability.[2] Treatment requires a precise radiographical evaluation of patients with ASD, including an assessment of the sagittal plane, which various studies have reported as having substantial importance in ASD.[3–5]

The clinical relevance of radiographical parameters in ASD evaluation underlines the necessity for a global ASD classification system that can offer consistent characterization of a clinical entity, a basis for comparison of different treatments, and a way of establishing recommended treatments. The ideal classification should include ease of use, groupings by clinical impact, and a high degree of reliability. Although there is an accepted classification for adolescent idiopathic scoliosis described by Lenke *et al*,[6] a widely accepted ASD classification is still being developed, however various efforts have been pursued in the past years. A recent review[7] reported previous published classifications systems for adult scoliosis based on

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TABLE 1. Radiographic Parameter Thresholds Predictive of an Oswestry Disability Index Score of 40

Radiographical Parameter	Radiographical Threshold	*r*
PI-LL	11°	0.45
PT	22°	0.38
SVA	46 mm	0.47

PI indicates pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis.

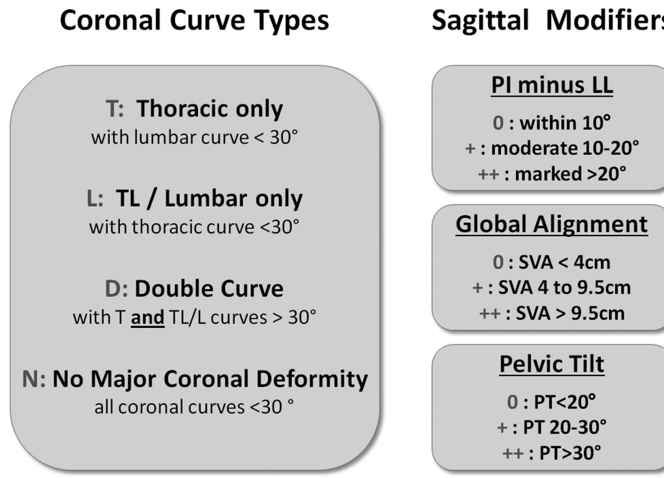

Figure 1. Guide to the classification system, including curve type and 3 sagittal modifiers. PI indicates pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis.

the pathogenesis of the deformation, a strong clinical relevance, or a rich descriptive system. The previously published Schwab classification system[8–10] has been developed using studies correlating health-related quality of life (HRQOL) scores and radiographical outcomes. It therefore meets a high clinical relevance but does not include pelvic parameters.

Recently, Lafage *et al*[11] have reported the fundamental role of pelvis as the main regulator of a chain of correlation between spine and lower limbs, and sagittal evaluation, therefore, a classification system must include spinopelvic parameters such as the sagittal vertical axis (SVA), the pelvic tilt (PT), and the relationship between pelvic incidence (PI) and lumbar lordosis (LL), expressed as PI-LL. These parameters have been shown to be highly correlated with pain and disability[11] and were used in order to set thresholds of correction[12] during realignment procedures (Table 1). The aim of this study is to present an updated and improved version of the Schwab classification system, including spinopelvic parameters with important clinical relevance and to establish the inter- and intra-rater reliability of this new classification system.

MATERIALS AND METHODS

The parameters defined in the hybrid Scoliosis Research Society (SRS)-Schwab classification were chosen on the basis of clinical relevance. This classification system uses frontal and sagittal full-length radiographs in order to provide a standard basis for classification that is easy to use. Because treatment of ASD centers on improving pain and disability, the parameters are strongly associated with HRQOL outcome scores. The cutoff values for the modifier grades were established using the outcome scores to have a strong clinical impact, as reported in previous studies[3,11] and determined in an ongoing study.

Classification

For the classification, the curve type is aimed at describing the relevant coronal aspects of the deformity. The sagittal components of the deformity are characterized through the 3 modifiers. The classification (Figure 1) is designed as follows:

The *curve type* is determined on the basis of maximal coronal angle measured according to standard Cobb technique.

Curve type T: Patients with a thoracic major curve of greater than 30° (apical level of T9 or higher) are classified with curve type T.

Curve type L: Patients with a lumbar or thoracolumbar major curve of greater than 30° (apical level of T10 or lower) are classified with curve type L.

Curve type D: Patients with a double major curve, with each curve greater than 30° are classified with curve type D.

Curve type N: Patients with no coronal curve greater than 30° (i.e. no major coronal deformity) are classified with curve type N (normal).

The first sagittal modifier takes into account 2 radiographical parameters: PI and LL. The *PI-LL modifier* represents the difference between the angle measure of the PI and the angle measure of the LL (*i.e.*, a proportional relationship between PI and LL). This measure is important because surgical planning for a patient with a small LL relative to the PI, *via* an osteotomy or osteotomies, should take into account the amount of postoperative LL necessary to achieve a harmonious alignment. The PI is measured as the angle between the line drawn perpendicular to the sacral end plate at its midpoint and the line drawn from the midpoint of the sacral end plate to the midpoint of the bicoxofemoral axis. The LL is the sagittal Cobb angle measured between the superior end plate of L1 and the superior end plate of S1.

Patients with a PI-LL value of less than 10° are classified with a *PI-LL modifier "0"*.

Patients with a PI-LL value between 10° and 20° are classified with a *PI-LL modifier "+"*.

Patients with a PI-LL value of greater than 20° are classified with a *PI-LL modifier "++"*.

PT is a crucial parameter in assessing spinal deformity, because high PT (increased pelvic retroversion) is a compensatory mechanism that can affect, and reduce, the apparent

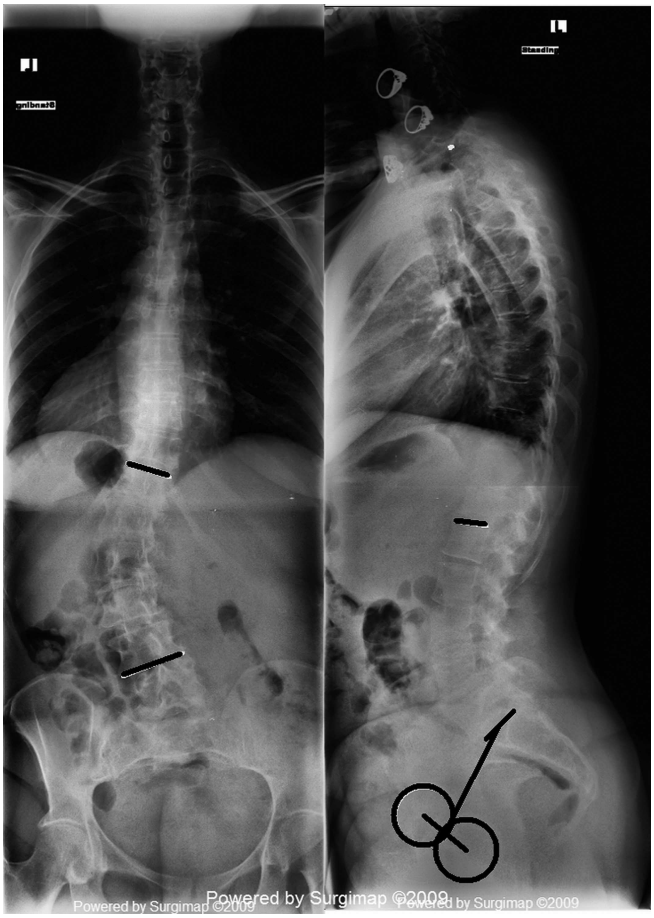

Figure 2. Example classification of a case with a lumbar curve (41°) with an apex in L2, a PI-LL of 20° (PI = 73°, LL = 53°), a pelvic tilt of 27°, and an SVA of 62 mm. The patient has a coronal curve type L, with the following sagittal modifiers: PI-LL +, PT +, SVA +. PI indicates pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis.

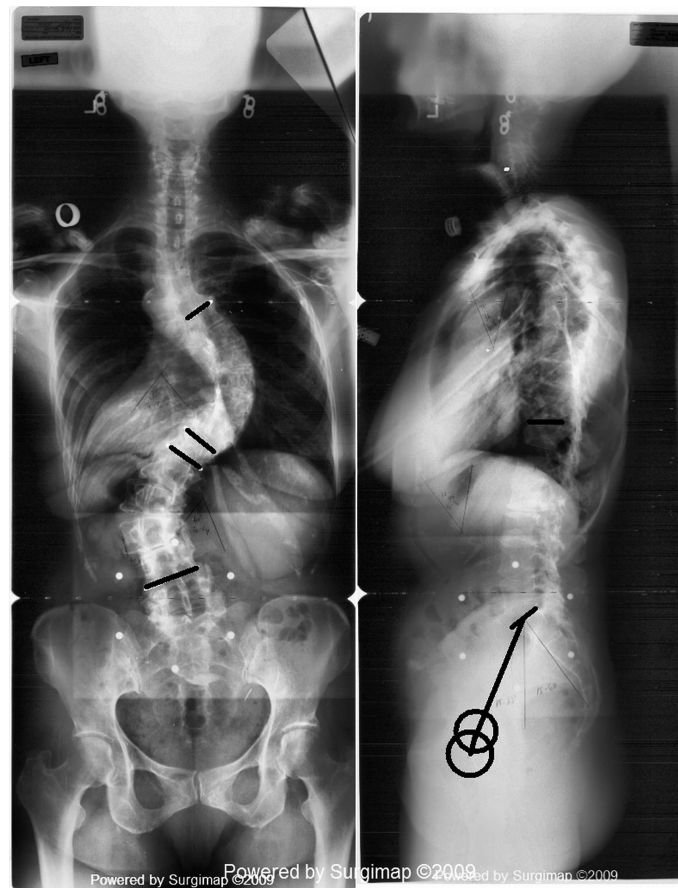

Figure 3. Example classification of a case with a double curve (thoracic 72°, apex T9; lumbar 59° apex L2–L3), a PI-LL of 15° (PI = 59°, LL = 44°), a pelvic tilt of 24°, and an SVA of 16 mm. The patient has a coronal curve type D, with the following sagittal modifiers: PI-LL +, PT +. PI indicates pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis.

extent of global sagittal malalignment.[11] In addition to being a parameter that is highly correlated with pain and disability, PT should factor into surgical planning as well. A recent study has shown that patients with similar SVA, but with greater PT, require larger corrections (osteotomies) to reduce the risk of postoperative failure than those with a smaller PT.[13] The *pelvic tilt modifier* assesses the degree of pelvic retroversion, with PT measured as the angle between the line connecting the midpoint of the sacral end plate to the midpoint of the bicoxofemoral axis and the vertical.

Patients with a PT of less than 20° are classified with a *PT modifier* "0".
Patients with a PT between 20° and 30° are classified with a *PT modifier* "+".
Patients with a PT of greater than 30° are classified with a *PT modifier* "++".

The *global alignment modifier* groups the global sagittal alignment based on radiographical cutoffs of SVA associated with increases in pain and disability. The SVA is defined as the offset between the sagittal C7 plumb line and the posterior, superior corner of the sacrum.

Patients with an SVA of less than 40 mm are classified with an *SVA modifier* "0".
Patients with an SVA between 40 and 95 mm are classified with an *SVA modifier* "+".
Patients with an SVA of greater than 95 mm are classified with an *SVA modifier* "++".

Figures 2 and 3 provide examples of cases that were classified in this study.

Classification Reliability

On the basis of the classification outlined earlier, 21 premarked cases were reviewed by 9 readers, composed of the authors and members of the SRS Adult Deformity Classification Committee. After approximately 1 week, each reader graded the cases for a second time in a different order. The cases were selected to represent a distribution of classification grades. All radiographical measurements were performed using Surgimap Spine imaging software (www.surgimap.com, provided by Nemaris Inc., New York, NY).

Inter- and intra-rater reliability measures were determined by calculating Fleiss' kappa coefficient using a dedicated

TABLE 2. Intra-rater Reliability—Fleiss' Kappa Value for Curve Type, Modifiers, and Entire Grade for Each Reader Based on the 2 Readings

Intrarater Reliability: Fleiss' Kappa Values					
	Curve Type	Modifiers			Entire Grade
		PI-LL	PT	SVA	
Reader 1	1.00	1.00	1.00	1.00	1.00
Reader 2	1.00	0.92	1.00	1.00	0.95
Reader 3	1.00	1.00	1.00	1.00	1.00
Reader 4	1.00	1.00	0.92	0.92	0.90
Reader 5	0.87	0.84	0.85	1.00	0.75
Reader 6	0.94	0.91	1.00	1.00	0.90
Reader 7	0.70	0.66	1.00	0.77	0.63
Reader 8	1.00	0.75	1.00	1.00	0.85
Reader 9	0.92	0.83	1.00	1.00	0.84
Average	0.94	0.88	0.97	0.97	0.87

PI indicates pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis.

TABLE 3. Inter-Rater Reliability—Fleiss' Kappa Value for Curve Type, Modifiers, and Entire Grade for Each Reader Based on the 2 Readings

Inter-Rater Reliability: Fleiss' Kappa Values					
	Curve Type	Modifiers			Entire Grade
		PI-LL	PT	SVA	
Reading 1	0.80	0.75	0.97	0.96	0.70
Reading 2	0.87	0.86	0.98	0.96	0.79
Average	0.84	0.8	0.97	0.96	0.75

PI indicates pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis.

MATLAB (Mathworks, Natick, MA) program. Kappa values of 0.00 to 0.20 were considered slight agreement, 0.21 to 0.40 fair agreement, 0.41 to 0.60 moderate agreement, 0.61 to 0.80 substantial agreement, and 0.81 to 1.00 almost perfect agreement.[14] Inter- and intra-rater percent agreement was calculated as well.

RESULTS

Radiographical parameters were measured for each case to determine classification criteria for curve type and each modifier. In the coronal plane, there were 3 patients classified with a curve type of T, 6 classified with L, 7 classified with D, and 5 classified with N. In the sagittal plane, PI ranged from 38° to 85°, with a median of 61° and LL ranged from −9° to 85°, with a median of 40°. The PI-LL parameter values ranged from −46° (LL greater than PI) to 70° (PI greater than LL), with a median of 25°, and 4 patients were classified with a PI-LL modifier of "0", 6 with "+", and 11 with "++". The PT ranged from 2° to 55°, with a median of 25°, and 4 patients were classified with a PT modifier of "0", 8 with "+", and 9 with "++". The SVA ranged from −63 to 243 mm, with a median of 34 mm, and 11 patients were classified with an SVA modifier of "0", 3 with "+", and 7 with "++".

Reliability

Intra-rater Reliability and Agreement

For curve type and each modifier, intrarater reliability was classified as "almost perfect." Fleiss' kappa coefficient averaged 0.94 (range, 0.70–1.0) for curve type, 0.88 (range, 0.66–1.0) for the PI-LL modifier, 0.97 (range, 0.85–1.0) for PT, and 0.97 (range, 0.77–1.0) for SVA. For the classification grade as a whole, with curve type and each modifier, the intrarater reliability was 0.87 (range, 0.63–1.0) (Table 2).

Between the 2 sets of readings, the curve type was graded consistently by each reader an average of 95.7% of the time, the PI-LL modifier 93.6%, the PT modifier 98.4%, and SVA modifier 97.9%. In 87.8% of cases, the readers assigned the same overall classification grade between readings.

Inter-Rater Reliability and Agreement

The inter-rater reliability for the curve type and modifiers was assessed for each reading. For curve type, the Fleiss' kappa coefficient improved from 0.80 to 0.87 from the first to the second readings. The kappa values for the PI-LL modifier improved from 0.75 to 0.86, for the PT modifier from 0.97 to 0.98, and for the SVA remained constant at 0.96. As a whole, the inter-rater reliability for the entire classification grade improved from 0.70 to 0.79 (Table 3).

DISCUSSION

ASD is an increasing health care issue due to the aging of Western societies, combined with functional expectations that can be associated with ASD. Unlike adolescent deformities, for which radiographical deformity predominantly determines surgical treatment, management of ASD is typically driven by considerations of pain and disability.[2] Recent studies have reported the general effectiveness of surgical treatment of patients with marked disability and the benefit of this approach compared with nonoperative care.[15,16] However, optimal treatment approaches for specific deformity patterns are lacking. This is due, in large part, to the absence of an accepted classification system and a systematic analysis of outcomes by specific categories. To address these considerations, the need for a comprehensive and clinically based classification system has emerged.

Radiographical analysis of ASD has historically been centered on the coronal plane, with the Cobb angle being the defining aspect of a deformity pattern. It is only during the last few years that classification systems have emerged that touch on the more clinically relevant aspects of ASD. The

Aebi classification system[17] is composed of 4 groups based on etiology. However, although this system is simple, its use for guiding treatment and surgical planning is difficult. An earlier SRS outline proposed another classification system,[18] using 7 curves types (6 coronal and 1 sagittal) and 3 modifiers (regional sagittal modifier, lumbar degenerative modifier, and global alignment modifier). This system has been shown to be reliable, but is difficult to use in daily practice because it remains mainly descriptive without taking into account clinical parameters. The previously published Schwab classification[8] was based on a different approach, focusing on clinically relevant parameters. Using a prospective evaluation of 947 patients, 5 types of curve and 2 modifiers were described (LL and subluxation modifiers). This system was reported to be reliable and strongly clinically relevant, because it was possible to establish a prediction model of outcomes and complications after ASD surgical management.[10] However, the main limitation of this classification system was the absence of spinopelvic sagittal parameters.

Recent studies have underlined the importance of sagittal plane analysis and the impact of the pelvis on spino-pelvic alignment and pain and disability.[11,19–21] According to Lafage *et al*,[11] SVA, PT, and a lumbar lordosis proportional to pelvic incidence (PI–LL) were strongly correlated with HQROL scores. Furthermore, PT was shown to be of great importance as it represents a compensatory mechanism in the chain of correlation of sagittal alignment. Anterior sagittal imbalance is associated with pelvic retroversion (evident through an increased PT), hip extension, and finally knee flexion when compensatory mechanisms are surpassed. More recently, these spinopelvic parameters were used to set thresholds of correction for sagittal realignment procedures.[12] On the basis of these recent results and improved global knowledge about management of patients with ASD, the previous classification has been updated and applied as a basis for the SRS-Schwab classification presented here. This current version responds to previous limitations, because it improves description of deformities and includes spinopelvic parameters highly correlated with HRQOL scores. In its present form, the deformity is described by its main coronal curve pattern (thoracic, thoracolumbar/lumbar, double, or sagittal curve) and its amplitude, using Cobb angle. Then 3 modifiers are applied: the relationship of PI and LL (PI-LL; "0" $< 10°$, "+" 10°–20°, and "++" $> 20°$), pelvic tilt (PT, "0" $< 20°$, "+" 20°–30°, and "++" $> 30°$), and sagittal vertical axis (SVA, "0" < 40 mm, "+" 40–95 mm, and "++" > 95 mm).

In meeting with requirements of a good classification system, data from this study show that there is excellent intra-rater reliability for curve type, each modifier and the entire classification with Fleiss' coefficient always greater than 0.81 and an intra-rater agreement between the 2 measures always above 80%.

The high degree of reliability showed that measurements on premarked films were consistent and demonstrated that applying the classification system is easy and consistent. The greater kappa values in the second set of readings also demonstrated a learning curve in application of the classification system. These results are in line with the reliability study of Lenke classification for adolescent idiopathic scoliosis,[6] and this improved classification system may constitute a framework for improving management of patients with ASD. The use of premarked cases can be criticized; however, this choice was made to assess the agreement in classification and not the agreement in picking radiographical landmarks.

Further classification efforts will include reliability study with nonpremarked cases, determining the incidence of each curve type using a consecutive enrollment database, and determining the success of different treatments to develop treatment algorithms based on the classification system.

CONCLUSION

Data from this study show that there is excellent inter- and intra-rater reliability and inter-rater agreement for curve type and each modifier. The high degree of reliability demonstrates that applying the classification system is easy and consistent.

➢ Key Points

- ❑ Although classifications in the pediatric population are well established, there is still a need for a complete classification for ASD.
- ❑ A previous classification system has been revised to include pelvic parameters, which have shown marked correlation with HRQOL measures in recent studies.
- ❑ This study demonstrates that the proposed new ASD classification system is clear and has excellent intra- and inter-rater reliability and agreement.

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