Toward the Development of a Comprehensive Clinically Oriented Patient Profile: A Systematic Review of the Purpose, Characteristic, and Methodological Quality of Classification Systems of Adult Spinal Deformity

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BACKGROUND: Existing adult spinal deformity (ASD) classification systems are based on radiological parameters but management of ASD patients requires a holistic approach. A comprehensive clinically oriented patient profile and classification of ASD that can guide decision-making and correlate with patient outcomes is lacking.

OBJECTIVE: To perform a systematic review to determine the purpose, characteristic, and methodological quality of classification systems currently used in ASD.

METHODS: A systematic literature search was conducted in MEDLINE, EMBASE, CINAHL, and Web of Science for literature published between January 2000 and October 2018. From the included studies, list of classification systems, their methodological measurement properties, and correlation with treatment outcomes were analyzed.

RESULTS: Out of 4470 screened references, 163 were included, and 54 different classification systems for ASD were identified. The most commonly used was the Scoliosis Research Society-Schwab classification system. A total of 35 classifications were based on radiological parameters, and no correlation was found between any classification system levels with patient-related outcomes. Limited evidence of limited quality was available on methodological quality of the classification systems. For studies that reported the data, intraobserver and interobserver reliability were good (kappa = 0.8).

CONCLUSION: This systematic literature search revealed that current classification systems in clinical use neither include a comprehensive set of dimensions relevant to decision-making nor did they correlate with outcomes. A classification system comprising a core set of patient-related, radiological, and etiological characteristics relevant to the management of ASD is needed.

KEY WORDS: Classification, Purpose, Characteristics, Adult spinal deformity, Systematic review

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Adult spinal deformity (ASD) is a single or multi-planar deformity of the spine that has a major impact on the health-related quality of life (HRQoL). ASD affects 32% of people aged over 50 yr and rises to 68% over 70 yr.[1] ASD is among the most significant health-care burdens compared to other chronic conditions.[2] ASD causes functional disability due to pain, neurological deficit, spinal muscle fatigue, and reduced ambulatory function. In contrast to adolescent idiopathic scoliosis where classification and surgical decisions can be based mainly on radiological parameters,[3] treatment of ASD requires a holistic bio-psychosocial approach that considers the etiology, clinical presentation, radiographic findings, and patient's general condition.[4,5]

Previous attempts by Aebi and the Scoliosis Research Society (SRS) to classify ASD were

ABBREVIATIONS: ASD, adult spinal deformity; **ODI,** oswestry disability index; **SRS,** Scoliosis Research Society; **QAREL,** quality score for diagnostic reliability studies

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based on causation and observed radiographic parameters, but they did not incorporate any clinical component or parameters that correlated with HRQoL outcomes.[6,7] Subsequently, Schwab[8] developed a new classification based on the apex of the curve on the coronal plane and 2 modifiers (lumbar lordosis and intervertebral subluxation). However, it was soon recognized that additional sagittal parameters were also important predictors of HRQoL, and a revised SRS-Schwab classification that incorporated spinopelvic parameters which correlated with HRQoL measures was developed.[9] This has been validated to categorize ASD, where patients with worse sagittal modifier grades have poorer HRQoL and require larger magnitudes of surgery.[10] Another commonly used classification, the Roussouly classification, is based on the sagittal spinal shapes of healthy asymptomatic volunteers.[11] Restoration of the sagittal spinal contour to the appropriate Roussouly types has been shown to reduce the incidence of mechanical complications postoperatively.[12,13]

Although a thorough analysis of the radiological parameters, in particular the sagittal plane, is of high clinical relevance in the surgical planning and treatment of ASD,[14-16] a classification system based solely on radiological factors does not guide clinical decision-making for treatment management nor can it function adequately as a research tool to compare and predict outcomes.[17] It has now been increasingly recognized that factors other than radiological parameters play an important role in the overall success of managing patients with ASD. The underlying wellbeing of patients is particularly important in making clinical decisions, such as corresponding clinical history and examination, nutrition, frailty, psychological distress, body mass index, and medical comorbidities. Therefore, there is a need for a comprehensive multimodal ASD classification that considers different bio-psychosocial factors that drive clinical decisions.

The main objective of this systematic review was to evaluate the classifications used in patients with ASD. Specifically, we sought to identify the purposes, characteristics, and adequacy (in terms of methodological measurement properties) of these classifications.

METHODS

Protocol, Search Strategy, and Inclusion Criteria

The review protocol was registered with PROSPERO ID (CRD42019120796).[18] The current review followed the recommendation and guidelines of the PRISMA (Preferred Reporting Items of Systematic Reviews and Meta-analyses).[19] An electronic search was conducted in MEDLINE, EMBASE, CINAHL, and Web of Science for literature published between January 2000 and October 2018, limited to human studies. The areas of search along with the associated search terms are listed in Table 1. The search strategy included terms relating to or describing the condition, classification, and methodological quality. References were managed with Endnote X9.3.2 (Clarivate Analytics) and Rayyan (Qatar Computing Research Institute [Data Analytics]).[20]

The retrieved references were screened and assessed for eligibility by 2 reviewers (M.v.H. and W.J.) independently, and according to the selection criteria described in Table 2. Full-text articles were obtained if eligibility could not be determined from the title and abstract. If no full-text article was available, the corresponding author was contacted. Any disagreement on the inclusion or exclusion of a full-text article was resolved by discussion. If no consensus could be reached between the 2 reviewers, 2 additional reviewers (K.Y.H.K. and N.B.) were consulted.

Risk of Bias Assessment

Risk of bias assessment was conducted separately on methodological quality of classifications for papers included in this review by 1 reviewer (W.J.) using the quality score for diagnostic reliability studies (QAREL).[21]

Data Extraction and Synthesis

All references agreed to be included were used for data extraction. Information concerning study characteristics, demographics, outcome relation data, methodological data, quality assessment of methodological studies, and resulting classification systems was gathered using a predeveloped electronic form, which was agreed by the review team. Data extraction was performed by 1 reviewer (W.J.) and checked by a second reviewer (M.v.H.). Results are presented qualitatively to address the objectives of the study in terms of the classification systems, their characteristics including their relations with validated outcome measures, and their measurement properties (validity [ie, construct and predictive validity] and reliability [ie, intra- and interobserver reliability]).

RESULTS

Literature Search and Study Characteristics

The results of the search and selection process are outlined in Figure. The search strategy identified 8447 unique references. After removal of duplicates and references before the year 2000, 4470 references were available for review. The selection procedure identified 162 studies that referenced to a classification system and met the eligibility criteria. An overview of the study characteristics is given in Table 3.

Risk of Bias Assessment

Most of the QAREL items could not be scored as the description of the methods used was poorly described. The quality of included studies is shown in Tables 4 and 5. Overall, due to the unclear methodology and lack of blinding, we could not draw definitive conclusions regarding the risk of bias in the studies selected.

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TABLE 1. The Areas of Search and the Associated Search Terms

Area	Search terms
ASD	((“Spine”[mesh] OR spinal[Tiab] OR spine[Tiab] OR sagittal[tiab]) AND (deformit*[Tiab] OR alignment[tiab])) OR “Spinal Curvatures”[Mesh] OR scoliosis[Tiab] OR lordosis[Tiab] OR kyphosis[Tiab] OR kyphoscoliosis[Tiab] OR Hypokyphosis[tiab])
Classification	(classification[MeSH Terms] OR “Spinal Curvatures/classification”[Mesh] OR classification*[Tiab] OR classifying[Tiab] OR categorisation[Tiab] OR categorising[Tiab] OR categorization[Tiab] OR categorizing[Tiab] OR categorized[Tiab] OR categorised[Tiab])

TABLE 2. Selection Criteria

	Inclusion	Exclusion
Patient	Adults $\geq$ 18 yr	
	ASD, ie, any type of abnormal curve of the spine (in any plane, including sagittal and coronal plane) irrespective from any condition/pathology	Nondeformity conditions (fractures, spondylolisthesis, vertebral body deformities, etc)
Type of intervention	The type of, or even the inclusion of, an intervention was not a selection criterion	
Types of studies	Experimental (randomised controlled trial) studies, observational studies, including cohort and case-control studies, case series with a minimum group size of 10 patients Clinical studies and review studies which refer to classifications and studies that assess methodological measurement properties of classification systems	Case reports, animal studies, in Vitro studies, biomechanical studies, and simulation studies
Types of classifications	All classifications	Classifications based on only one parameter, studies that evaluated only part(s) of a classification, simple measurements (degrees etc) where a deformity assessment (lordosis, cobb, etc) is assessed on a linear scale instead of classifying measures
Outcomes	Classification systems Methodological measurement properties (validity and reliability) Treatment outcomes Baseline characteristics	

Classification Systems

We identified 54 different ASD classification systems (overview is shown in **Supplemental file 1**). The targeted anatomical areas varied from the whole patient including pain or functional scores (4; 7.4%), whole body posture (1; 1.9%), whole spine (26; 48.1%), cervical (9; 16.7%), thoracolumbar (9; 16.7%), and lumbar (5; 9.3%). From the 163 studies that referenced to a classification system, the most frequently identified ones were SRS-Schwab (74 times), Schwab (17 times), Ames (12 times), Aebi (11 times), and SRS (11 times). The majority of the classifications (35; 64.8%) included radiological parameters only, while the remaining classifications relied on a combination of dimensions, including clinical, demographic, etiology, postural (Table 6). Out of the 35 radiological classifications, 13 used alignment parameters only, while the rest used a combination of curve type, degree of subluxation, extent of degeneration, flexibility and 3-dimensional parameters. In terms of the *purposes of the classification*, treatment guidance was the main purpose in 14 (25.9%), clinical diagnosis in 7 (13.0%), complication risk assessment in 4 (7.4%), outcome prediction in 2 (3.7%), a combination of the above in 4 (7.4%), and not reported in 23 (42.6%).

Relations With Outcome

No study assessed the effects of using a classification system on outcomes compared with another classification or using none (overview is shown in **Supplemental file 2**). Nine studies reported outcomes by classification strata.[1,22-29] Three of these studies used the simplified SRS-Schwab classification and categorized the sagittal modifiers according to the severity of the deformity: mild or none, 0 or 1+; moderate, 2 to 3+; and marked, 4 to 6+ modifiers.[22,26,29] Kyrölä et al[22] found that the oswestry disability index (ODI) total score, function/activity

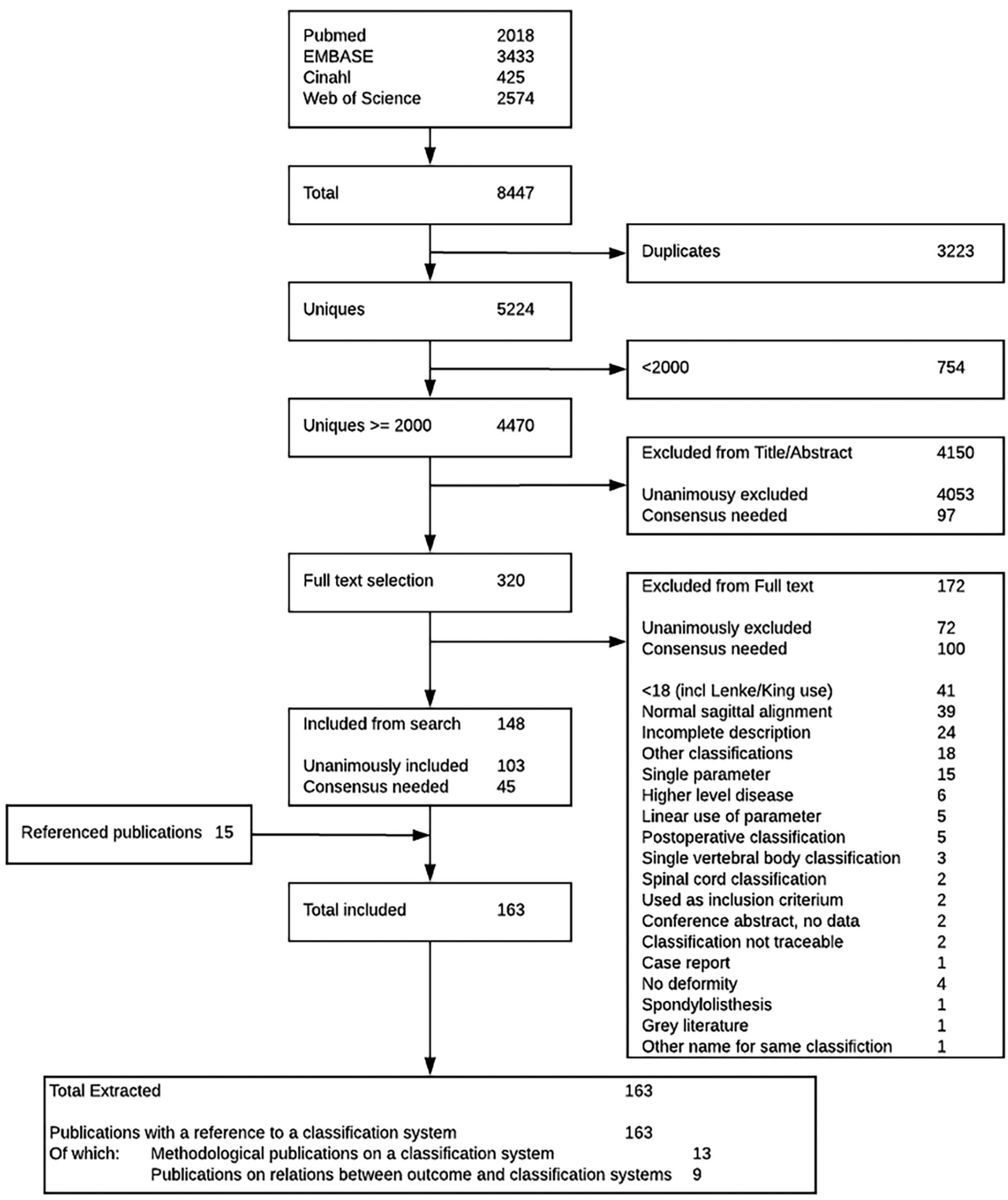

FIGURE. *Flowchart showing results of literature search.*

and self-image/appearance domains of SRS-30 deteriorated with severity of the deformity. Passias et al[26] classified them into aligned and malaligned groups according to the sagittal modifiers and found no difference in ODI, SRS, and physical component summary of SF-36 at 2 yr postoperatively between the 2 groups. Using the Aebi classification, Mataliotakis et al[23] found that surgical complication rates were different by Aebi types: type I has a complication rate of 63% to 66%, type III has a complication rate of 8% and type III has a complication rate of 40% to 66%, but no statistical analysis was reported. Yoshida et al[28]

TABLE 3. Overview of Included Studies

Total included studies	Grand total	163
Clinical relevance and usefulness	Total clinical relevance and usefulness	163
	Reviews	23
	Classification development	20
	Observational studies	118
	Randomised controlled trials	0
	Survey	2
Methodological studies	Total clinimetric studies	13
	Validity – construct, predictive, or discriminant	4
	Reliability – total	8
	Reliability – intraobserver reliability	6
	Reliability – interobserver reliability	7
Relation between classification systems and outcome	Total clinical relation studies	9
Classification systems identified	Total	54

TABLE 4. Quality of Methodological Studies Assessed by QAREL

Study	Study type	Qarel_1	Qarel_2	Qarel_3	Qarel_4	Qarel_5	Qarel_6	Qarel_7	Qarel_8	Qarel_9	Qarel_10	Qarel_11
Chazano[45]	Construct validity	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Lamartina[34]	Reliability	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Yes
Liu[35]	Reliability	Unclear	Yes	Yes	Yes	Unclear	Unclear	Unclear	Yes	Unclear	Yes	Yes
Mummaneni[36]	Reliability	Yes	Yes	Yes	No	Unclear	Unclear	Unclear	Unclear	Unclear	Yes	Yes
Nielsen[37]	Reliability	Yes	Yes	Yes	Yes	Unclear	Unclear	Unclear	Yes	Unclear	Yes	Yes
Nielsen[46]	Construct validity	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Obeid[47]	Construct validity	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Passias[48]	Construct validity	Yes	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Yes	Yes
Rajasekaran[38]	Reliability	Yes	Yes	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Yes	Unclear
Ruangchainikom[39]	Reliability	Yes	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Schwab[9]	Reliability	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Yes	Unclear	Yes	yes
Yamamoto[40]	Reliability	No	Yes	Unclear	Unclear	Yes	Yes	Yes	Unclear	Unclear	Unclear	Unclear
Yoshida[28]	Construct validity	Yes	Yes	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	N/A	Yes	Yes

developed a sliding scale based on independent predictors of total perioperative complications after ASD surgeries and found that it had a high sensitivity of predicting complications. Xie et al[27] reviewed 28 patients with kyphoscoliotic deformities over 100° who underwent posterior vertebral column resection. Patients were divided according to their morphological classification, but the reported correction rates and complications were not correlated with the classification groups.

Two studies on cervical deformity correlated classification strata with outcomes. Miller et al[24] categorized patients as not frail, frail, or severely frail according to the cervical deformity frailty index for patients undergoing cervical spine deformity surgery. The incidence of major complications and medical complications increased with increasing frailty (gamma correlation coefficient = 0.25 and 0.30, respectively). In another study, using the Katssura classification of curve patterns of the cervical spine,[30] Park et al[25] found that clinical adjacent segment pathology requiring reoperation after anterior cervical fusion had no relationship with either the alignment of the fusion mass or the overall cervical sagittal alignment.

Measurement Properties

We identified 13 studies that reported measurement properties in 10 classification systems. These properties included construct validity,[31-33] predictive validity,[28] intraobserver reliability,[34-40] and interobserver reliability.[9,35-38,40] None of the studies reported on all relevant measurement properties.

Construct Validity

A prospective study assessing the SRS-Schwab modifiers at predicting severe disability (ODI > 40) found that having at least 1 abnormal modifier identified 80% (sensitivity) of patients with severe disability and had a false positive rate of 60% (specificity) (**Supplemental file 3**). The positive predictive value was weak (53%) and the negative predictive value was moderate (70%).[31] In another study using 3 levels of threshold to classify cervical malalignment, Passias et al[32] found that the more stringent

TABLE 5. Description of QAREL Items

QAREL item	Item description
Qarel_1	Was the test evaluated in a sample of subjects who were representative of those to whom the authors intended the results to be applied?
Qarel_2	Was the test performed by raters who were representative of those to whom the authors intended the results to be applied?
Qarel_3	Were raters blinded to the findings of other raters during the study?
Qarel_4	Were raters blinded to their own prior findings of the test under evaluation?
Qarel_5	Were raters blinded to the subjects' disease status or the results of the accepted reference standard for the target disorder (or variable) being evaluated?
Qarel_6	Were raters blinded to clinical information that was not intended to form part of the study design or testing procedure?
Qarel_7	Were raters blinded to additional cues that are not part of the test?
Qarel_8	Was the order of examination varied?
Qarel_9	Was the stability (or theoretical stability) of the variable being measured taken into account when determining the suitability of the time interval among repeated measures?
Qarel_10	Was the test applied correctly and interpreted appropriately?
Qarel_11	Were appropriate statistical measures of agreement used?

From: Intra- and inter-rater reliability of movement and palpation tests in patients with neck pain: a systematic review, Anders Jonson et al, *Physiotherapy: Theory and Practice*, published March 4, 2018 by Taylor & Francis, reprinted by permission of the publisher (Taylor & Francis Ltd, http://www.tandfonline.com).

definition of cervical alignment proved effective in evaluating preoperative and surgical factors that contributed to postoperative cervical malalignment after ASD corrective surgery, with an area under the curve of 89.22%.

Predictive Validity

Yoshida et al[28] is the only study that reported on predictive validity (**Supplemental file 4**). The sliding scale proposed in the study has a sensitivity of 90.7%, specificity of 58.1%, positive predictive value of 54.7%, and negative predictive value of 91.2% for total perioperative complications after ASD surgeries.

Intraobserver Reliability

Three studies reported on the intraobserver reliability of the SRS-Schwab classification, and the range of Fleiss kappa value was between 0.67 and 0.87 (**Supplemental file 5**).[9,35,37] Other intraobserver reliability studies reported on the Rajasekaran classification for kyphosis,[38] an algorithm for minimally invasive surgery in ASD,[36] and the Kendall classification for overall posture,[40] with a kappa value of between 0.72 and 0.86.

Interobserver Reliability

Two studies reported on the interobserver reliability of the SRS-Schwab classification, and found the Fleiss kappa values to be 0.55 and 0.73 (**Supplemental file 6**). Studies reported on other classifications had a kappa value of around 0.8.[34,36,38-40]

DISCUSSION

In this systematic review, the classification systems used in the treatment of ASD were investigated, and their purposes, characteristics, and measurement properties were evaluated. In total, 54 classification systems for ASD were found. Treatment guidance in relation to the classification strata was the main reported purpose of classifications and the most frequently used system was the SRS-Schwab classification. A total of 35 of the classifications were solely based on radiological parameters. Overall, the evidence on the relation between outcomes and classification strata was limited, and no evidence was available on the effect of classification systems on outcomes. There was also limited evidence on the measurement properties of the classification systems, with uncertain quality for the diagnostic reliability studies. Reliability of those classifications that could be evaluated had a kappa value of at least 0.8, which is considered as perfect agreement.[41] However, blinding was not systematically used and thus may lead to an overestimation of the reliability.

The complexity of ASD management is attributed to a wide-ranging pathology in a challenging group of patients, often with multiple comorbidities, and different curve characteristics. Earlier classification systems were based on morphological descriptions and etiological foundation,[6] but as later studies revealed the importance of sagittal balance in patient reported outcomes,[15] more recent classifications concentrated on sagittal spinopelvic parameters and overall sagittal alignment.[7,9,11] Although classifications based on sagittal parameters were able to group patients with similar radiological characteristics, management guidelines could not be applied universally within groups, since treatment decisions are generally based on nonradiological factors.[28,42,43] Furthermore, it is now appreciated that factors driving patient satisfaction following ASD surgeries are not solely dependent on sagittal alignment restoration.[44] A classification system based on radiological parameters alone is evidently inadequate for surgeons

TABLE 6. Spinal Region and Parameters Assessed of Included Classifications

Area	Parameters assessed in classification	Classification name
Cervical	Deformity	Hann algorithm
	Frailty	Adult cervical deformity frailty index
Thoracolumbar	Frailty	Adult spinal deformity frailty index
Whole patient	Activity; Pain	Baseline clinical classification
	Comorbidities	Modified frailty index
	Pathology; clinical	ASA Physician Status classification system
Whole spine	Posture	Nakada
Cervical	Alignment; deformity; myelopathy;horizontal gaze	Ames cervical spine deformity
Lumbar	Clinical; deformity; radiological	Zeng
	Deformity; pain	Ploumis lumbar
Thoracolumbar	Deformity; diagnostic	Metz-Stavenhagen
Whole spine	Deformity, pain	Ploumis
	Numerical rating	Surgical indication score-ASD
	Stability; etiology	Faldini
Whole patient	Age, acceptable operation time and blood loss, 3CO or fusion segments $>$ 10	Yoshida
Whole spine	Etiology	SRS classification
	Potential of curve progression	Aebi
Lumbar	Numerical rating	Silva Classification
Whole body	Posture	Wiles
Cervical	Alignment	Cervical alignment classification
		Grauer
	Alignment; balance	Cervical sagittal balance classification
	Alignment; deformity	Toyama
	Deformity	Katsuura
		Modified Ohara
Lumbar	Alignment	Schwab lumbar classification
	Balance	Lee morphologic classification of saggital decompresssion
Thoracolumbar	Alignment	Schwab preliminary
		Smith
		Spinal curvature
		Spinal thoracolumbar curvature
	Curve type, lumbar lordosis, intervertebral subluxation index, global balance	Schwab
	Deformity, degeneration; balance	SRS
	Pathological	Berjano-Lamartina
Whole spine	Alignment	Lamartina-Berjano
		Lee
		Mezghani
		Rothenfluh
		Simplified SRS-Schwab
		Takemitsu
	Alignment; balance	Bridwell
		Kendall
		SRS-Schwab
	Alignment; balance; anatomy	Brunei-Gavriliu
	Alignment; balance; flexibility	Taneichi
	Alignment; deformity	MISDEF
	Balance	Fujimori
		Mac-Thiong
	CT 3D	Kawakami
	Deformity	Kim
		Simmons
		Sponseller
	Kyphosis	Rajasekaran
		Wang

to classify the disease entity, formulate management algorithms, and compare outcomes for research purposes.

This systematic review confirms that existing classification systems include a diverse but noncomprehensive number of dimensions. Furthermore, their effects on outcomes are not well-researched, and the evidence between the relation of outcome and classification levels is limited. The underlying measurement properties of these classifications have not been evaluated by good quality studies that have a low risk of bias. Overall, based on the available literature, current classifications of ASD do not allow a comprehensive multimodal (bio-psychosocial) classification of patients holistically, which not only considers radiographic parameters, but also symptomatology, comorbidities, psychosocial parameters, and other concordant and relevant imaging modalities. Such a classification system is crucial in differentiating patients between treatment approach and helping establish treatment guidelines and compare outcomes according to the classification levels.

Limitations

This study has several limitations. First, this review included selection of classification tools and methodologies in clinical use in the literature but there is a possibility that not all classification systems have been identified. Nonetheless, we believe our search terms were very sensitive, yielding a total of 4470 references. Second, when the targeted spinal area of the classification was not unclear, but the whole spine was assessed to generate the classification, it was determined to be in the "whole spine." Third, only whole classifications were included in this review. Hence, studies that evaluated only part of a classification or based on only 1 parameter were excluded. Fourth, analysis of the measurement properties for items or modifiers that compose the classification systems was beyond the scope of this review and was not performed. Fifth, the end of the search period was 2 yr ago and as a consequence, more recent publications were not included. The purpose of our review was to evaluate different classifications used and to highlight that none of the existing classification systems fulfilled a comprehensive clinically oriented approach for ASD patients. To our knowledge, as yet, no new and different classification systems have been published.

CONCLUSION

In this systematic review, 54 classification systems for ASD were identified and described. The most frequently described and used system to characterize the spine for preoperative planning was the SRS-Schwab classification. No classification included a comprehensive set of multimodal (bio-psychosocial) dimensions that are relevant to patients with ASD, that support decision-making for treatment management, and that contribute to treatment outcomes. No evidence was found on the effect of classification systems on outcome. A new adequate classification system for ASD of high methodological quality, considering these shortcomings, is needed.

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Supplemental File 1. List of included classifications.
Supplemental File 2. Classifications in relation to outcomes.
Supplemental File 3. Construct validity of classification systems.
Supplemental File 4. Predictive validity of the Yoshida sliding scale.
Supplemental File 5. Intraobserver reliability of classifications.
Supplemental File 6. Interobserver reliability of classifications.