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REVIEW ARTICLE

Adult spinal deformity correction surgery using age-adjusted alignment thresholds: clinical outcomes and mechanical complication rates. A systematic review of the literature

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Abstract

Purpose Adult spinal deformity (ASD) surgery gives good clinical outcomes but has a high rate of mechanical complications (MC). In 2016, Lafage described the age-adjusted alignment thresholds (AAAT) to adapt the correction in relation to patient's age proposing less aggressive corrections for the elderly population. The aim of this review was to clarify the effectiveness of AAAT to achieve good health-related quality of life (HRQoL) and their relationship with post-operative MC.

Materials and methods We performed a review of the literature, including articles reporting data on post-operative HRQoL and MC rates in relation to the AAAT. Data were stratified according to whether they matched the AAAT, dividing the population in undercorrected (U), matched (M) and overcorrected (O). The quality of the included studies was assessed using the GRADE and MINORS systems.

Results Six articles reporting data from 1,825 patients were included. The different categories (U, M and O) had homogeneous pre-operative sagittal parameters ($p > 0.05$) that became statistically different after surgeries ($p < 0.05$). Proximal junctional kyphosis (PJK) was more frequent in the O group compared to U ($p = 0.05$). Post-operative HRQoL parameters were similar in the 3 groups ($p > 0.05$). The quality of the included studies was generally low with a high bias risk.

Conclusion The results extrapolated from this review are interesting, as for the same HRQoL the U group had a lower MC rate. Unfortunately, the results are inconsistent, mainly because of the low quality of the included studies and the lack of reporting of some important patient- and surgery-related factors.

Keywords Age-adjusted alignment thresholds · Adult spinal deformity · Adult scoliosis · Sagittal balance · Mechanical complications

Introduction

Due to the ageing of the world's population, ASD is becoming an increasingly common condition, causing back pain, neuropathy, disability and excessive costs to health systems [1–4]. ASD surgery has been shown to be effective in improving patient outcomes with a progressive reduction in costs for healthcare systems [5]. Nevertheless, ASD surgery is still associated with a high post-operative MC rate, especially in older patients or when major corrections are performed [6, 7].

Adequate pre-operative planning to achieve correct sagittal balance with proper alignment is crucial to improve patient's HRQoL and ultimately reduce post-operative MC rate [8, 9]. Over the past decades, many studies on sagittal alignment have been conducted and formulas proposed to improve patient outcomes and reduce MC, but age has only been marginally considered in these pre-operative plannings [10–12]. It is known that sagittal alignment normative values may change with age and consequently physical function and HRQoL may deteriorate [13–15].

In 2016, Lafage et al., proposed age-specific realignment targets for ASD patients' surgery planning [16]. According to the authors, the goal of ASD surgical correction is to find an ideal (age-related) range of alignment correction that correlates with as little disability as possible; the authors

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point out that a more modest correction of the deformity may be necessary in elderly subjects to achieve an acceptable HRQoL. Elderly subjects naturally have an element of sagittal imbalance with a reduction in lumbar lordosis (LL), a modest increase in anterior trunk shift and compensatory pelvic retroversion; furthermore, elderly patients may have associated muscle degeneration and impaired neurosensory postural control [17–19]. Following the concept that "the surgeon cannot make the degenerated and deformed spine as new", the authors proposed formulas to achieve age-corrected spino-pelvic alignment parameters (PT, PI-LL, SVA and T1 pelvic angle (TPA)) that are associated with satisfactory patient-reported outcomes [16, 20] (Fig. 1).

The aim of our systematic review is to analyse the evidence in the current literature concerning the actual validity of the age-adjusted alignment thresholds (AAAT) for achieving good HRQoL and their relation to the occurrence of post-operative MC.

Materials and methods

Inclusion criteria and outcome measures

We performed a systematic review of the literature, following the Cochrane Handbook of Systematic Reviews of interventions [21] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [22] for study selection (Fig. 2). The research was conducted from 1 January 2016 to 1 April 2023 in the following databases: the Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE/PubMed, Embase, Scopus, the Science Citation Index Expanded from Web of Science, ScienceDirect. The search was conducted using the keywords: "adult spinal deformity correction", "mechanical complications spinal surgery", "junctional kyphosis", "spinal surgery failure", "spinal revision surgery", "spinal surgery implant-related complications", "adult spinal deformity", "Age-specific", "Age-adjusted Alignment Thresholds", "elderly", "realignment", "sagittal alignment", "sagittal balance", "sagittal malalignment", "spino-pelvic alignment", "Age-adjusted alignment". We only included original retrospective or prospective articles focusing on AAAT, which extensively

$$\text{PI-LL} = \frac{(Age-55)}{2} + 3 \qquad \text{PT} = \frac{(Age-55)}{3} + 20$$

$$\text{SVA} = 2\,(Age - 55) + 25 \qquad \text{TPA} = \frac{(Age-55)}{2} + 16$$

Fig. 1 Formulae for Age-Adjusted Ideal PI-LL (pelvic incidence minus lumbar lordosis mismatch), PT (pelvic tilt), SVA (sagittal vertical axis) and TPA (T1-pelvic angle)

reported radiological and clinical data and MC rates with a minimum 6-month follow-up (FU). We excluded all case reports, technical notes, abstracts, editorial comments, ex vivo studies, pre-clinical studies (in animal or cadaveric models) and non-English publications. We collected the following data: number of patients, gender, age, mean FU, male-to-female ratio (M:F), mean number of levels fused, the AAAT parameters (PT, PI-LL, SVA and TPA), HRQoL parameters (ODI and SRS-22) and the MC rate (proximal junctional kyphosis, PJK: > 10° kyphosis between the UIV and + 2 vertebrae; proximal junctional failure, PJF: defined as a symptomatic PJK requiring a surgical revision). Whenever possible, data were stratified according to whether they matched the AAAT, dividing the population in undercorrected (U), matched (M) and overcorrected (O).

Assessment of study quality and risk of bias

The level of evidence of the included studies was assessed through the adjusted Oxford Centre for Evidence- Based Medicine 2011 Levels of Evidence [23]. Two separate observers (FV and MS) defined the quality of the studies using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) system [24]. The risk of bias was classified using the Methodological Index for Non-Randomised Studies (MINORS) [25]. In case of doubt about the score, a third observer (EQ) intervened. Each MINORS entry was given a score of 0 if absent, 1 if present but inadequate and 2 if present and adequate. The ideal score for uncontrolled studies was 16: these types of studies were considered at considerable risk of bias when the overall score was ≤ 12 and at low risk of bias when > 12.

Statistical analysis

Statistical analysis was performed using the SPSS version 20.0 for Windows (IBM Corporation, Armonk, NY, USA). All categorical variables were expressed as number of cases or percentages. Continuous variables were reported as mean ± standard deviations (SD). The distribution of the population in the different groups (U, M and O) according to the AAAT parameters was assessed with a nonparametric Kruskal–Wallis test. The comparison between the separate groups (U, M and O) concerning the correction of the main AAAT parameters was performed using a student t-test. The incidence of MC in the 3 groups and the clinical outcomes were compared with a Mann–Whitney test. Two-sided p values and/or the 95% confidence interval (CI) were reported, and significance was accepted at $p < 0.05$.

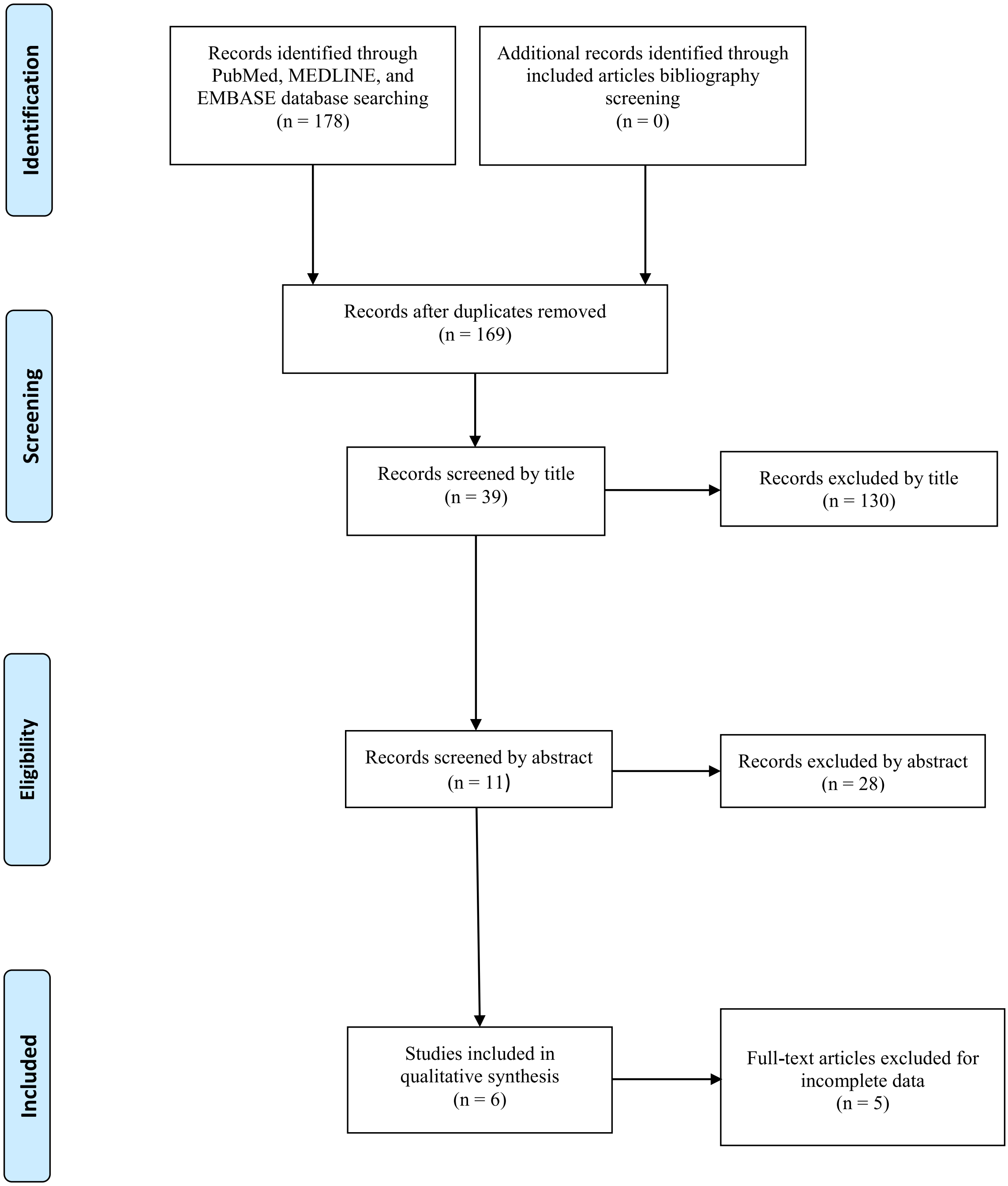

Fig. 2 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart for the search and inclusion strategy

Results

After a thorough review, we finally included 6 retrospective articles: all articles were LoE III [26–31]. Actually, 11 articles would have been suitable to be included but in an attempt to raise the impact of this review we excluded 5 of them because they reported incomplete data. The 6 articles included 1,825 patients with a mean age of 63.2 ± 4.3 years (CI 95% 58.6 to 67.7) and 79.9% were females; the mean number of levels fused was 7.4 ± 1.9 (CI 95% 4.4 to 10.5) and the mean FU was 27.5 ± 23.4 months (CI 95% 2.9 to 52) (Table 1).

The mean pre-operative sagittal parameters were: SVA 96.9 ± 29.9 mm (CI 95% 59.8 to 134), PT 30.5 ± 4.6° (CI 95% 24.7 to 36.2) and PI-LL 31.9 ± 14° (CI 95% 14.5 to 49.3). (Unfortunately, TPA was reported by only one author and could not be analysed.) Post-operatively, mean SVA

Table 1 Included articles

Authors	Type of study	LoE	Pop	Mean age (yrs)	M:F	Mean FU (months)	Fused levels
[26]	Retrospective	3	679	61	156:523	12	–
[27]	Retrospective	3	343	57 ± 15.1	56:284	24	–
[28]	Retrospective	3	122	61.7 ± 14.6	43:79	6	10
[29]	Retrospective	3	78	67.7 ± 6.8	4:74	24	7.8 ± 1.9
[31]	Retrospective	3	409	63	82:327	26.6	> 6
[30]	Retrospective	3	194	68.5	22:172	72.3 ± 27.3	5.9 ± 2.1

LoE: level of evidence; Pop: population; yrs: years; FU: follow-up

became 35.7 ± 16.3 mm (CI 95% 18.6 to 52.7), PT was 22.7 ± 1.3° (CI 95% 21.3 to 24) and PI-LL was 8.9 ± 4.3° (CI 95% 4.4 to 13.4) (Table 2).

The population was stratified in order of U, M or O in relation to the AAAT as follows: SVA, 28.4 ± 5.7% (CI 95% 14.3 to 42.4) were U, 28.9 ± 3.8% (CI 95% 19.5 to 39.3) were M and 42.8 ± 9.2% (CI 95% 20 to 65.6) were O; PI-LL, 33.1 ± 8.8% (CI 95% 19 to 47.2) were U, 27.9 ± 10.7% (CI 95% 10.9 to 44.9) were M and 40.2 ± 8.5% (CI 95% 26.7 to 53.7) were O; PT, 36.4 ± 6.2% (CI 95% 20.9 to 51.9) were U, 25.3 ± 3.6% (CI 95% 16.3 to 34.3) were M and 38.3 ± 9.8% (CI 95% 13.9 to 62.8) were O (TPA could not be analysed due to insufficient data). Using a nonparametric Kruskal–Wallis test, no statistically significant difference was observed in the distribution of the population based on the different AAAT parameters (SVA, $p = 0.479$; PI-LL, $p = 0.445$; PT, $p = 0.676$). Overall, 32.6 ± 4% (CI 95% 22.7 to 42.6) were U, 27.4 ± 1.9% (CI 95% 22.8 to 32) were M and 40.4 ± 2.3% (CI 95% 34.8 to 46.1) were O (Table 3).

Unfortunately, only two articles [29, 30] reported on the sagittal parameters' correction in the different AAAT categories. In category U, the pre-operative sagittal parameters were SVA 126 ± 64.5 mm (CI 95% -453.4 to 705.4), PI-LL 56.9 ± 16.6° (CI 95% -92.5 to 206.2), PT 40.9 ± 4.2° (CI 95% 2.8 to 79); these parameters were corrected post-operatively as follows: SVA 39.4 ± 0.5 mm (CI 95% 34.9 to 43.8), PI-LL 26.7 ± 2.4° (CI 95% 5.1 to 48.3), PT 30.4 ± 2.8° (CI 95% 5 to 55.8). In category M, the pre-operative sagittal parameters were SVA 98 ± 29.7 mm (CI 95% -168.8 to 364.8), PI-LL 41.3 ± 9.1° (CI 95% -40 to 122.6), PT 32.6 ± 3.5° (CI 95% 1.4 to 63.7); these parameters were corrected post-operatively as follows: SVA 22.3 ± 3.3 mm (CI 95% -7.6 to 52.1), PI-LL 9.1 ± 0.3° (CI 95% 6.6 to 11.6), PT 20.2 ± 0.4° (CI 95% 16.4 to 24). Finally, in category O, the pre-operative sagittal parameters were SVA 108.6 ± 45.5 mm (CI 95% -300.5 to 517.7), PI-LL 38.6 ± 10.3° (CI 95% -53.6 to 130.7), PT 31.7 ± 3.5° (CI 95% 0.5 to 62.8); these parameters were corrected post-operatively as follows: SVA 2.4 ± 7.5 mm (CI 95% − 64.9 to 69.7), PI-LL − 6.4 ± 2.9° (CI 95% − 32.4 to 19.7), PT 13.3 ± 0.1° (CI 95% 12.6 to 13.9). Pre-operatively the populations were homogeneous analysing the 3 different parameters ($p > 0.05$) while post-operatively all AAAT parameters mean values reached a statistically significant difference ($p < 0.05$) with the only exception of the M Vs O post-operative SVA ($p = 0.076$).

Analysing the PJK rate, these occurred in 28.5 ± 13.2% (CI 95% -4.2 to 61.3) of U patients, 36.1 ± 11.2% (CI 95% 8.5 to 64.3) of M patients and 53.9 ± 17.8% (CI 95% 9.8 to 98.1) of O patients with a significant difference between the U and O groups ($p = 0.05$). PJF occurred in 14 ± 13.4% (CI 95% − 19.4 to 47.3) of the U, 22.9 ± 14.4% (CI 95% − 12.8 to 58.7) of the M and 28.9 ± 20.4% (CI 95% − 21.8 to 79.7) of the O but no statistically significant difference was observed ($p > 0.05$). Unfortunately, analysis of the MC rate by age was not possible due to the inconsistency of the data (Table 4).

Regarding clinical outcomes, the most frequently used parameters were ODI and SRS-22. The ODI parameters in relation to the AAAT were as follows: U, 33 ± 6.8 (CI 95% 22.2 to 43.9); M, 30.6 ± 8.4 (CI 95% 17.2 to 44); O, 32.9 ± 12.5 (CI 95% 13 to 52.9). The SRS-22 in relation to the AAAT were U, 3.5 ± 0.1 (CI 95% 3.3 to 3.6); M, 3.6 ± 0.2 (CI 95% 3.2 to 4); O, 3.4 ± 0.5 (CI 95% 2.1 to 4.7). For clinical outcomes, no statistically significant difference was observed between the separate groups ($p > 0.05$) (Table 5).

All included articles were judged to be of low quality according to the GRADE system, mainly due to their retrospective nature, and the risk of bias was high with a mean MINORS score of 11.2 ± 1 (CI 95% 10.1 to 12.2) (Tables 6 and 7).

Discussion

When treating an ASD, it is nowadays well accepted that the goal of surgery is to achieve a correct sagittal balance that respects the concept of conus of economy proposed by Dubousset [32, 33]. What is still debated is how to align the spine to achieve the correct balance while avoiding post-operative MC. To date, there are two main philosophies of correction. The first one proposed by Yilgor et al., the GAP score, in which the authors hypothesise that by matching the ideal alignment using formulas based on pelvic incidence (PI) the MC rate could be largely reduced [11]; unfortunately, despite the excellent results reported in the

Table 2 Sagittal alignment parameters

Authors			Mean preop SVA (mm)	Mean postop SVA (mm)	Mean preop TPA (°)	Mean postop TPA (°)	Mean preop PI–LL (°)	Mean postop PI–LL (°)	Mean preop PT (°)	Mean postop PT (°)
[26]			109.6	36.1	–	–	27.9	5.4	29.5	23.4
	Tot	PJK	–	31.6	–	–	–	1.9	–	23.1
		No–PJK	–	41.2	–	–	–	8.2	–	23.6
	<40 yrs	PJK	–	–16.5	–	–	–	–10	–	11
		No–PJK	–	32.8	–	–	–	7.8	–	21.4
	40–65 yrs	PJK	–	35.1	–	–	–	3.1	–	23.6
		No–PJK	–	25.1	–	–	–	7.3	–	23.2
	>65 yrs	PJK	–	41.6	–	–	–	0.8	–	23
		No–PJK	–	53.3	–	–	–	9.8	–	24.7
[27]			–	65.8±77.9	–	–	–	15.6±21.7	–	23.6±11
[28]			73.1±73.8	35.8±51.8	–	–	20.5±21.8	9.5±17.7	27.1±12	24±10.9
[29]		Undercorr	171.6±72.9	39.7±49.4	–	–	68.6±16.8	25±14.2	43.9±11.2	28.4±13.6
		Matched	119±71	19.9±35.2	–	–	47.7±17.1	8.9±6.4	35±8.8	19.9±9.7
		Overcorr	140.8±73.5	−2.9±35.8	–	–	45.8±15.1	−8.4±9.1	34.1±10.4	13.2±7.3
[31]			80±71	33±52	25.8±12.3	18.5±10.4	20.6±19.1	3.5±14.4	26.1±10.4	22.5±10
[30]		No–PJF	68.9±53.3	24.9±29.7	–	–	34.5±19.4	13.2±12.6	31.1±10.4	22.2±9.8
		PJF	86.2±63.5	23.9±36.1	–	–	38.7±20.2	8.8±12.9	32.6±11.6	21.5±9.8
		Undercorr	80.4±5.8	39±33.4	–	–	45.1±16.3	28.4±8.3	37.9±9.5	32.4±10
		Matched	77±62.8	24.6±32.3	–	–	34.9±19.6	9.3±6.1	30.1±10.8	20.5±6.4
		Overcorr	76.4±59.9	7.7±26.7	–	–	31.3±21.6	−4.3±4.3	29.2±10.9	13.3±5.5

SVA: sagittal vertical axis; TPA: T1 pelvic angle; PI-LL: pelvic incidence minus lumbar lordosis; PT: pelvic tilt; PJK: proximal junctional kyphosis

Table 3 Population distribution in the different AAAT categories

Authors	Age-adjusted Alignment Thresholds											
	SVA (%)			TPA (%)			PI-LL (%)			PT (%)		
	U	M	O	U	M	O	U	M	O	U	M	O
[26]	–	–	–	–	–	–	–	–	–	–	–	–
[27]	32.8	33.1	34	–	–	–	36.8	24.3	38.9	38.9	25.7	35.4
[28]	30.3	27.7	42	–	–	–	43.6	23.9	32.5	41	28.7	30.3
[29]	–	–	–	–	–	–	23.9	43.6	37.2	–	–	–
[31]	22	25.8	52.3	–	–	–	28	19.8	52.3	29.3	21.5	49.3
[30]	–	–	–	–	–	–	–	–	–	–	–	–

U: undercorrected; M: matched; O: overcorrected

Table 4 Mechanical complication rates in different AAAT categories

Authors		NO-PJK (%)	PJK (%)	S-PJK (%)	PJF (%)
[26]		–	45.1	–	–
[27]		–	–	–	–
[28]		–	–	–	–
[29]	Under	–	13.3	–	13.3
	Matched	–	26.5	–	26.5
	Over	–	48.3	–	27.6
[31]	Under	56.5	36.1	6.5	0.9
	Matched	51.7	34.1	7.1	7.1
	Over	38.6	39.6	12.6	9.2
[30]	Under	–	36.2	–	27.7
	Matched	–	48.6	–	35.2
	Over	–	73.8	–	50

PJK: proximal junctional kyphosis; S-PJK: severe PJK; PJF: proximal junctional failure

original article, these have not been confirmed by the current literature [34]. The second theory is that of tailoring the necessary correction to patients according to their age: less aggressive procedures might be appropriate for older patients and correlate with fewer MC [9, 10]. The concept of a tailored approach has been further developed by Lafage et al. who centralised the importance of age as one of the main parameters to be considered when planning an ASD correction: the authors point out that in the general population, due to normal degeneration processes, it is normal for older subjects to have worse alignment parameters (PT; SVA; PI-LL; TPA) and that these may correspond to same HRQoL scores equal to those of younger subjects with better spinal alignments [16].

The result of the current review confirms how, despite significant differences in post-operative sagittal parameters ($p < 0.05$), HRQoL (ODI and SRS-22) is statistically

Table 5 Clinical outcomes

Authors	ODI			SRS-22		
	U	M	O	U	M	O
[26]	–	–	–	–	–	–
[27]	30.6	26.3	27	3.5	3.7	3.7
[28]	–	–	–	–	–	–
[29]	26.3	26.7	24.9	–	–	–
[31]	32.8	26.2	28.1	3.5	3.7	3.7
[30]	42.4	43.2	51.6	3.4	3.4	2.8

ODI: Oswestry disability index; SRS-22: Scoliosis Research Society-22; U: undercorrected; M: matched; O: overcorrected

Table 6 GRADE system evaluation of the included studies

Authors	Apriori GRADE	Risk of bias	Inconsistency of Results	Indirectness of evidence	Imprecision	Reporting bias	Final GRADE
[26]	Low	**Y**	**N**	**N**	**N**	**Y**	Low
[27]	Low	**Y**	**N**	**N**	**Y**	**Y**	Low
[28]	Low	**Y**	**N**	**N**	**Y**	**Y**	Low
[29]	Low	**Y**	**N**	**N**	**N**	**Y**	Low
[31]	Low	**Y**	**N**	**N**	**Y**	**Y**	Low
[30]	Low	**Y**	**N**	**N**	**N**	**Y**	Low

Y: yes; N: no

Table 7 MINORS criteria for risk of bias: 0, absent; 1, present but inadequate; 2, present and adequate

Authors	Clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoint appropriated to the aim of the study	Unbiased assessment of the study endpoint	Follow–up period appropriate to the aim of the study	Loss to follow-up less than 5%	Prospective calculation of the study size	Total MINORS score for non-controlled studies
[26]	2	2	2	2	1	2	1	0	12
[27]	2	2	2	2	1	2	1	0	12
[28]	2	2	2	2	1	2	1	0	12
[29]	2	2	0	2	1	2	1	0	10
[31]	2	2	1	1	0	2	1	0	11
[30]	2	2	0	2	1	2	1	0	10

equal ($p > 0.05$) regardless of whether patients are U, M or O in relation to the AAAT. This result could confirm the idea that less aggressive corrections may be sufficient to achieve acceptable clinical post-operative outcomes [9, 35]. Arima et al. showed that, at least in the Japanese population, the minimal clinically major difference in the SRS-22 was smaller in patients older than 70 years than in those younger than 70 years, which may imply that older patients have lower expectations than younger ones [36]. In the pre-operative planning phase, the surgeon should consider what the patients' goals are: an elderly patient could probably accept a moderate level of disability (ODI 20 to 40) because it is part of the normal degenerative process of ageing, and this target could be reached with less aggressive corrections than those that should be proposed to younger patients with higher expectations [37].

As anticipated, the most important aspect to consider in ASD correction is the overall balance of the spine, which should be achieved by correcting the curves according to the specific alignment of each subject [33]. Unfortunately, one of the weaknesses of this review is that the AAAT parameter of overall balance, TPA, could not be analysed because it is rarely reported. On the other hand, SVA has been consistently reported, but this parameter has several limitations as it is not an angular parameter and only considers the thoracolumbar segments; it has already been reported that consideration of overall balance of the spine, possibly using the odontoid to hip axis angle (OD-HA), is more appropriate in this kind of pathology [38]. Overall balance analysis using T1 or C7 as the most cranial vertebra is not sufficient, as it is of foremost importance to include the cervical spine in the balance analysis, as the cranio-cervical complex may exert a strong lever arm on the UIV, possibly playing a role in the occurrence of PJK [39–41].

Considering the rate of PJK in relation to the AAAT, this review shows how the O patients have a higher incidence of this MC than U patients ($p < 0.05$). This could be explained by the fact that an overcorrection of the LL might cause a posterior shift of the trunk with a negative SVA, and this may create an unfavourable lever arm on the UIV that might not be tolerated by elderly patients with weak muscles and osteoporosis. This could be particularly evident if patients are unable to tilt their pelvis anteriorly, a condition known as pelvic non-responders that can be seen in up to 75% of ASD patients [28, 42, 43]. Interestingly, the rate of PJK did not translate into a higher PJF rate in the O patients ($p > 0.05$) and this may explain why the clinical outcomes were similar; this contradictory result can reduce the clinical impact of the previous finding and the possibility of validating the AAAT, as previously reported by Dial et al. [44]. The contradictory rate of PJK and PJF may be a consequence of the small sample included in the review and the overall low quality of the included studies.

Unfortunately, the current literature does not report data stratified by age: it would be very interesting to evaluate the MC rate and HRQoL by dividing the population by age (e.g. in young adults, middle age and elderly) and to match the results by AAAT group (U, M and O); in order to demonstrate whether elderly people have better outcomes with less aggressive corrections than younger patients who might benefit from more aggressive ones, these groups should be analysed separately and stratified according to whether or not they matched the AAAT [45].

This review has several other limitations; one of the main ones being that the authors did not use homogeneous intervals to define whether a patient was U, M or O in relation to the AAAT. Lafage et al. in 2017 divided patients into the distinct categories considering the mismatch between the ideal AAAT and the post-operative parameters without clearly defining the intervals [26]. Two authors considered a target alignment range of ± 10 years from the expected AAAT as the limits of AAAT matching [27, 28]. Two other authors used the PI-LL mismatch differentiating the patients in: U, PI-LL $< -10°$; M, PI-LL $\pm 10°$; O, PI-LL $> 10°$ [29, 30]. Finally, Lafage et al. in 2022 proposed the sagittal age-adjusted score (SAAS), in which they used the differences between ideal and post-operatives PI-LL, PT and TPA, assigning 0 points if the parameter was within 10 years of the ideal range, 1 point if it was between 10 and 30 years, −1 if it was between −10 and −30 years, 2 points between 30 and 50 years and −2 points between −30 and −50 years; they then calculated a score given by the 3 parameters and a SAAS of -2 or less defined the U group, a SAAS between -1 and + 1 was M and a SAAS 2 or more defined the O [31]. Not using the same intervals reduces the possibility of standardising outcomes and consequently reduces the impact of these age-adjusted thresholds.

There are several other weaknesses: first of all, the AAAT does not provide any notion on the distribution of the lumbar lordosis, and this parameter was not reported in the included studies, but today we know that not all patients have the same spine shape and it is essential to distribute the lordosis correctly on the basis of the type of Roussouly of each patient and more generally distribute 2/3 of the angle at the L4S1 segments [46, 47].

Furthermore, the surgical techniques used to achieve corrections have only been reported in rare cases and this is a huge bias, as we know that there are surgical factors, such as performing a pedicle subtraction osteotomy, which increase the risk of mechanical and general complications and consequently worsen the outcomes [9, 48, 49].

Finally, there are important patient-related factors such as the BMD, paraspinal muscle quality and the frailty status that can affect surgical outcomes and MC rate, but none of these factors were considered in the included studies [50–52]. Actually, it might be even more pertinent to consider patient's biological age and not only the chronological one. Since several distinct factors play a role in ASD surgery outcomes, an aid in pre-operative planning could come from the use of artificial intelligence, which should be based on multicentric registries collecting prospective and highly accurate data [53, 54].

In conclusion, we can state that the AAAT seems promising in ASD surgery planning, as it tries to adapt the correction according to the patient's age. From this review, it seems that overcorrections increase the incidence of MC and that the clinical outcomes are similar despite the AAAT category: this could lead the surgeon to prefer less extreme corrections that give good clinical outcomes with fewer MC. Unfortunately, the evidence derived from this review is very weak and cannot validate the AAAT mainly due to a non-standardised and low-quality literature.

Conclusion

The concept proposed by Lafage et al. with the AAAT is very interesting and the initial results extrapolated from this review seem promising in that equal HRQoL outcomes correspond to lower rates of PJK in the undercorrected group. Unfortunately, a more precise analysis of the data points to an overall low quality of the available literature, mainly due to non-standardised data collection and patient stratification. Further prospective studies with homogeneous data on clinical, radiological and mechanical complication outcomes could validate this interesting guideline.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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