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ORIGINAL ARTICLE

Adherence to the Obeid coronal malalignment classification and a residual malalignment below 20 mm can improve surgical outcomes in adult spine deformity surgery

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Abstract

Purpose Coronal balance is a major factor impacting the surgical outcomes in adult spinal deformity (ASD). The Obeid coronal malalignment (O-CM) classification has been proposed to improve the coronal alignment in ASD surgery. Aim of this study was to investigate whether a postoperative CM < 20 mm and adherence to the O-CM classification could improve surgical outcomes and decrease the rate of mechanical failure in a cohort of ASD patients.

Methods Multicenter retrospective analysis of prospectively collected data on all ASD patients who underwent surgical management and had a preoperative CM > 20 mm and a 2-year follow-up. Patients were divided in two groups according to whether or not surgery had been performed in adherence to the guidelines of the O-CM classification and according to whether or not the residual CM was < 20 mm. The outcomes of interest were radiographic data, rate of mechanical complications and Patient-Reported Outcome Measures.

Results At 2 years, adherence to the O-CM classification led to a lower rate of mechanical complications (40 vs. 60%). A coronal correction of the CM < 20 mm allowed for a significant improvement in SRS-22 and SF-36 scores and was associated with a 3.5 times greater odd of achieving the minimal clinical important difference for the SRS-22.

Conclusion Adherence to the O-CM classification could reduce the risk of mechanic complications 2 years after ASD surgery. Patients with a residual CM < 20 mm showed better functional outcomes and a 3.5 times greater odd of achieving the MCID for the SRS-22 score.

Keywords Adult spinal deformity · Coronal alignment · Health-related quality of life · Patient-related outcome measures · Mechanical complications · Obeid coronal malalignment classification

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Introduction

While sagittal malalignment is often considered the main drive of poor surgical outcomes after adult spine deformity (ASD) correction [1], persistent coronal malalignment (CM), defined as lateral displacement of the C7 coronal plumbline from the central sacral vertical line (CSVL), is also correlated with poor functional and radiological outcomes and implant failure [2, 3]. In fact, a greater coronal tilt of L4 or L5 and type C coronal malalignment according to Bao classification (CM > 3 cm with a shift to the concave side of the curve) have been identified as risk factors for poor outcomes after degenerative lumbar scoliosis surgery [4, 5]. In contrast, coronal realignment has been associated with a significant improvement of radiographic and clinical parameters, Health-Related Quality of Life scores (HRQoL) and self-image assessment [6]. Thus, surgical planning should consider both coronal and sagittal parameters to avoid pitfalls in the management of this challenging deformity [7, 8]. When considering coronal realignment, different strategies should be adopted according to the type and location of the main curve [9, 10]. The Obeid coronal malalignment (O-CM) classification identifies six types of coronal deformity and provides surgical strategies for each [11]; however, it is not yet known whether adherence to this classification yields an improvement of surgical outcomes. Aim of this study was to investigate whether adherence to the O-CM algorithm and a postoperative CM < 20 mm improved radiological and clinical outcomes in a large cohort of ASD patients.

Material and methods

The study was conducted following the guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement [12].

O-CM classification and surgical planning

The O-CM classification identifies six types of coronal deformity: 1A1 (concave CM with flexible thoracolumbar/lumbar main curve), 1A2 (concave CM with rigid thoracolumbar/lumbar main curve), 1B (concave CM with main cervicothoracic/thoracic curve), 2A1 (convex CM with flexible, non-degenerated lumbosacral junction), 2A2 (convex CM with rigid, degenerated lumbosacral junction) and 2B (main short lumbosacral deformity/convex-like CM) [11]. This classification system has been shown to have good intra- and inter-observer reliability in the identification and classification of different CM types [13]. For each curve type, the algorithm suggests a specific correction strategy (CS), region of interest (ROI) and fusion length (FL) [11].

Patient population

This was a retrospective review of a prospective ASD database collected from five centers. All patients were enrolled into an institutional review board-approved protocol by the respective sites. Data from all consecutive patients who underwent ASD surgery with a minimum follow-up of 2 years were obtained. Inclusion criteria were: age > 18 years and presence of a spinal deformity defined by one of the following parameters: Cobb angle ≥ 20°, pelvic tilt (PT) ≥ 25°, sagittal vertical axis (SVA) ≥ 5 cm or thoracic kyphosis (TK) ≥ 60°. For the present study, only patients with a preoperative CM > 20 mm were included for analysis.

Study design

Based on preoperative standing full-length spine X-rays, patients were classified according to the 6 types of the Obeid-CM classification. The type of corrective surgery was assessed on postoperative full-length spine X-rays. The classification was carried out by two of the authors, both experienced spine surgery consultants. Disagreements were discussed with a third author until a unanimous decision was taken. Fusion length, use of anterior release, lumbosacral fusion, and grade and location of osteotomy were recorded.

Patients were divided in two groups according to whether or not surgery had been performed following the indications of the O-CM classification. Specifically, the authors assessed whether the correction strategy (CS), region of interest (ROI) and fusion length (FL) were in accordance with the algorithm: had all three points been respected in the surgical planning, the patient was classified as “Adherence to the O-CM group.” In case of discordance of one or more criteria, the patient was classified as “Non-adherence to the O-CM group.”

For each of the six types of CM deformities, surgical planning criteria were as follows: for type 1A1, CS was multilevel posterior column osteotomies (PCO) or anterior release; for type 1A2 and 1B, CS was a 3-column osteotomy (3-CO) at the apex of the main curve. For type 2A1, CS was main curve correction with FL limited to L4 or above. For type 2A2, the ROI was the main lumbar curve, the CS was 3-CO or anterior release at the lumbosacral junction, and the FL was extended to the pelvis. Type 2B required short fusion of the lumbosacral junction in terms of FL, with CS consisting of a 3-CO at the apex of the lumbosacral curve [11].

The choice of the surgical strategy was solely decided by the surgeon conducting the procedure, and many considered patients had been operated prior to the publication of the O-CM classification.

Outcomes of interest

Radiographic data were collected before surgery and at 6 months and 2 years postoperatively (coronal balance, Cobb angle, global tilt—GT and PI). All measurements were conducted on whole spine, frontal and lateral x-rays using the KEOPS Balance Analyzer 3D software (S.M.A.I.O.). Leg length discrepancy (LLD) was evaluated for all patients, but as the observed LLD was not clinically significant in any of the considered cohorts, this parameter was not included in further analysis. Functional outcomes were evaluated with the Scoliosis Research Society-22r (SRS-22r), the Oswestry Disability Index (ODI) and the Short Form Health Survey (SF-36), which were obtained at baseline and at each follow-up. In addition, the occurrence of mechanical complications was recorded.

The “Adherence” and “Non-adherence” groups were compared for baseline characteristics (age, gender, BMI, ASA score, radiographic characteristics and functional outcomes). Radiographic parameters, functional outcomes and rate of mechanical complications at the 2-year follow-up were compared between the two groups. The considered mechanical complications were rod breakage and pseudarthrosis-related complications, screw break and implant loosening, and junctional segmental complications such as such as kyphosis (PJK), failure (PJF) and adjacent segment degeneration. Pseudoarthrosis was diagnosed either on CT scan or when a rod breakage was observed in the X-ray imaging.

As a secondary outcome, the functional scores of the patients who did and did not achieve a correction of the CM after surgery were compared (CM $<$ 20 mm vs. CM $>$ 20 mm at the 2-year follow-up).

Lastly, different variables were compared between patients who did or did not achieve the SRS-22r Minimum Clinically Important Difference (MCID) of 0.77 [14].

Statistical analysis

Qualitative variables were analyzed in terms of frequencies and percentages for each parameter. Quantitative variables were expressed as means and standard deviations (SD).

For the analysis on adherence vs non-adherence to the O-CM classification and the analysis on clinical outcomes in patients with CM at 2 years $>$ or $<$ 20 mm, baseline comparability was tested and *T* tests and Chi^2 tests were performed to compare the two groups for continuous and dichotomous variables, respectively. In case of baseline differences, a propensity score was calculated and used to perform a match-paired analysis (caliper = 0.2 SD) to adjust for possible confounders. The propensity score was calculated considering all obtained baseline data (demographic, radiographic and functional outcomes parameter), with a caliper of 0.2 SD set for the matching.

To investigate what outcomes of interest were associated with the achievement of a the SRS-22r MCID, *T* test and a logistic regression were conducted for continuous and dichotomous/categorical variables, respectively.

Results

Of the 258 eligible patients, 205 (79.46%) had an available 2-year follow-up and were included in the analysis.

Outcomes of interest

Mechanical complications

Among the included patients, 105 were O-CM type 1 and 153 O-CM type 2. The summary of the baseline characteristics of the patients is shown in Table 1.

Considering the baseline differences between the two groups, a propensity score was calculated considering all obtained baseline data (demographic, radiographic and functional outcomes parameter) and was then used to perform a match-paired analysis.

The observed mechanical complications were distributed as follows: 46% were rod breakage and pseudarthrosis-related complications; 22% were screws breaks and implant loosening; 32% were proximal junctional segment complications, such as kyphosis (PJK), failure (PJF) and adjacent segment degeneration.

At 2 years, the unadjusted analysis showed fewer mechanical complications in the “adherence group” compared to the “non-adherence group” (31.1% vs 51.0%; $p = 0.008$). In each of the adherence subgroups (adherence to CS, adherence to FL and adherence to ROI), mechanical complication rates were lower compared to the no adherence group, but only statistical significance was achieved for the adherence to CS group (31% vs 54.8% $p = 0.003$).

The matched-paired analysis based on the propensity score included 122 patients, 92 from the adherence 30 from the non-adherence group. Only the correction strategy adherence comparison yielded significant results, but the

Table 1 Baseline characteristics of the included patients

	All patients $n = 258$	Adherence group $n = 209$	Non-adherence group $n = 49$	p value
General characteristics				
Women sex, n (%)	209 (81)	177 (84.7)	32 (65.3)	0.002
Mean age, years (+/− SD)	54.95 (18.06)	54.01 (18.33)	58.96 (16.43)	0.067
Mean BMI, kg/m^2 (+/− SD)	24.88 (4.30)	24.62 (4.26)	26.01 (4.3)	0.043
ASA				
1	61 (23.6)	55 (26.3)	6 (12.2)	0.004
2	159 (61.6)	130 (62.2)	29 (59.2)	
3	38 (14.7)	24 (11.5)	14 (28.6)	
Pre-op X-ray				
Mean coronal balance (C7 to CSVL) mm (+/− SD)	43.08 (26.67)	42.25 (26.41)	46.61 (27.72)	0.305
Mean real Cobb curve angle, degree (+/− SD)	47.53 (22)	48.51 (21.42)	43.28 (24.13)	0.138
Mean global tilt, mm (+/− SD)	31.50 (19.38)	30.59 (19.57)	35.61 (18.12)	0.112
Mean pelvic incidence, degree (+/− SD)	55.07 (12.44)	55.25 (12.61)	54.30 (11.74)	0.638
Pre-op functional outcomes				
Mean ODI, % (+/− SD)	41.34 (19.90)	41.12 (19.57)	42.27 (21.45)	0.719
Mean SRS-22 total score (+/− SD)	2.69 (0.66)	2.7 (0.66)	2.65 (0.66)	0.680
Mean SF-36-PCS (+/− SD)	35.38 (9)	35.53 (9.19)	34.75 (8.22)	0.587
Mean SF-36-MCS (+/− SD)	42.17 (11.55)	42.37 (11.55)	41.36 (11.59)	0.583
Pelvic fixation, n (%)	143 (55.4)	33 (67.3)	110 (52.6)	0.062
O-CM modifiers				
Type 1, n (%)				
1A1	57 (22.1)	52 (24.9)	5 (10.2)	
1A2	34 (13.2)	22 (10.5)	12 (24.5)	
1B	14 (5.4)	10 (4.8)	4 (8.2)	
Type 2, n (%)				
2A1	71 (27.5)	66 (31.6)	5 (10.2)	
2A2	55 (21.3)	46 (22)	9 (18.4)	
2B	27 (10.5)	13 (6.2)	14 (28.6)	

Table 2 Summary of the unadjusted comparison of the rate of mechanical complications in the adherence and non-adherence groups, in the unadjusted and match-paired analysis

	Mechanic complications at 2 years (%)			
	Unadjusted analysis		Match-paired analysis	
All parameters	Adherence group $n = 209$	31.1%	Adherence group $n = 92$	42.4%
	Non-adherence group $n = 49$	51.0%	Non-adherence group $n = 30$	60.0%
	p value	**0.008**	p value	0.09
Correction strategy	Adherence group $n = 216$	31.0%	Adherence group $n = 98$	41.8%
	Non-adherence group $n = 42$	54.8%	Non-adherence group $n = 24$	66.7%
	p value	**0.003**	p value	**0.02**
Region of interest	Adherence group $n = 249$	34.1%	Adherence group $n = 116$	44.8%
	Non-adherence group $n = 9$	55.6%	Non-adherence group $n = 6$	83.3%
	p value	0.18	p value	0.06
Fusion length	Adherence group $n = 236$	33.5%	Adherence group $n = 108$	45.4%
	Non-adherence group $n = 22$	50.0%	Non-adherence group $n = 14$	57.1%
	p value	0.12	p value	0.40

Bold values highlight statistically significant comparisons

Table 3 Summary of the comparison of coronal and sagittal alignment between the adherence and non-adherence groups

	Unadjusted analysis			Match-paired analysis		
		C7-CSVL at 2 years	Correction of C7-CSVL pre-op versus 2 years		C7-CSVL 2 years	Correction of C7-CSVL pre-op versus 2 years
All parameters	Adherence group $n=168$	20.2 (16.6)	16.6 (17.6)	Adherence group $n=92$	21.1 (17.6)	25 (26.4)
	Non-adherence group $n=34$	26.8 (17.4)	9.7 (17.4)	Non-adherence group $n=30$	21.3 (16.4)	23.9 (25)
	p value	**0.04**	**0.04**	*p* value	0.9	0.8
Correction strategy	Adherence group $n=173$	20.1 (16.7)	16.4 (16.7)	Adherence group $n=98$	20.7 (17.2)	25.5 (26.2)
	Non-adherence group $n=29$	28.4 (16.4)	8.1 (16.4)	Non-adherence group $n=24$	22.9 (17.6)	21.7 (24.4)
	p value	**0.01**	**0.01**	*p* value	0.6	0.6
Region of interest	Adherence group $n=195$	20.9 (16.8)	15.6 (16.8)	Adherence group $n=116$	21.4 (17.5)	24.4 (25.6)
	Non-adherence group $n=7$	32.9 (15.5)	3.6 (15.4)	Non-adherence group $n=6$	15.3 (8.9)	30.6 (36.5)
	p value	0.06	0.06	*p* value	0.5	0.6
Fusion length	Adherence group $n=187$	21 (16.7)	15.5 (16.7)	Adherence group $n=108$	21.4 (17.6)	24.6 (25.9)
	Non-adherence group $n=15$	24.9 (18.9)	11.5 (18.9)	Non-adherence group $n=14$	18.7 (14.1)	24.8 (27.4)
	p value	0.3	0.4	*p* value	0.6	0.9

Data are expressed in mm and as mean (SD)

CSVL Central sacral vertical line

Bold values highlight statistically significant comparisons

rate of complication was still consistently higher in the non-adherence group. Data are summarized in Table 2.

Coronal alignment

At 2 years, the coronal alignment and C7-CSVL correction was significantly better in the adherence vs non-adherence group in the unadjusted analysis. These results were not reflected in the adjusted analysis. A summary of the data is shown in Table 3.

Health-related quality of life

Considering the patients who did and did not achieve a CM < 20 mm at 2 years follow-up, the two groups showed a good baseline comparability in all the considered parameters (except the preoperative coronal balance), so that an adjusted analysis was not necessary (Table 4).

Overall, a persistent malalignment (CM > 20 mm) was associated with a poorer quality of life for most analyzed scores and subdomains 2 years after surgery. Details are shown in Table 5.

Discussion

In the presented cohort, adherence to the O-CM classification, and in particular to the correction strategy, could reduce the risk of mechanic complications 2 years after ASD surgery. Patients with a CM < 20 mm at the 2-year follow-up showed better functional parameters than those with a CM > 20 mm, and a CM < 20 mm resulted in a 3.5 times greater odd of achieving the MCID for the SRS-22 score.

Coronal alignment assessment has gained a lot of interest during the past few years [4, 15]. Following more than a decade of major focus on the study of sagittal alignment, significant advances have been made in understanding this field, including creation of multiple radiographic assessment parameters [16–19] and development of techniques to treat it in order to achieve satisfactory clinical and radiological outcomes [20]. However, it has become progressively clear that

Table 4 Summary of the baseline comparability between the two analyzed groups

	CM > 20 mm at 2 years	CM < 20 mm at 2 years	*p* value
Demographic data			
Mean age, years (+/− SD)	58.23 (16.20)	54.54 (18.52)	0.169
Mean BMI, kg/m^2 (+/− SD)	25.34 (4.46)	25.10 (4.13)	0.711
Preoperative radiographic data			
Mean coronal balance (C7 to CSVL) mm (+/− SD)	50.07 (27.22)	38.63 (19.65)	**0.002**
Sagittal balance, mm (+/− SD)	76.54 (65.45)	61.28 (70.12)	0.146
Mean global tilt, degree (+/− SD)	34.22 (17.35)	31.75 (20.85)	0.411
Pelvic tilt, degree (+/− SD)	24.78 (10.83)	25.01 (13.17)	0.901
Lordosis, degree (+/− SD)	34.94 (21.03)	38.59 (21.97)	0.270
Mean pelvic incidence, degree (+/− SD)	55.49 (12.61)	55.62 (13.51)	0.951
Preoperative functional outcomes			
Mean ODI, % (+/− SD)	43.29 (19.82)	41.44 (19.18)	0.536
Mean SRS-22 total score (+/− SD)	2.68 (0.60)	2.68 (0.63)	0.936
Mean SF-36-PCS (+/− SD)	34.54 (7.98)	35.51 (9.10)	0.464
Mean SF-36-MCS (+/− SD)	42.29 (12.17)	42.54 (10.98)	0.888
Radiographic data at 2 years follow-up			
Sagittal balance, mm (+/− SD)	34.63 (42.63)	32.68 (50.72)	0.789
Mean global tilt, degree (+/− SD)	23.97 (13.11)	23.68 (14.22)	0.891
Pelvic tilt, degree (+/− SD)	21.16 (9.47)	20.77 (10.13)	0.799
Lumbar lordosis, degree (+/− SD)	51.18 (14.24)	51.55 (15.85)	0.873
Mean pelvic incidence, degree (+/− SD)	55.46 (12.54)	55.98 (13.25)	0.793

Bold values highlight statistically significant comparisons

coronal balance is also a major factor that impacts final outcomes. Multiple studies have shown that postoperative coronal malalignment is associated with worse HRQoL scores after ASD surgeries [3], especially with long fusions to the upper-thoracic spine [6], where the residual global coronal malalignment is clinically less tolerated because of the lack of compensation mechanisms leading to worse clinical outcome. In addition, other studies have shown that residual malalignment > 30 mm is associated with worse functional outcome after coronal realignment surgery [6, 21].

In order to better understand the coronal component of the global spinal alignment, various classifications have been recently published [5, 11]. The Obeid-CM classification proposed six coronal malalignment subtypes according to different modifiers, in addition to offering a treatment algorithm to guide the surgical strategy for each subtype. The results of the present study showed that a postoperative CM < 20 mm improved functional outcomes. At 2 years, following the O-CM algorithm significantly decreased mechanical failure and provided significantly better alignment in both planes.

Matsumara et al. showed that postoperative coronal imbalance negatively impacted HRQoL scores, especially the satisfaction domain of the SRS-22. Their series included 37 ASD patients: since all patients who presented with a postoperative CM had a shift toward the convexity of the main thoracolumbar/lumbar curve, the authors concluded that an adequate correction of the lumbosacral curve might prevent postoperative coronal imbalance [3]. This finding is consistent with that of the present study, in which the treatment algorithm for subtype 2A2 of the O-CM classification advises correction of the lumbosacral junction through posterior column or three-column osteotomies to correct the oblique lumbosacral take-off and avoid postoperative CM.

A study by Tanaka et al., involving 121 ASD operated patients, showed that postoperative CM had no significant association with the clinical outcomes evaluated by the ODI and Roland–Morris Disability Questionnaire, but correlated with the frequency of rod fracture [2]. These results are overall not dissimilar to those of the adjusted analysis of the presented work.

The SRS-22r total score with its different subdomains usually shows small differences when comparing the outcomes of the two considered populations. The MCID for the SRS-22r score and domains have been previously published [22, 23] and are useful for assessing treatment outcomes to detect a true clinically meaningful difference between two groups of patients. MCID values were studied in a multivariate analysis in the current study and showed that a postoperative CM < 20 mm resulted in a 3.5 times greater

Table 5 Comparison of the functional outcomes in patients who did and did not achieve a CM < 20 mm at the 2-year follow-up

Functional scores	CM > 20 mm at 2 years	CM < 20 mm at 2 years	*p* value
SRS 22r, *n* (%)	72 (43)	96 (57)	
Total score			
Mean (SD)	3.4 (0.7)	3.8 (0.7)	**0.01**
Function/activity			
Mean (SD)	3.4 (0.8)	3.7 (0.8)	**0.05**
Pain			
Mean (SD)	3.4 (1.1)	3.7 (1)	**0.05**
Self-image/appearance			
Mean (SD)	3.4 (0.9)	3.7 (0.9)	**0.02**
Mental health			
Mean (SD)	3.4 (0.8)	3.7 (0.9)	0.07
Satisfaction with management			
Mean (SD)	4.1 (0.9)	4.4 (0.7)	**0.01**
ODI n(%)	70 (42.7)	94 (57)	
Total score			
Mean (SD)	29.77 (22)	24.9 (19)	0.1
Pain intensity			
Mean (SD)	1.6 (1.4)	1.3 (1.1)	0.07
Walking			
Mean (SD)	1.4 (1.5)	1 (1.4)	**0.05**
Sitting			
Mean (SD)	1.3 (1.1)	1 (1)	0.07
Standing			
Mean (SD)	2 (1.6)	1.4 (1.4)	**0.01**
SF-36, *n* (%)	71 (43.3)	93 (56.7)	
Body pain			
Mean (SD)	41.8 (9.7)	45.1 (11)	**0.04**
General health			
Mean (SD)	46.6 (10)	49.9 (9.8)	**0.04**

Bold values highlight statistically significant comparisons

chance to obtain SRS-22r score improvement that reached MCID (> 0.77 over 5 points) [14]. This finding emphasizes the importance of targeting an acceptable coronal alignment (< 20 mm), along with restoration of an optimal sagittal balance [1, 21, 23] and the use of pelvic fixation [24], to increase the chances of functional success. Non-modifiable and patient-related parameters such as high PI, high preoperative LL and good physical status must also be considered before realignment surgery, as they represent favorable factors for an acceptable postoperative outcome.

This study does not come without limitations. First, this was a retrospective study, with all the possible related biases and most importantly loss to follow-up in the functional outcomes' analysis. However, the number of patients remained sufficient to enable satisfactory and acceptable statistical analysis. Second, data regarding smoking status and presence of osteoporosis, two factors that may affect the rate of mechanical complications, were not available to the investigators. The present work focused on isolating the effects of coronal malalignment on surgical outcomes, providing a stepping stone toward a better understanding of the complex tridimensional relationship of coronal and sagittal alignment and clinical parameters.

Conclusion

CM < 20 mm might be the best target for the coronal alignment after ASD surgery, as this associated with better surgical outcomes and with a 3.5 times higher odd of achieving the MCID for the SRS-22 score. The O-CM classification may represent a powerful tool to achieve such a target, as its algorithm provides detailed surgical strategies regarding which lead to a lower risk of mechanical complications in the presented cohort.

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Data availability Data can be made available in anonymized form and upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval This study was approved by the IRBs of all involved institutions.

Consent to participate and publication Due to the retrospective nature of the study, consent to participate or for publication was not required.

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