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How much postoperative shoulder imbalance is satisfactory for Lenke 1/2 adolescent idiopathic scoliosis patients?

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Abstract

Background: The recognition of shoulder imbalance in patients with adolescent idiopathic scoliosis (AIS) has garnered increasing attention among spine surgeons. Nevertheless, there is an inconsistency in the definitions of shoulder imbalance, and the relationships between radiological parameters and patient satisfaction remain inadequately explored.

Objective: This study aimed to determine the correlated shoulder imbalance parameter leading to patient acceptable symptom state (PASS) for Lenke 1/2 AIS patients after correction surgery, based on Scoliosis Research Society-22r questionnaires.

Methods: Lenke 1/2 type patients from 2 tertiary hospitals undergoing pedicle-screw fixation and correction surgery from 2017 to 2021 were enrolled. One patient who replied positively to both No. 21 and 22 questions was defined as achieving PASS. Basic patient information and shoulder imbalance parameters were calculated and compared pre-surgery and at follow-up (at least 24 months). Binary logistic regression analysis and receiver operating characteristic (ROC) curve were performed.

Results: One hundred twenty-eight patients (99 females, mean age 14.8 years) were enrolled. A total of 105 (82.0%) achieved PASS. Clavicle-chest cage angle difference (CCAD) was an independent risk factor correlated with treatment satisfaction (odds ratio = 0.674, $p = 0.01$), with a cutoff value of 7.3° (area under the curve: 0.75, 95% CI: 0.655–0.846; sensitivity: 91.7% and specificity: 64.4%).

Conclusions: In Lenke 1/2 AIS patients, there was a significant correlation between CCAD and the state of PASS. Patients were more inclined to be satisfied with surgical treatment when the CCAD was less than or equal to 7.3°.

Abbreviations: AIS = adolescent idiopathic scoliosis, AUC = area under the curve, CA = clavicle angle, CCAD = clavicular–thoracic cage angle difference, CHD = coracoid height difference, CRID = clavicle-rib cage intersection difference, FRA = first rib tilt angle, MTC = main thoracic curve, PASS = patient acceptable symptom state, PSI = postoperative shoulder imbalance, ROC = receiver operating characteristic, RSH = radiographic shoulder height, SRS = Scoliosis Research Society, T1T = T1 tilt.

Keywords: adolescent idiopathic scoliosis, shoulder imbalance, SRS-22r

1. Introduction

The incidence of scoliosis among Chinese adolescents ranges from 1.5% to 2.4%, with approximately 90% being adolescent idiopathic scoliosis (AIS).[1,2] Scoliosis can cause various postural deformities, including trunk deviation, rib hump, uneven shoulders, and asymmetrical waist contours, significantly impacting adolescents' physical and mental health. Based on standing full-spine anteroposterior and lateral radiographs, AIS can be classified into Lenke types 1 to 6.[3] AIS patients with Lenke 1 and 2 types, characterized by main thoracic curve (MTC), usually presented obvious rib hump and uneven shoulders. Surgical correction is typically performed when the MTC exceeds 45°. With the widespread application of all-pedicle-screw instrumentation for scoliosis correction, the corrective force for MTC has become stronger compared to previous fixation systems. However, this may simultaneously affect the proximal structural or

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nonstructural upper thoracic curve, leading to postoperative shoulder imbalance (PSI).[4,5] A number of surveys have shown that PSI, with an incidence of 5% to 12.5%, has become an important indicator affecting patient satisfaction with surgical outcomes.[6,7]

Evaluation of PSI can be conducted through radiographic and cosmetic assessment. Radiographic assessment primarily measures shoulder-related parameters on radiographs through bilateral comparisons. Commonly used parameters include clavicle angle (CA) and radiographic shoulder height (RSH). Some scholars have pointed out that radiographic parameters alone cannot accurately reflect true PSI.[8] Given that shoulder imbalance is primarily reflected in appearance, some scholars have proposed cosmetic evaluation indicators such as shoulder area index.[9] As the correlations between radiographic and cosmetic parameters still require further investigation, X-ray measurements remain the most common indicators for evaluating PSI currently. However, the criteria and classification standards for shoulder imbalance are mostly subjectively determined. Kuklo et al. used RSH as the standard, defining ≥3 cm as severe imbalance, 2–3 cm as moderate imbalance, 1–2 cm as mild imbalance, and <1 cm as balanced.[10] Although such classification methods are simple and convenient, they fail to fully consider patients' subjective feelings and experiences.

In recent years, the Scoliosis Research Society–22 (SRS–22) questionnaire has been increasingly applied in evaluating clinical outcomes. Combining radiographic measurements with subjective scales to determine whether shoulders are balanced has gradually gained attention.[11] The concept of patient acceptable symptom state (PASS), defined as the highest symptom level below which patients feel well, has become an increasingly popular outcome indicator. PASS has recently been adopted in scoliosis correction surgery for assessing surgical results. To our knowledge, no study has examined PASS in evaluating PSI among patients with AIS. The purpose of this study was to (1) analyze the correlation between radiographic parameters and patient satisfaction; (2) identify key radiographic indicator and threshold correlated with achieving PASS.

2. Methods

2.1. Participants

Patients aged between 10 and 18 with Lenke type 1 or 2 AIS from a tertiary hospital were included. All underwent posterior correction and fusion surgery with pedicle screws between January 2017 and December 2021. The exclusion criteria were as follows: prior history of spine surgery; lack of full spine X-ray radiographs preoperatively and at follow-ups (at least 24 months); images with poor quality preventing measurements, and missing SRS-22r results at follow-ups. The study was approved by local review board (KY20232256-F-2).

2.2. Data assessment

Baseline characteristics included gender, age, body mass index and follow-up duration. Surgical data included upper instrumented vertebra and the number of fixed segments. Treatment satisfaction was determined from SRS-22r questionnaires. The criteria of achieving PASS for one patient were (1) answered "very satisfied" or "satisfied" for item No. 21 "Are you satisfied with the results of your back management?" (2) answered "definitely yes" or "probably yes" for No. 22 "Would you have the same management again if you had the same condition?." Patients who simultaneously met both criteria were classified into the PASS group.

2.3. Radiologic evaluation of shoulder imbalance

All parameters were measured through Surgimap software (version 2.3.2.1, Globus Medical Inc., Pennsylvania) preoperatively and at follow-ups. The measurements included three categories: external, internal, and comprehensive shoulder parameters.

2.4. External shoulder parameters

CA: The angle between the line connecting the highest points of bilateral clavicles and the horizontal line.[12]

RSH: The vertical distance difference between soft tissue above bilateral acromioclavicular joints.[10]

Coracoid height difference (CHD): The vertical distance difference between the highest points of bilateral coracoid processes.[12]

Clavicle-rib cage intersection difference (CRID): The vertical height difference between bilateral clavicle-rib cage intersection points.[12]

2.5. Internal shoulder parameters

T1 tilt (T1T) angle: The angle between the T1 superior endplate and the horizontal line.[12]

First rib tilt angle (FRA): The angle between the line connecting the highest points of bilateral first ribs and the horizontal line.[12]

2.6. Comprehensive shoulder parameter

Clavicular-thoracic cage angle difference (CCAD): The angular difference between left and right sides, measured between the line connecting proximal and distal midpoints of the clavicle and the perpendicular line to the thoracic central line.[13]

2.7. Statistical analysis

Data were analyzed using SPSS software (version 22, SPSS, Chicago, Illinois). Categorical variables are expressed as *n* (%). Continuous variables are expressed as mean ± standard deviation or median (Q1, Q3). The intra- and interclass correlation coefficient test was used to assess group agreement. Imaging parameters and results of SRS-22r between groups were compared with independent sample

t-tests, chi-squared tests, and Fisher's exact tests, based on the parametric qualities. Comparisons within group preoperatively and at follow-ups were obtained with paired sample *t*-tests. As patients may be unsatisfied with either the left or right shoulder higher, calculations are based on absolute values of parameters in order to find potential differences better. Univariate and binary logistic regression analyses were employed to identify factors associated with achieving PASS cutoff values for treatment satisfaction and each SRS-22r domain. After collinearity diagnosis, significant predictors not at risk of collinearity were entered into multivariate modeling. Candidate variables for the analysis were shoulder imbalance parameters, age, sex, and each preoperative SRS-22r domain score, using stepwise regression based on Akaike's information criterion. Receiver operating characteristic (ROC) curve analysis was performed to identify the optimal cutoff point at which sensitivity and specificity would be maximal for achieving PASS. The discriminative ability of ROC curve was interpreted by the area under the curve (AUC) as noninformative (AUC ≤ 0.5), poor (0.5 < AUC < 0.7), or good (AUC ≥ 0.7). A p-value < 0.05 was considered significant. A subgroup analysis to determine if Lenke type affected the cutoff value. Patients were divided into two groups, Lenke type 1 (n = 105) and Lenke type 2 (n = 23), for ROC analysis performed in the same manner as above.

3. Results

A total of 128 (29 males, 99 females; 105 with Lenke type 1 and 23 with type 2) patients were finally enrolled. The mean age was 14.8 ± 3.6 years, and mean follow-up duration was 46.0 ± 13.5 months (ranging from 24 to 62 months). Upper instrumented vertebra distributions were 70 (54.7%) at T2, 46 (35.9%) at T3 and 12 (9.4%) at T4. Lumbar curve modifier classifications were 71 (55.5%) in type A, 33 (25.8%) in type B, and 24 (18.7%) in type C. Seven minor complications were recorded, including 5 patients with delayed wound healing and 2 patients with transient neurological weakness. All patients recovered with observation and conservative management. At follow-ups, 105 (82.0%) patients achieved PASS for treatment satisfaction.

The intraclass correlation coefficients from two researchers were 0.934 for CA, 0.854 for RSH, 0.903 for CHD, 0.832 for CRID, 0.915 for T1T, 0.943 for FRA, and 0.901 for CCAD. The interclass correlation coefficients were 0.866 for CA, 0.883 for RSH, 0.821 for CHD, 0.905 for CRID, 0.966 for T1T, 0.845 for FRA, and 0.940 for CCAD.

Paired comparisons of the preoperative and 2-year postoperative parameters of deformity and SRS-22r scores are summarized in Table 1. All radiographic parameters and SRS-22r domains significantly improved, except for CA. Three domains (pain, appearance, and mental health) of the SRS-22r demonstrated significant correlations with treatment satisfaction scores. The strongest correlation was observed for the appearance domain (R = 0.546, p < 0.001), followed sequentially by pain (R = 0.38, p = 0.007) and mental health (R = 0.29, p = 0.043). No significant association was found between the function domain score and treatment satisfaction (R < 0.01, p = 0.995). The PASS cutoff value for SRS-22r domains was 3.8 (AUC: 0.823) for self-image. The AUCs for pain (0.69), function (0.63), subtotal (0.64), and mental health (AUC: 0.66) were all < 0.7. A total of 101 patients (78.9%) achieved the PASS cutoff value for self-image.

Binary analysis revealed that the independent factor for achieving the PASS cutoff value for SRS-22r treatment satisfaction and self-image was CCAD (Table 2). A lower CCAD angle was a significant factor for achieving satisfaction. ROC analysis showed that the cutoff value of CCAD was 7.3° (AUC: 0.75, 95% CI: 0.655–0.846; sensitivity: 91.7% and specificity: 64.4%) for treatment satisfaction (Fig. 1A) and 8.9° (AUC: 0.818, 95% CI: 0.696–0.939; sensitivity: 81.2% and specificity: 86.4%) for self-image (Fig. 1B).

Subgroup analysis to determine if Lenke type affected the CCAD cutoff value. Patients were divided into 2 type groups for ROC analysis performed in the same manner as above. The cutoff value of the CCAD for achieving satisfaction was 7.0° (AUC: 0.80, 95% CI: 0.69–0.93) in Lenke type 1 subgroup and 7.5° (AUC: 0.71, 95% CI: 0.66–0.92) in Lenke type 2 subgroup.

Case presentation

A 13-year-old girl presented with AIS (Fig. 2A, B) and an MT curve of 68°; the curve pattern was Lenke type 2AN, and the preoperative CCAD was 12.9°. The patient's preoperative SRS-22r self-image score was 2.2. Posterior spinal fusion with pedicle-screw fixation from T3–L3 was performed without complications. Radiographs obtained 42 months after surgery revealed residual CCAD of 5.1°. The patient's 2-year postoperative SRS-22r self-image score was 3.9.

4. Discussion

This study integrated commonly used radiographic shoulder balance parameters for scoliosis with the SRS-22 questionnaire, focusing on patient satisfaction to analyze radiographic factors influencing postoperative satisfaction in Lenke type 1/2 AIS patients and determine optimal radiographic thresholds for achieving PASS. The SRS-22 questionnaire demonstrates good reliability and validity and has been widely used for scoliosis patients both domestically and internationally.[14] Results showed that 82% of patients were satisfied with surgical outcomes in our cohort, possibly due to the widespread adoption of all-pedicle-screw instrumentation and ideas of selective fusion that preserve more motion segments and reduce complications.[15]

Our findings revealed significant correlations between follow-up satisfaction and most domains of SRS-22r. No

Table 1

Paired comparison of preoperative and postoperative parameters of shoulder imbalance and SRS-22r scores.

Parameter and outcome	Pre-op	Follow-up	*p* value
Shoulder imbalance			
CA (°)	2.7 ± 2.2	2.3 ± 1.9	0.138
RSH (mm)	10.8 (2.0, 20.3)	4.5 (0, 13.3)	0.018
CHD (mm)	12.3 (1.5, 15.9)	6.5 (0.6, 13.2)	0.024
CRID (mm)	6.5 (1.1, 14.3)	4 (0.3, 10.1)	0.049
T1T (°)	7.6 (3.5, 12.2)	4.8 (3.3, 8.2)	0.012
FRA (°)	7.5 ± 5.7	5.2 ± 3.6	0.04
CCAD (°)	8.5 (3.6, 18.3)	5.5 (3.0, 8.9)	0.003
SRS-22r			
Function	4.1 (3.2, 4.5)	4.6 (4.0, 4.9)	< 0.001
Pain	4.1 ± 0.5	4.2 ± 0.5	0.039
Appearance	3.5 ± 0.7	4.1 ± 0.7	< 0.001
Mental health	4.0 (3.5, 4.4)	4.3 (3.7, 4.8)	< 0.001

CA= clavicle angle, CCAD = clavicular thoracic cage angle difference, CHD = coracoid height difference, CRID = clavicle-rib cage intersection difference, FRA = first rib tilt angle, RSH = radiographic shoulder height, T1T = T1 tilt, SRS = Scoliosis Research Society.

Table 2

Factors associated with achieving PASS cutoff value for SRS-22r treatment self-image and satisfaction.

	Crude analysis	Binary analysis	
Variables	***p* value**	**OR (95% CI)**	***p* value**
Self-image			
Sex	0.95		
Age	0.025	0.654 (0.546–1.113)	0.75
Pre-op self-image	0.059	2.632 (0.66–11.435)	0.104
Radiographic parameters postop			
CA	0.346		
RSH	0.573		
CHD	0.678		
CRID	0.643		
T1T	0.476		
FRA	0.443		
CCAD	0.021	0.524 (0.641–0.963)	0.033
Satisfaction			
Sex	0.578		
Age	0.323		
Radiographic parameters postop			
CA	0.256		
RSH	0.113		
CHD	0.597		
CRID	0.652		
T1T	0.121		
FRA	0.589		
CCAD	0.005	0.674 (0.427–0.853)	0.01

CA = clavicle angle, CCAD = clavicular-thoracic cage angle difference, CHD = coracoid height difference, CI = confidence interval, CRID = clavicle-rib cage intersection difference, FRA = first rib tilt angle, OR = odds ratio, RSH = radiographic shoulder height, T1T = T1 tilt.

correlation was found with the SRS-22 function domain ($R < 0.01$, $p = 0.995$), possibly because Lenke 1 and 2 AIS corrections primarily focus on the thoracic curve while preserving lumbar mobility. Current treatment philosophy emphasizes maximal preservation of lumbar segments while considering the risk of distal adding-on phenomenon, with fixation rarely extending to L4 or below.[16,17] Additionally, the limited natural mobility of thoracic vertebrae (due to their overlapping "shingle-like" arrangement) means instrumentation has minimal impact on daily function. The strongest correlation was with appearance scores, reflecting adolescents' heightened body image concerns during puberty. Proximal fixation and main curve correction in Lenke 1/2 AIS inevitably affect shoulder balance, which directly impacts appearance evaluation. Notably, most thoracic-dominant AIS patients present little pain preoperatively. While patients may report early postoperative discomfort due to surgical wounds or pain sensitivity, these typically resolve during bone remodeling, warranting further investigation of pain-satisfaction correlations.

Radiographic parameters remain the most commonly used indicators for shoulder imbalance assessment. In this study, we employed 2 traditional key shoulder balance parameters: CA and RSH, whose preoperative to postoperative changes effectively reflect the correction of shoulder balance.[18] The CHD evaluates shoulder balance by measuring key scapular landmarks and demonstrates good predictive value for shoulder imbalance.[19] The CRID shows strong correlation with patients' subjective perception of balance.[20] Additionally, the T1T angle and FRA serve as important indicators for assessing intrinsic shoulder balance and complement the evaluation of both extrinsic and intrinsic shoulder balance. However, the current radiographic assessment of shoulder balance has several limitations. First, there is no consensus on the definition of shoulder imbalance, with different studies adopting varying parameters and inconsistent normal value thresholds. For instance, proposed normal ranges include 2° to 3° for CA and 10, 15, or 20 mm for RSH.[21] This lack of standardized definitions and thresholds contributes to significant heterogeneity in studies predicting PSI. With the increasing adoption of the SRS-22 questionnaire across medical centers in China, patient satisfaction with treatment outcomes has gained greater emphasis. About 82% of patients in our study achieved PASS, similar to the 85% reported in previous studies.[22] Our findings showed that all radiographic parameters except CA demonstrated significant improvement at final follow-up. This may be attributed to the limitation of CA in accounting for soft tissue asymmetry.

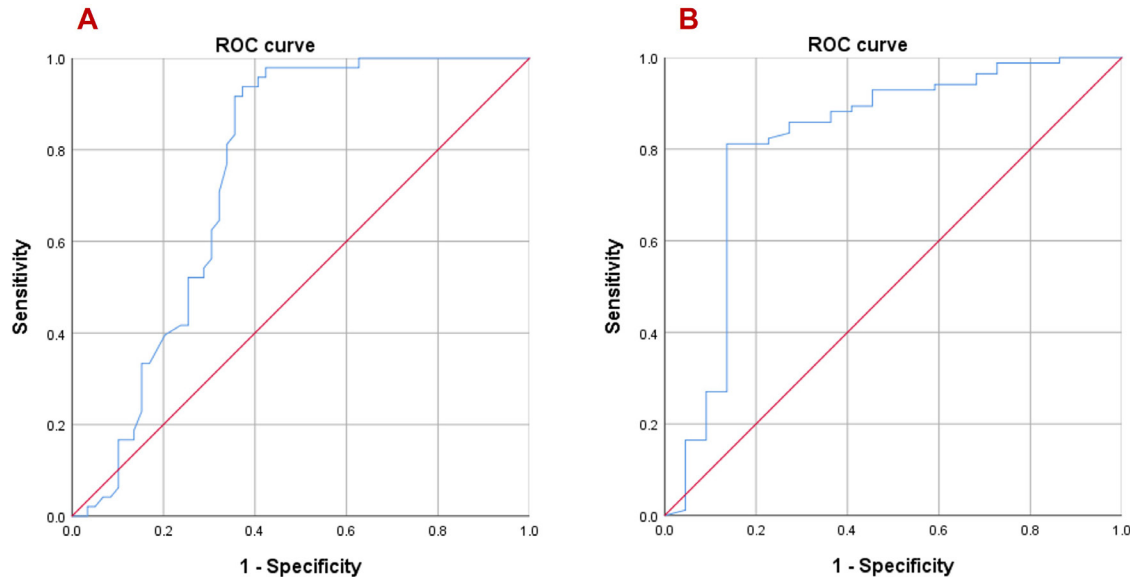

Figure 1. (A) ROC curve of CCAD for treatment satisfaction. (B) ROC curve of CCAD for self-image. CCAD = clavicular-thoracic cage angle difference, ROC = receiver operating characteristic.

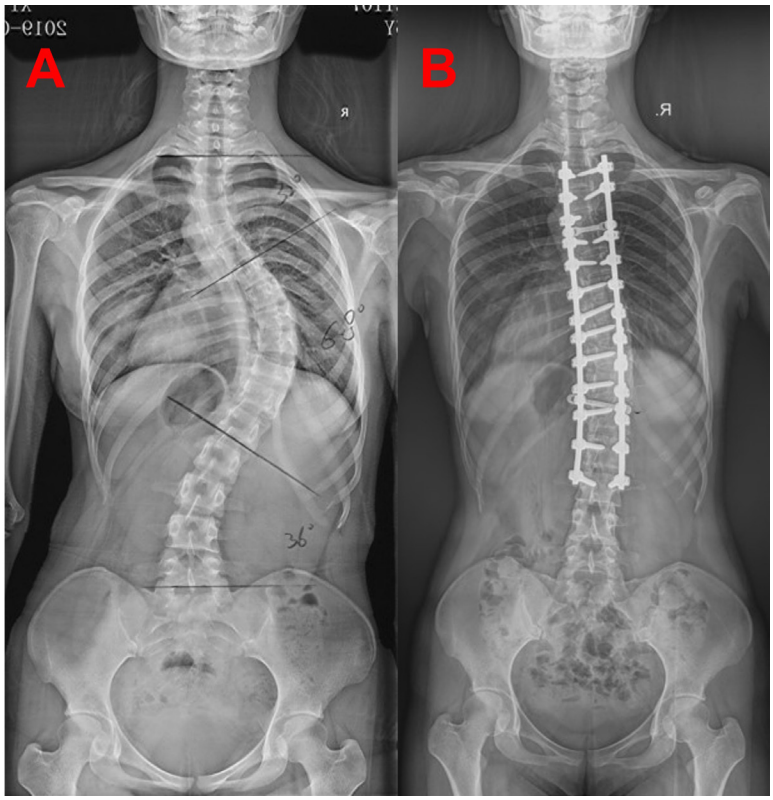

Figure 2. A 13-year-old girl presented with Lenke 2AN AIS. (A) Preoperative CCAD was 12.9°. (B) CCAD at 42 months follow-up was 5.1°. AIS = adolescent idiopathic scoliosis, CCAD = clavicular-thoracic cage angle difference.

The study employed binary logistic regression analysis to identify independent radiographic predictors of post-operative satisfaction in AIS correction, incorporating 3 parameters: RSH, T1T angle, and CCAD. The results demonstrated that CCAD was the sole independent radiographic predictor of achieving PASS. CCAD was initially proposed by Japanese scholar Yagi et al., whose subsequent research identified preoperative CCAD as a risk factor for predicting PSI.[13,23] It should be noted that, in their studies, RSH is considered the gold standard for shoulder imbalance assessment, and CCAD served as an auxiliary indicator. Chinese researchers have further established that CCAD shows a strong correlation with cosmetic parameters and can serve as an important metric for shoulder balance evaluation.[24] Particularly, in Lenke type 1 and 5 AIS patients, preoperative CCAD has

demonstrated predictive value for PSI and correlates significantly with both patient and surgeon satisfaction.[25] These findings underscore that shoulder balance assessment should incorporate patients' subjective perceptions and evaluations, warranting further investigation.[26,27]

Our study fundamentally challenges this paradigm by establishing CCAD value directly against the benchmark of patient-reported satisfaction (PASS). This shift underscores a critical evolution in surgical outcome evaluation: moving from a surgeon- or imaging-centric "balance" to a patient-centered "acceptable state." Through ROC curve analysis of postoperative CCAD for satisfaction prediction, we obtained an AUC of 0.75 (95% CI: 0.655–0.846; sensitivity: 91.7% and specificity: 64.4%), with an optimal threshold of 7.3°. We therefore recommend maintaining postoperative CCAD ≤ 7.3° as a clinically relevant reference for surgeons.

The superior correlation of CCAD with patient satisfaction may be attributed to its unique anatomical and biomechanical significance. CCAD is less susceptible to measurement errors caused by patient positioning and axial rotation. When a patient stands with slight trunk rotation, traditional parameters such as RSH and CA can be significantly affected, leading to inaccurate assessments. However, as CCAD uses the thoracic central line as its internal reference, it inherently corrects for minor rotational malpositioning. This makes it a more robust and reliable metric across different scans and clinical settings. CCAD's biomechanical rationale aligns closely with the functional anatomy of the shoulder. The clavicle acts as a crane for the shoulder. Its angle relative to the thorax dictates the functional and cosmetic position of the entire arm and shoulder. An abnormal CCAD signifies an imbalance in the muscular forces (from trapezius, sternocleidomastoid, etc.) and ligamentous restraints that stabilize the clavicle. This biomechanical disruption is what patients ultimately perceive as an "uneven" shoulder, both at rest and during movement. In contrast, traditional parameters such as T1T reflect the foundational spinal inclination but may be masked by soft tissue or compensatory scapular positioning, making them less perceptible to the patient. Unlike CA and RSH, which are simple linear or angular measurements of skeletal prominence, CCAD is a composite parameter that integrates the orientation of the clavicle (the most visible bony landmark of the shoulder) relative to the central axis of the thorax. The clavicle articulates with the sternum medially and the scapula laterally; its position is thus influenced not only by the spinal deformity but also by the compensatory positioning of the pectoral girdle. A high CCAD indicates that one clavicle is significantly more elevated and horizontally oriented than the other, which directly translates to the visually conspicuous "high shoulder" or "sloping shoulder" appearance that patients find bothersome.

The current study has several limitations. First, as a single-center retrospective investigation with a relatively small sample size and limited follow-up duration, the findings may be subject to selection bias. Second, the cosmetic evaluation of spinal deformity in Chinese patients may be influenced by cultural and ethnic factors.[28,29] Although the radiographic parameters included in this study demonstrated correlations with cosmetic parameters, the lack of systematic incorporation of standardized cosmetic assessment measures may limit the comprehensive evaluation of shoulder imbalance. Third, the work focused on all-pedicle-screw instrumentation. More research is essential to determine whether the conclusion was acceptable in different surgical strategies (e.g., selective fusion and thoracoscopic surgery). Finally, while postoperative CCAD was identified as a reliable predictor for achieving optimal patient satisfaction, the study did not establish surgical correction protocols and suggestions from CCAD. Future research should incorporate a more comprehensive analysis incorporating both sagittal and coronal parameters to better inform surgical decision-making and optimize correction strategies.

Acknowledgments

Not applicable.

Ethical statement

The studies involving human participants were reviewed and approved by the Institutional Review Board of The First Affiliated Hospital, Air Force Medical University (KY20232256). The approval contained a waiver for written informed consent based on the retrospective and anonymous character of the study.

Conflicts of interest

The authors have no conflicts of interest to disclose.

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Data availability statement

Data collected and analyzed for the study are available from the corresponding author upon reasonable request.

Author contributions

Designed the study: Fang Xie, Zhuojing Luo, Xueyu Hu.
Data collection and analysis: Meng Bai, Xingxing Zhu, Yian Li, Ying Wang.
Manuscript writing: Fang Xie, Ge Yang, Fei Wang, Jianglong Ling.

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