



Simplified S1 vertebral bone quality (vbq) score to assess proximal junctional kyphosis after Lenke 5 adolescent idiopathic scoliosis surgery

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Abstract

Background Proximal junctional kyphosis (PJK) is a common complication following corrective surgery for adolescent idiopathic scoliosis (AIS) with a Lenke 5 curve. Previous studies have suggested that PJK may be associated with osteopenia, which is prevalent in AIS patients. MRI-based vertebral bone quality (VBQ) scores have been proposed as a valuable tool to assess preoperative bone quality. However, accurately measuring VBQ scores in Lenke 5 AIS patients with a structural lumbar curve can be challenging. Recently, a simplified S1 VBQ score has been proposed as an alternative method when the traditional VBQ score is not applicable. This study aims to evaluate the predictive value of the simplified S1 VBQ score in predicting the occurrence of PJK after corrective surgery for Lenke 5 AIS.

Methods We conducted a retrospective analysis of patient data to assess the predictive utility of the S1 VBQ score for PJK in Lenke 5 AIS patients. Demographic, radiographic, and surgical data were collected, and S1 VBQ scores were calculated based on preoperative T1-weighted MRI images. Univariate analysis, linear regression, and multivariate logistic regression were performed to identify potential risk factors for PJK and to assess the correlation between other variables and the S1 VBQ score. Receiver operating characteristic analysis and area under the curve values were used to evaluate the predictive efficiency of the S1 VBQ score for PJK.

Results A total of 105 patients (aged 15.50 ± 2.36 years) were included in the analysis, of whom 24 (22.9%) developed PJK. S1 VBQ scores were significantly higher in the PJK group compared to the non-PJK group (2.83 ± 0.44 vs. 2.48 ± 0.30 , $P < 0.001$), and there was a significant positive correlation between the S1 VBQ score and proximal junctional angle (PJA) ($r = 0.46$, $P < 0.0001$). Multivariate analysis revealed that the S1 VBQ scores and preoperative thoracic kyphosis (TK) were significant predictors of PJK.

Conclusion This study provided evidence that higher S1 VBQ scores were independently associated with PJK occurrence following corrective surgery for Lenke 5 AIS. Preoperative measurement of the S1 VBQ score on MRI may serve as a valuable tool in planning surgical correction for Lenke 5 AIS.

Keywords Adolescent idiopathic scoliosis · Proximal junctional kyphosis · Vertebral bone quality score · MRI · Lenke 5

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Introduction

Adolescent idiopathic scoliosis (AIS) is a complex deformity that involves axial rotation of the vertebral body, lateral curvature of the spine on the coronal plane, and abnormal sagittal alignment [1]. Proximal junctional kyphosis (PJK), which is defined as a postoperative proximal junctional angle (PJA) greater than 10° , is among the most common postoperative complications encountered in Lenke 5 AIS patients [2].

Although the etiology of proximal PJK remained poorly understood, several studies have suggested that osteopenia/osteoporosis may be an important risk factor after spinal correction surgery [3–6]. It has been reported that a significant proportion of AIS patients have lower bone mineral density (BMD) compared to the general population [7–10]. Although dual-energy X-ray absorptiometry (DEXA) is considered the gold standard for detecting BMD, it is not routinely used as a preoperative examination for adolescent idiopathic scoliosis (AIS) patients. Instead, Ehresman et al. proposed a novel MRI-based vertebral bone quality (VBQ) score, which has been validated as a useful tool for evaluating bone mineral density [11]. The VBQ score involves calculating the signal intensity (SI) values of the L1–L4 vertebral bodies and normalizing them by dividing by the mean SI value of the cerebrospinal fluid (CSF) at L3 from the midsagittal plane of a lumbar spinal non-contrast-enhanced T1-weighted MRI.

However, obtaining midsagittal plane L1–L4 vertebral body SI values in Lenke 5 AIS patients can be challenging due to the lateral curvature of the lumbar spine. Recently, a novel simplified S1 VBQ score has been verified as a promising alternative method to assess bone mineral density (BMD) for patients with lumbar degenerative diseases [12]. This method can be utilized when L1–L4 SI values are not available, such as trauma, infection, or deformity in related regions. In this study, we firstly evaluated the efficacy of the simplified S1 VBQ score in predicting the incidence of PJK in Lenke 5 AIS patients.

Methods

Patient selection

A retrospective study was conducted to investigate the relationship between proximal junctional kyphosis (PJK) after Lenke 5 adolescent idiopathic scoliosis (AIS) surgery and vertebral body quality (VBQ) scores. We included Lenke 5 AIS patients who underwent posterior fusion surgery at our department of West China Hospital between January 2010 and May 2020. The inclusion criteria were: (1) patient age ranging from 11 to 18 years at the time of the surgical intervention; (2) possession of a preoperative T1-weighted non-contrast-enhanced MRI scan without any prior lumbar instrumentation; (3) possession of both immediate postoperative and the most recent follow-up full-length lateral radiographs; and (4) a minimum radiographic follow-up of 24 months. Patients who had surgical intervention for conditions, such as malignancies, infections, trauma, or those diagnosed with chronic liver disease, renal failure, and metabolic bone disease other than osteopenia or osteoporosis, were excluded from the study. All procedures and methods

were approved by the research ethics committee of West China Hospital, and informed consent was obtained from all participants. All protocols were conducted in accordance with the research principles set forth in the Declaration of Helsinki.

Surgical procedure

All surgeries in this study were performed by two senior surgeons from the same surgical team. Prior to fusion, a Smith-Petersen osteotomy was conducted. polyaxial screws were placed at the upper and lower instrumented vertebrae (UIV and LIV), while monoaxial screws were employed at other levels. To correct scoliosis and lumbar spine rotation, intraoperative techniques such as rod rotation, apical vertebral derotation via direct vertebral rotation, convex compression, and concave distraction were implemented.

Radiographic assessment

All patients in this study underwent standing full-length posteroanterior plain radiography. Radiographic measurements of various parameters were obtained before surgery, 3 days post-surgery, and at the final follow-up. The parameters included the main Cobb angle, lumbar Cobb angle, reduced bending angle, correction rate of the two curves, pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), lumbar lordosis (LL), PI–LL, thoracic kyphosis (TK), proximal junctional angle (PJA), and sagittal vertical axis (SVA). Risser sign, an indicator of skeletal maturity, was also assessed.

VBQ score calculation

As described in previous literature [12], the VBQ score was determined using SI measurements taken from the midsagittal plane of non-contrast-enhanced T1-weighted magnetic resonance imaging (MRI) of the spine. The SI of the S1 vertebra was measured by placing a region of interest (ROI) on the S1 vertebra on the midsagittal slice, while the SI of CSF at the L3 level is also recorded in Fig. 1. The S1 VBQ score was then calculated in a similar manner to the L1–L4 VBQ score:

$$\text{SimplifiedS1VBQScore} = \frac{\text{SI}_{\text{S1}}}{\text{SI}_{\text{CSF}}}$$

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics Version 23.0 (IBM Analytics, New York, USA), and figures were generated using GraphPad Prism version 9.3.0 (GraphPad Software, San Diego, California USA).

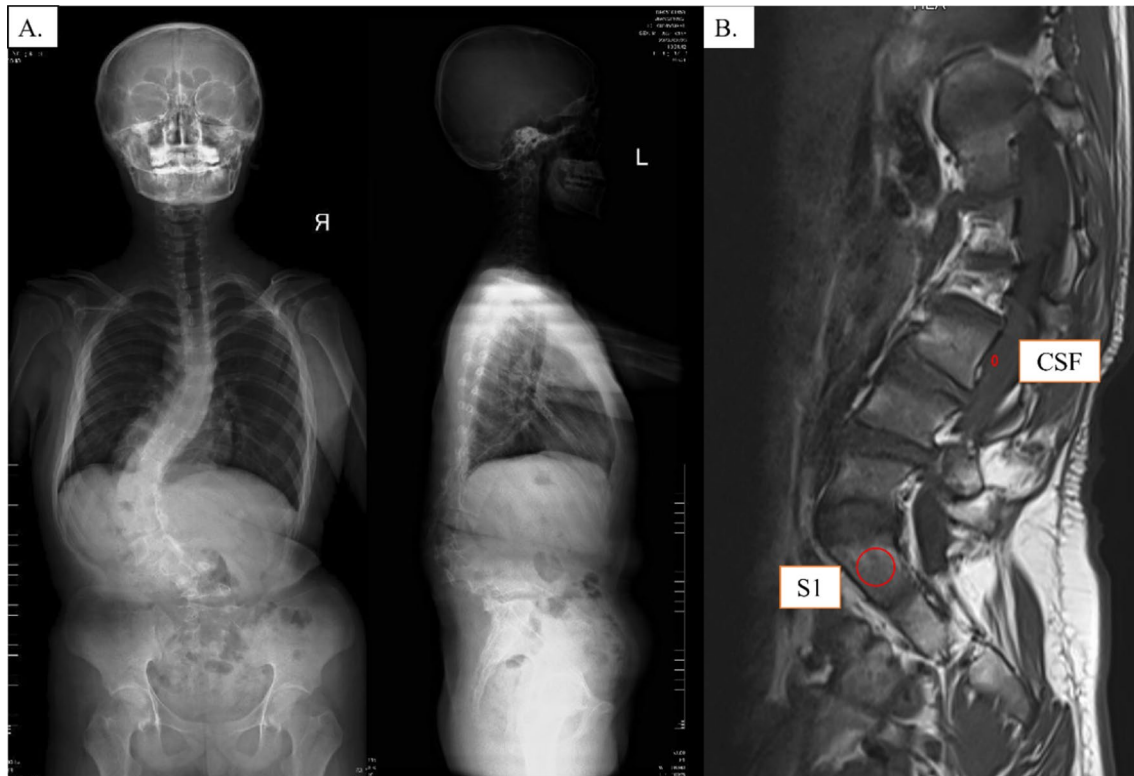


Fig. 1 **A:** a typical standing full-length posteroanterior plain radiography of Lenke 5 AIS, which clearly showed that the structural lumbar curve makes it extremely difficult to measure the VBQ score in

the same plane. **B:** The signal intensity of regions of interest (circles) used for computing S1 vertebral bone quality (VBQ) score on sagittal non-contrast-enhanced T1-weighted MRI

Continuous variables were presented as mean \pm standard deviation (SD), and intergroup differences were evaluated by Student's *t* test for statistical significance. All data normality was tested by Kolmogorov–Smirnov test. All relevant clinical risk factors were subsequently included in a multivariate logistic regression model. Cutoff values were determined by the Youden index via receiver operating characteristic (ROC) curve analysis, and the area under the curve (AUC) of significant continuous variables was calculated. The correlation between PJA and VBQ score was evaluated by univariate linear regression. Model residuals had a normal distribution and showed no heteroscedasticity. $P < 0.05$ was considered statistically significant.

Results

General characteristics of study population

A total of 105 patients, including 83 females and 22 males, were included in this study, with a mean age of 15.50 ± 2.36 years. The mean Risser sign in the PJK and non-PJK groups was 2.96 ± 1.94 and 3.48 ± 1.64 , respectively. The average follow-up period was 42.58 ± 12.45

months and 42.49 ± 11.17 months for the non-PJK and PJK groups. Preoperative general characteristics did not differ significantly between the non-PJK and PJK groups (Table 1). During the follow-up period, two patients with PJK underwent revision surgery due to low back pain, as well as loosening of internal fixation.

Predictors of PJK/PJF

Upon univariate analysis, the following factors were identified as significant risk factors for proximal junctional kyphosis (PJK) when comparing patients with and without PJK: VBQ score (2.83 ± 0.44 vs. 2.48 ± 0.30 , $P < 0.01$), TK (preoperative: 27.06 ± 11.12 vs. 19.14 ± 7.58 , $P < 0.01$; postoperative: 26.12 ± 5.87 vs. 20.50 ± 4.81 , $P < 0.01$), and postoperative LL (54.49 ± 8.91 vs. 50.55 ± 8.84 , $P = 0.05$), as presented in Table 2. Notably, a statistically significant positive correlation between VBQ score and posterior junctional angle (PJA) was observed ($r = 0.46$, $P < 0.01$; Fig. 2). Multivariate logistic regression analysis revealed that VBQ score and preoperative TK were independent predictor associated with PJK, with an odds ratio of 26.49 and 1.118, respectively (Table 3, Fig. 3).

Table 1 General characteristics of the patients ($N=105$)

Variable	PJK group ($N=24$)	Non-PJK group ($N=81$)	<i>P</i> value
Age(years)	15.25 ± 2.80	15.58 ± 2.22	0.55
Height(cm)	161.83 ± 9.30	158.51 ± 8.83	0.11
Sex			
Male	5	17	
Female	19	64	0.99
Weight(kg)	53.06 ± 5.95	51.57 ± 7.48	0.37
BMI(Kg/m ²)	20.21 ± 0.50	20.42 ± 1.44	0.48
Mean follow-up, months	42.58 ± 12.45	42.49 ± 11.17	0.97
Risser sign	3.13 ± 1.85	3.48 ± 1.64	0.44
Fusion segments (<i>n</i>)	8.00 ± 2.17	7.23 ± 2.35	0.14
UIV distribution			0.96
T7	2(8.3%)	5(6.2%)	
T8	2(8.3%)	10(12.3%)	
T9	1(4.2%)	2(2.5%)	
T10	9(37.5%)	31(38.3%)	
T11	10(41.7%)	33(40.7%)	
Preoperative Cobb angle of main curve(°)	54.97 ± 7.13	52.63 ± 6.35	0.13
Preoperative Cobb angle of secondary curve (°)	32.04 ± 4.32	30.94 ± 3.49	0.20

Predictive efficiency and inter-association of VBQ score

To assess the accuracy of VBQ scores in predicting PJK, a receiver operating characteristic (ROC) curve was generated with a diagnostic accuracy of 75.0% (95% CI=61.83–88.17%; Fig. 4). The Youden index identified an optimal cutoff value for the VBQ score at 2.715, which demonstrated a sensitivity of 66.67% and a specificity of 85.19%. Additional univariate linear regression analyses were conducted to investigate potential associations between patient-related general characteristics and the VBQ score. However, the results showed no significant correlation between patient general characteristics and VBQ scores (Table 4).

Discussion

Since the introduction of vertebral bone quality (VBQ) score as a promising tool for assessing bone mineral density (BMD), numerous studies have demonstrated its utility in evaluating complications of spinal surgery, such as screw loosening and cage subsidence after lumbar fusion [13, 14]. Unlike traditional bone quality assessment methods including dual-energy X-ray absorptiometry (DEXA) and computed tomography (CT), which involves radiation exposure, VBQ score was readily available via MRI and was thus more acceptable to patients. PJK, as one of the most common postoperative complications of AIS, has been shown to be closely associated with osteopenia [3]. However, before the introduction of VBQ score, we rarely

performed bone quality assessment in AIS patients before surgery, VBQ score makes up for insufficient preoperative understanding of bone quality in AIS patients. Nevertheless, due to the structural lumbar curve in Lenke 5 AIS, it was difficult to accurately measure the VBQ score using traditional measurement methods. Recently, the S1 VBQ score was demonstrated to be a promising tool for identifying poor bone quality in patients with lumbar degenerative diseases, particularly when the L1–L4 VBQ method was unavailable. The study demonstrated that the S1 VBQ scoring exhibited good homogeneity when compared with traditional bone density evaluation methods, such as DEXA and quantitative computed tomography (QCT) [12]. Building on this finding, we initially confirmed that the newly reported S1 VBQ score exhibited good predictive efficacy for the incidence of PJK following Lenke 5 AIS surgery.

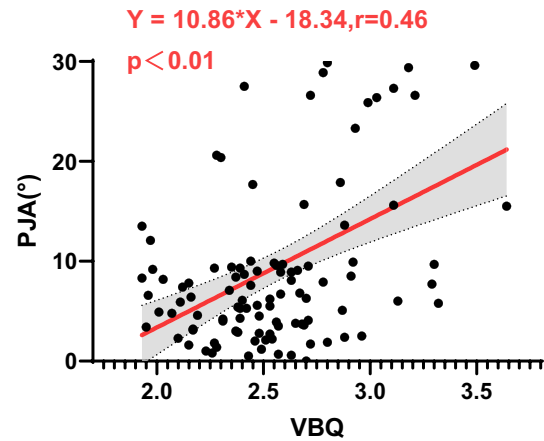
In our study, the preoperative and postoperative TK, postoperative LL and S1 VBQ scores were significantly larger in PJK group compared with non-PJK group. According to previous literature, PJK might be a compensatory mechanism due to a change in spinal balance, and the patients with higher TK were reported to have a greater risk of PJK [15], which was consistent with our findings. In addition, the cause of PJK may also be overcorrection of LL [16]. Hence, larger postoperative LL could lead to PJK after surgery. In multivariate logistic regression analysis, the S1 VBQ scores and preoperative TK became the significant predictors for PJK occurrence, indicating that after excluding the interference of other factors, S1 VBQ score was still a relatively sensitive parameter to evaluate the risk of PJK.

Table 2 Radiographic parameters in patients with and without proximal junctional kyphosis

Variable	PJK group (N=24)	Non-PJK group (N=81)	P value
S1 VBQ scores	2.83 ± 0.44	2.48 ± 0.30	0.00*
PI(°)	46.40 ± 6.60	45.28 ± 7.83	0.52
PT(°)			
Preoperative	6.58 ± 4.81	6.84 ± 4.34	0.80
Postoperative	8.00 ± 6.22	9.26 ± 4.31	0.26
Change in PT	-1.42 ± 8.40	-2.42 ± 5.70	0.50
Final follow-up			
SS (°)			
Preoperative	39.83 ± 8.43	38.44 ± 8.88	0.49
Postoperative	38.40 ± 7.82	36.02 ± 7.76	0.19
Change in SS	1.42 ± 8.40	2.42 ± 5.70	0.74
Final follow-up			
LL(°)			
Preoperative	54.30 ± 8.64	50.78 ± 8.44	0.08
Postoperative	54.49 ± 8.91	50.55 ± 8.84	0.05*
Change in LL	0.19 ± 1.99	-0.23 ± 2.44	0.44
Final follow-up			
TK(°)			
Preoperative	27.06 ± 11.12	19.14 ± 7.58	0.00*
Postoperative	26.12 ± 5.87	20.50 ± 4.81	0.00*
Change in TK	-0.95 ± 11.67	1.37 ± 8.93	0.30
Final follow-up			
SVA (mm)			
Preoperative	-10.34 ± 21.78	-7.66 ± 17.39	0.53
Postoperative	-4.10 ± 16.39	-8.45 ± 15.65	0.24
Change in SVA	6.24 ± 25.29	-0.79 ± 24.99	0.23
Final follow-up			
PI-LL(°)			
Preoperative	-7.90 ± 9.64	-5.50 ± 10.81	0.33
Postoperative	-8.09 ± 9.69	-5.27 ± 11.08	0.26
Final follow-up			

Bold*, indicates statistically significant differences ($p < 0.05$)

As a novel approach to assessing bone quality, the VBQ scoring system offered the advantage of being radiation-free due to its reliance on MRI examinations. This may potentially expand our understanding of preoperative bone quality in patients for whom traditional radiation-based bone density assessments were not recommended. Moreover, the accuracy of traditional DEXA measurements has been questioned for certain degenerative diseases due to the presence of osteophyte proliferation [17, 18]. To date, numerous studies have reported the application of VBQ scoring in predicting cage subsidence, vertebral fragility fractures, and screw loosening [13, 19, 20]. However, as mentioned previously, the conventional lumbar VBQ scoring may be limited in its application for specific

**Fig. 2** A linear regression showed a statistically significant, positive correlation between VBQ score and PJA**Table 3** Multivariate logistic regression analysis for potential risk factors of proximal junctional kyphosis after Lenke 5 AIS surgery

Variable	Odds ratio	95% CI	P value
Age(years)	1.032	0.467–2.280	0.937
Female sex	0.306	0.020–4.567	0.390
BMI(Kg/m ²)	0.851	0.500–1.449	0.553
VBQ score	1.388	1.155–1.668	0.000*
PI	1.008	0.926–1.097	0.855
Preoperative TK	1.118	1.043–1.199	0.002*
Preoperative PT	1.032	0.906–1.040	0.636
Preoperative SVA	1.005	0.970–1.029	0.789
Preoperative LL	1.067	0.993–1.146	0.078
Risser sign	0.707	0.291–1.718	0.444

Bold*, indicates statistically significant differences ($p < 0.05$)

conditions, as it requires capturing MRI signal intensity from L1–L4. Since MRI can also obtain images from different planes, future MRI-based VBQ scores, like the S1 VBQ score, may be developed to target individual vertebrae or other specific levels. This would enable us to assess preoperative bone quality in patients from a broader range of perspectives. In conclusion, this study demonstrated that in Lenke 5 AIS patients with preoperative S1 VBQ scores exceeding 2.715, it may be necessary to exercise greater caution in surgical planning to achieve improved prognoses for spine surgeons.

The study also had some limitations. Firstly, it is a single-center, retrospective investigation with a relatively limited sample size. In addition, the absence of a preoperative DEXA scan for patients with AIS prevents a meaningful comparison of VBQ score. Moreover, laboratory values including calcium, phosphorus, glomerular filtration rates,

Fig. 3 Forest plot of multivariate logistic regression analysis for potential risk factors of PJK after Lenke 5 AIS surgery

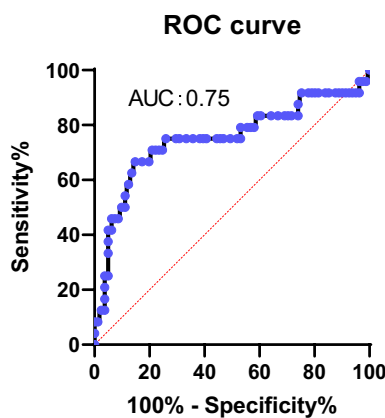
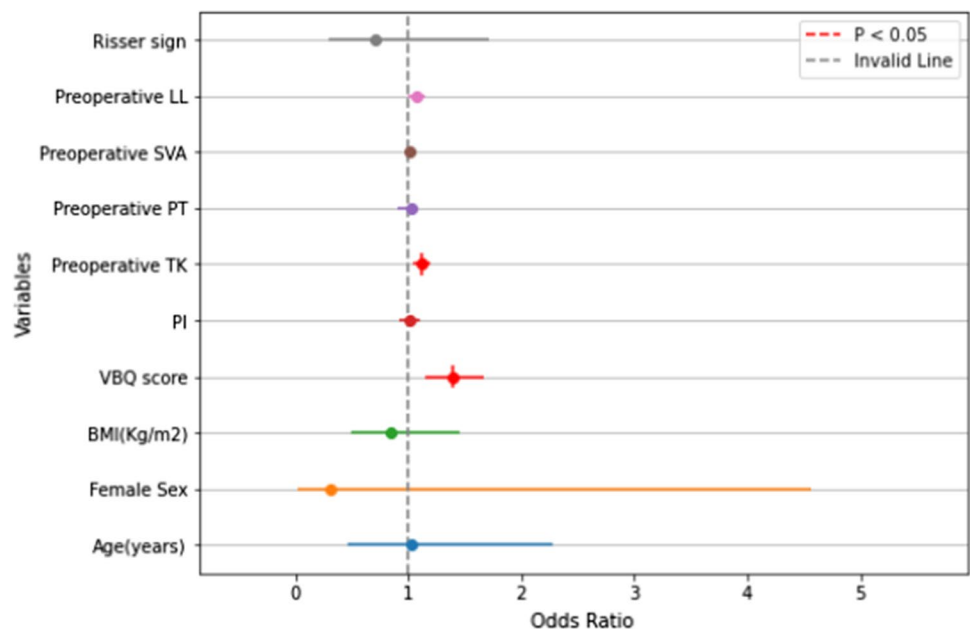


Fig. 4 Receiver operating characteristic (ROC) curve for multivariate model using VBQ score as a predictor of proximal junctional kyphosis, AUC: area under the curve

Table 4 Univariate linear regression analysis for association between patient general characteristics and VBQ score

Variable	Estimate	Std. error	P value
Age (years)	-0.9625	0.6245	0.1264
Female sex	0.05060	0.2164	0.8159
Height	-0.3763	2.413	0.8764
Weight	-0.3611	1.918	0.8511
BMI	-0.09603	0.3452	0.7815
Risser sign	-0.7894	0.4461	0.0798

bone-specific alkaline phosphatase, parathyroid hormone, and vitamin D levels were not considered in the analyses, thereby warranting further investigation.

Conclusion

This was the first study assessing the prognostic utility of the novel simplified S1 VBQ score for predicting the occurrence of PJK after Lenke 5 AIS correction surgery. The S1 VBQ score demonstrated a diagnostic precision of 75% in PJK risk prediction. Hence, S1 VBQ score evaluation may be an effective alternative way when classic VBQ score was difficult to measure and held promise in advancing bone quality assessment and PJK prediction among Lenke 5 AIS patients.

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Author contributions JW and CZ conceived and designed the study, as well as drafted the initial manuscript. YA, YH, QC, and HD performed the preliminary analyses. GF, LL, and YS critically reviewed and revised the manuscript to ensure significant intellectual content. All authors have approved the final manuscript for submission and accept responsibility for all aspects of the work.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest All authors declare that they have no competing interests.

Ethics statement This study was approved by the Ethics Committee of the West China Hospital. The participant consent was written and was performed in accordance with the ethical standards of the Declaration of Helsinki.

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