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ORIGINAL ARTICLE

Degenerative lumbar scoliosis patients with proximal junctional kyphosis have lower muscularity, fatty degeneration at the lumbar area

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Abstract

Purpose To assess the lumbar muscle conditions on the incidence of proximal junctional kyphosis (PJK) after long-level correction and instrumentation surgery for degenerative lumbar scoliosis (DLS) patients with a minimum 2-year follow-up.

Methods Eighty-four DLS patients undergoing long instrumented fusion surgery (≥ 5 vertebrae) were retrospectively studied. According to the occurrence of PJK at the final follow-up, patients were divided into the PJK group and the Non-PJK group. Patient characteristics, surgical variables and radiographic parameters were analyzed statistically. The lumbar muscularity (cross-sectional area of muscle–disc ratio × 100) and fatty degeneration (signal intensity of muscle–subcutaneous fat ratio × 100) were evaluated on magnetic resonance imaging .

Results The prevalence of PJK was 20.24%. Gender, age at surgery, body mass index, uppermost instrumented vertebrae level, fusions extending to the sacrum, and levels fused were not significantly different between the groups. Lower bone mineral density, smaller functional cross-sectional area (FCSA) of paraspinal extensor muscles (PSE), higher lean muscle–fat index and total muscle–fat index of PSE, greater preoperative thoracolumbar kyphosis (TLK), smaller preoperative sacral slope (SS), larger preoperative sagittal vertical axis were identified in PJK group. Logistic regression analysis showed that osteoporosis, preoperative TLK > 15°, SS > 24°, FCSA of PSE > 138.75, and total muscle–fat index of PSE > 4.08 were independently associated with PJK. The final follow-up VAS score for back pain was higher, and SRS-22 subcategories of pain, function, self-image, and total score were significantly lower in the PJK group.

Conclusion Osteoporosis, lower lumbar muscularity and higher fatty degeneration, preoperative greater TLK and smaller SS were found to be strongly associated with the presence of PJK in DLS.

Keywords Degenerative lumbar scoliosis · Proximal junctional kyphosis · Paraspinal muscle · Fatty degeneration

Introduction

Degenerative lumbar scoliosis (DLS) is a spinal deformity defined as a lumbar Cobb angle greater than 10° without previous history of scoliosis [1]. DLS is common with prevalence ranging from 7.5 to 68% [2–7], which was about 13.3% in the Chinese Han population aged more than 40 years old [8]. With the aging of the population, the incidence of DLS will continue to increase [3, 4, 7]. DLS can cause severe back and leg pain symptoms in patients and resulting in a compromise in health-related quality of life [9]. Surgical treatment can be considered for DLS patients that have no relief with conservative treatment. Decompression for neurological elements combined with long-level instrumented fusion could be considered for patients with DLS [10, 11].

Although good results can be expected with surgical treatment, high complication rate has been reported, and proximal junctional kyphosis (PJK) is a common and problematic complication after multilevel instrumented spinal fusion [12–15]. PJK has been defined as a 10° or greater in proximal junction angle (PJA) as measured by the Cobb angle from the caudal endplate of the uppermost instrumented vertebrae (UIV) to the cephalad endplate of the second vertebrae cranial to the UIV (UIV + 2) and at least 10° greater than the preoperative measurement [16, 17]. Due to

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the different study population and duration of follow-up, the incidence of PJK ranges from 17 to 41% [16–18]. The pathogenic mechanisms of PJK are multifactorial, and older age [19, 20], large preoperative sagittal parameters [20], greater curvature correction [17, 20–22], posterior and anterior–posterior spinal fusion [16, 22], fusion to the sacrum [19, 22], low bone mineral density [14, 21, 22] and high body mass index [19] have been reported. Recently, lower muscularity and higher fatty degeneration have been reported as risk factor of PJK [21]. To the best of our knowledge, no studies have demonstrated lumbar muscle conditions on the incidence of PJK following instrumented posterior spinal fusion for DLS patients. The purpose of this study is, therefore, to identify the radiographic consequences and lumbar muscle conditions on the incidence of PJK after the surgical treatment of DLS, and to elucidate the clinical consequences of PJK.

Materials and methods

Participant and data collection

After obtaining approval of the Ethics Committee (IRB00006761-M2018076) in our institution, we retrospectively analyzed DLS patients undergoing posterior multilevel spinal fusion (PSF) from April 2009 to September 2016. All patients undergoing long-level instrumentation and fusion stopping at the thoracolumbar junction (from T9 to L2) with pedicle screws and rods after decompression were included. Inclusion criteria were age ≥ 40 and minimum of five vertebrae fused. Patients with tumors, infections, traumatic spine pathology and undergoing revision surgery were excluded from the study. The patients were divided into two groups based on the occurrence of PJK.

Demographic information collected included gender, age at surgery, body mass index, presenting symptoms, duration of symptoms, comorbidity and bone mineral density (BMD). All patients had standing full spine X-ray preoperatively, ≤ 6 weeks postoperatively and at final follow-up. Preoperative radiographic evaluation included Cobb angle, apical vertebral translation (AVT), coronal vertical axis from the central sacrum vertical line (CSVL), sagittal vertical axis (SVA), thoracic kyphosis (TK, T5–T12), thoracolumbar kyphosis (TLK), lumbar lordosis (LL, L1–S1), pelvic incidence (PI), pelvic tilt (PT), sacral slope(SS), difference between pelvic incidence and lumbar lordosis (PI-LL) and proximal junctional angle (PJA). The PJA was determined by the sagittal angle subtended by the inferior endplate of the uppermost instrumented vertebra (UIV) and the superior end plate of the vertebrae two levels above the UIV (UIV + 2). The definition of PJK was PJA 10° or greater and at least 10° greater than the corresponding preoperative measurement [17]. The patients underwent a dual-energy x-ray absorptiometry (DEXA) scan before surgery to evaluate the bone mineral density.

Back and leg pain visual analogue scale (VAS) score, Oswestry disability index (ODI), Japanese Orthopedic Association (JOA) score (29 points) and the Scoliosis Research Society questionnaire-22 were employed to evaluate clinical outcomes preoperatively and at final follow-up.

Surgical procedure

In all cases included in this study, meticulous surgeries were performed by the three senior authors (Yan Zeng, Zhongqiang Chen, Weishi Li), who had at least 15 years of spinal surgery experience before. All surgical strategies and approaches were discussed and decided by these surgeons before the operation. After satisfactory anesthesia, all patients were placed in a prone position with abdomen free. Meticulous exposure of the spine and posterior decompression fusion and fixation with the pedicle screw was performed by the senior authors. Whether to perform the osteotomy and intervertebral fusion or not were decided by the surgeons according to the patients' radiological and clinical findings. Using the posterior midline approach, the spinous processes, lamina and facet joints of instrumented segments were exposed. After the pedicle screws had been implanted by free-hand technique, neural decompression by laminectomy and discectomy was performed. Posterior column osteotomy (PCO) ($n = 48$) and pedicle subtraction osteotomy (PSO) ($n = 4$), if needed, were applied. Then, a cage with autogenous bone granules tamponade was placed into the appropriate intervertebral space. During the procedure of decompression, osteotomy and fusion, surgeons carefully protected the neural elements. After rod assembly, posterolateral fusion was performed in all patients. Before closing the wound, the bleeding was cautiously stanched and negative suction drainage placed routinely.

Paraspinal muscle measurements

Magnetic resonance imaging (MRI) was performed in all enrolled patients on the 3.0 T system (Siemens, Germany or General Electric, USA) to measure muscle area and T2 signal intensity. Axial MRI images were aligned parallel to the middle of each disc at L1–L2, L2–L3, L3–L4, L4–L5 and L5–S1. After scanning, the images were saved in Digital Imaging and Communications in Medicine (DICOM) format for Picture Archiving and Communication System. The conditions of the psoas (PS), quadratus lumborum (QL) and lumbar paraspinal extensor muscles (PSEs, including multifidus [MF] and erector spinae [ES]) were analyzed using the cross-sectional area (CSA) and signal intensity (SI) at axial T2-weighted image.

In order to decrease the bias caused by differences in individual body size, the area of the muscles was divided by intervertebral disc area of the same level and multiplied by 100 (muscle CSA/disc CSA*100) to represent the lumbar muscularity in each individual. Similarly, the degree of fatty change was estimated as muscle–fat index at each level by muscle–subcutaneous fat SI ratio multiplied by 100 [21]. The region of interest (ROI) of the area of lean muscle tissue excluding fatty infiltration was drawn to determine the functional cross-sectional area (FCSA) [23], the muscle–fat index of the lean muscle within the ROI was defined as lean muscle–fat index (LMFI). Gross cross-sectional area (GCSA) was determined by drawing the outer perimeter of the muscle including any areas of intramuscular fat, and the muscle–fat index of the GSCA was defined as total muscle–fat index (TMFI). The GCSA of PS and QL were not measured since it was too difficult to distinguish their border, and the T2 signal intensity of PS and QL were measured by FCSA instead (Fig. 1).

Two spinal surgeons independently performed the measurements without referring back to previous imagines, and measurements were repeated after 2 weeks with same protocol to measure the intra-observer and inter-observer reproducibility and reliability.

Statistical analysis

The data were analyzed by SPSS software version 22 (SPSS Inc., Chicago, IL). The descriptive results were expressed as mean and standard deviation (SD) for continuous variables with an approximately normal distribution or as the median (interquartile range) otherwise. Categorical values were presented as frequency and percentage. Simple comparisons of continuous data between groups were carried out with the Student's t test or Mann–Whitney U test, depending on whether the distribution was normal or abnormal, respectively. Categorical variables were compared using the X^2 test or Fisher's exact test. Intra-observer reproducibility and inter-observer reliability were calculated using one-way analysis of variance and the intra-class correlation coefficient (ICC). Variables with P values < 0.05 in the univariate analyses, as well as a number of variables selected by experts, were entered into a multivariate logistic regression model to identify the independent risk factors of PJK. A P value < 0.05 was considered statistically significant.

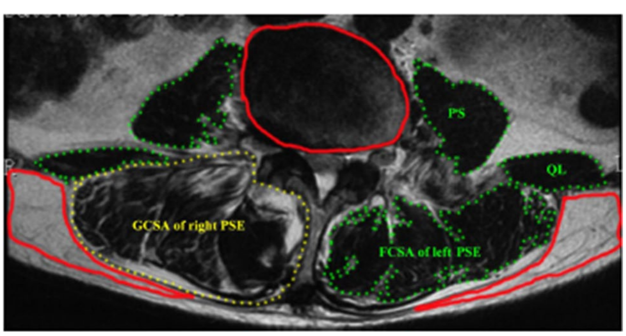

Fig. 1 Measurement of paraspinal muscular parameters on MRI. The functional cross-sectional area (FCSA) of psoas muscle (PS), quadratus lumborum (QL) and left paraspinal extensor muscles (PSEs, including multifidus [MF] and erector spinae [ES]), were outlined by green dotted lines. Regions of intervertebral disc and muscle-subcutaneous fat were outlined by red solid lines. For right PSEs, gross muscle was outlined on the right side by yellow dotted line

Results

There were a total of 84 patients who met the inclusion criteria for the study with the average follow-up of 40.83 months. The prevalence of PJK was 20.24% (17/84). Gender, age at surgery, BMI, presenting symptoms, duration of symptoms, comorbidity, follow-up time, American Society of Anesthesiologists (ASA) physical status classification, operation duration, osteotomy, UIV level (lower thoracic vs. upper lumbar), fusions extending to the sacrum and levels fused were not significantly different between groups. Lower bone mineral density was observed in PJK group (0.59 ± 0.09 g/cm^2 in PJK group vs. 0.66 ± 0.10 g/cm^2 in Non-PJK group, P = 0.016. T-score: − 2.36 ± 0.79 vs. − 1.61 ± 0.91, P = 0.010) (Table 1).

The CSA measurements of the paraspinal muscles and disc showed excellent intra-observer and inter-observer reliability (ICC = 0.82 and 0.96, respectively), indicating that the measurements were reliable. In the PS and QL assessment, the lumbar muscularity was not significantly different between the two groups. However, the FCSA of PSE in the PJK group was statistically smaller than the Non-PJK group at all levels. No significant differences in the GCSA of PSE between the groups were observed (Table 2). The assessment of intra-observer and inter-observer reliability showed excellent agreement between the two measurements for mean SI of muscle and subcutaneous fat (ICC 0.86 and 0.95, respectively). The LMFI and TMFI of PSE in the PJK group were higher than in the non-PJK group at all levels (Table 3). In the PS and QL assessment, the degree of fatty change between the groups was not significantly different (P > 0.05).

The radiographical parameters are summarized in Table 4. The coronal parameters, including Cobb angle, AVT and CSVL were similar in both groups during the preoperative, immediate postoperative and final follow-up period. No preoperative and early postoperative TK and LL revealed a statistically significant difference between the two groups, but we found LL in the PJK group was significantly

Table 1 Characteristics of two groups with or without the occurrence of PJK

	PJK group ($n=17$)	Non-PJK group ($n=67$)	P value
Gender			
Female:Male (n)	15:2	56:11	0.922
Age at surgery (year)	63.53 ± 7.33	62.69 ± 6.40	0.738
BMI (kg/m^2)	26.34 ± 4.40	26.31 ± 3.52	0.976
Presenting symptoms			
Low back pain	3	5	0.284
Back and lower limb symptoms	14	58	
Lower limb symptoms	0	4	
Duration of symptoms (years)[a]	10.00 (5.00,18.00)	10.00 (4.00,20.00)	0.889
Diabetes Mellitus (n)	4	8	0.406
Hypertension (n)	6	29	0.551
Follow-up time (m)[a]	34.00 (22.00,58.00)	34.00 (28.00,44.50)	0.925
ASA (I:II:III)	1:15:1	8:54:5	0.738
Operation duration (min)	283.06 ± 81.98	278.81 ± 69.91	0.819
Osteotomy (n)			
PCO	7	41	0.201
PSO	2	2	
UIV level			
Lower thoracic	12	44	0.701
Upper lumbar	5	23	0.701
Fusions extending to the sacrum	11	46	0.755
Levels fused	6.47 ± 2.10	5.87 ± 1.27	0.435
Bone mineral density (g/cm^2)	0.59 ± 0.09	0.66 ± 0.10	**0.016**
T-score	− 2.36 ± 0.79	− 1.61 ± 0.91	**0.010**

Bold represents statistically significant

PJK proximal junctional kyphosis; *BMI* body mass index; *ASA* American Society of Anesthesiologists, *PCO* posterior column osteotomy, *PSO* pedicle subtraction osteotomy, *UIV* upper instrumented vertebra

The values are given as mean ± standard deviation and [a]Median (Q1, Q3). A P value of < 0.05 was considered to indicate statistical significance

smaller than the Non-PJK group at the final follow-up. Preoperative, immediate postoperative and follow-up TLK were significantly greater in the PJK group ($P<0.05$). The pelvic incidence was not different between groups. Preoperative abnormal pelvic retroversion, high PT, was observed in both groups and was slightly greater in the PJK group (27.29 ± 8.44° vs. 24.68 ± 11.04°, $P=0.367$). Immediate postoperative PT was less than 20° in both groups, and the PJK group had greater PT at the final follow-up though there was no statistical significance. There was a significant difference in the pre- to immediate postoperative change in PT (11.76 ± 8.53° vs. 5.09 ± 8.12°, $P=0.004$). Preoperative and final follow-up SS was approximately 8° smaller in the PJK group. Preoperative, immediate postoperative and final follow-up PI-LL were similar in both groups. Preoperative SVA (71.16 ± 52.68 mm vs. 39.59 ± 44.70 mm, $P=0.042$) and change (58.92 ± 62.11 mm vs. 15.38 ± 53.36 mm, $P=0.019$) of SVA were observed significantly greater in the PJK group. Immediate postoperative SVA was restored within the normal range in both groups. The preoperative PJA was similar between two groups, and change in PJA between pre- and immediate postoperative was significantly greater in the PJK group than the Non-PJK group (5.83 ± 3.67 vs. 2.04 ± 6.16, $P=0.026$).

Multivariate regression analysis demonstrated that preoperative bone mineral density less than − 2.5 (odds ratio (OR) = 14.12, 95% confidence interval (CI) = 1.33–19.53, $P=0.028$), preoperative TLK more than 15°(OR = 24.59, 95% CI = 2.02–39.75, $P=0.012$), Preoperative SS less than 24°(OR = 28.80, 95% CI = 1.44–56.63, $P=0.028$), FCSA of PSE less than 138.75(OR = 22.56, 95% CI = 1.60–31.69, $P=0.021$), TMFI of PSE more than 44.08 (OR = 16.44, 95% CI = 1.34–28.45, $P=0.029$) were the independent risk factors contributing to the occurrence of PJK.

There were no significant differences in the VAS score for back pain, VAS score for leg pain, JOA score, ODI and each parameter of SRS-22 at the preoperative baseline in the two groups. PJK group had significantly higher VAS scores for back pain at the final follow-up (3.60 ± 1.99 vs. 2.24 ± 1.66, $P=0.015$) and less change in VAS for back pain. The final

Table 2 Lumbar muscularity (CSA of muscle–disc ratio × 100) of the paraspinal muscles of two groups using MRI

Parameters	Levels	PJK group ($n = 17$)	Non-PJK group ($n = 67$)	P value
PS CSA	L1–L2	21.57 ± 7.65	22.91 ± 5.99	0.482
	L2–L3	42.36 ± 13.06	45.29 ± 7.56	0.399
	L3–L4	60.14 ± 8.89	61.38 ± 10.92	0.665
	L4–L5	80.11 ± 23.92	85.28 ± 11.91	0.213
	L5–S1	104.23 ± 14.61	101.06 ± 15.26	0.457
QL CSA	L1–L2	14.01 ± 5.33	17.08 ± 6.25	0.096
	L2–L3	21.71 ± 9.71	22.01 ± 7.63	0.895
	L3–L4	29.98 ± 12.87	30.47 ± 10.64	0.873
	L4–L5	34.09 ± 4.49	32.91 ± 4.39	0.342
	L5–S1	Not checkable	Not checkable	–
FCSA of PSE	L1–L2	148.15 ± 14.45	192.34 ± 29.45	**< 0.001**
	L2–L3	144.44 ± 25.39	162.26 ± 27.59	**0.016**
	L3–L4	126.64 ± 20.21	148.88 ± 25.95	**0.002**
	L4–L5	120.17 ± 20.00	139.48 ± 25.75	**0.005**
	L5–S1	90.17 ± 20.41	114.53 ± 21.40	**< 0.001**
GCSA of PSE	L1–L2	251.42 ± 22.45	254.05 ± 26.47	0.708
	L2–L3	236.30 ± 25.05	234.59 ± 26.24	0.809
	L3–L4	220.78 ± 28.09	215.33 ± 33.49	0.539
	L4–L5	230.46 ± 20.78	225.33 ± 35.89	0.447
	L5–S1	224.89 ± 23.51	223.04 ± 31.14	0.820

Bold represents statistically significant

PJK proximal junctional kyphosis; *CSA* cross-sectional area; *GCSA* gross cross-sectional area; *FCSA* functional cross-sectional area; *PS* Psoas; *QL* quadratus lumborum; *PSE* paraspinal extensor muscle

The values are given as mean ± standard deviation. A P value of < 0.05 was considered to indicate statistical significance

follow-up SRS-22 subcategories of pain, function, self-image and total SRS-22 score were significantly lower in the PJK group. However, the final follow-up and change of VAS score for leg pain, ODI and JOA score were similar among the groups (Table 5).

Discussion

Degenerative lumbar scoliosis is a progressive coronal deformity, including sagittal malalignment, that usually occurs in patients over 40 years of age**.** As we know, DLS is a spinal deformity defined as a lumbar Cobb angle greater than 10° without previous history of scoliosis [1, 24], and the Cobb angle is generally below 40° [12]. Curve prevalence in adult degenerative scoliosis(ADS) is inversely proportional to curve magnitude. The prevalence of 10°, 10–20° and > 20° curves is 64, 44 and 24%, respectively [24]. However, the SRS-Schwab classification defines curves < 30° as normal [25]. This classification is an adult spinal deformity (ASD) classification system. Patients with ASD are a heterogeneous group and may present with varying degrees and types of curvatures. DLS patients included those with asymmetric disc collapse, facet arthritis and stenosis. Hence, DLS should be considered as a unique subgroup of ASD. In a study comparing the results of distal fusion to L5 versus the sacrum in the long instrumented fusion for degenerative lumbar scoliosis, the average preoperative Cobb angle was 24.7° (range 11–45°) in the L5 group and 22.8° (range 13–42°) in the sacrum group [26]. Iizuka et al. [27] reported 49 subjects with radiographic DLS with Cobb angle 18.6 ± 8.5°. In a meta-analysis including 14 studies of 811 patients, the preoperative Cobb angle was from 16.3° to 32.3°. The average preoperative Cobb in PJK and non-PJK group in our study were 32.31° and 28.73°, respectively, which were similar to previous studies.

PJK is drawing much more attention because PJK could lead to progressive decompensation in the sagittal plane, neurological compromise, revision surgery and worse clinical outcomes [15, 20]. The prevalence of PJK in adult spine deformity (ASD) patients varied widely from 10 to 45% [15]. In our study, PJK was observed in 17 patients with a prevalence of 20.24%, which was similar to that reported in Wang's study [28] in DLS patients. Our data suggested that preoperative lower muscularity and higher fatty degeneration of PSE at the lumbar area, osteoporosis, preoperative larger TLK and smaller SS lead to PJK. Furthermore, PJK

Table 3 Degree of fatty change (mean signal intensity of muscle–subcutaneous fat ratio × 100) of the paraspinal muscles of two groups using MRI

Parameters	Levels	PJK group ($n=17$)	Non-PJK group ($n=67$)	*P* value
LMFI of PS	L1–L2	12.22 ± 1.62	11.69 ± 3.37	0.405
	L2–L3	12.48 ± 2.64	11.59 ± 2.99	0.285
	L3–L4	13.37 ± 2.27	11.99 ± 3.26	0.106
	L4–L5	12.08 ± 1.97	11.37 ± 3.54	0.430
	L5–S1	11.95 ± 2.04	10.57 ± 4.25	0.068
LMFI of QL	L1–L2	15.81 ± 2.34	15.83 ± 3.91	0.984
	L2–L3	16.06 ± 1.91	15.63 ± 4.23	0.547
	L3–L4	17.00 ± 3.34	15.98 ± 5.08	0.435
	L4–L5	19.47 ± 3.15	18.34 ± 6.19	0.468
	L5–S1	Not checkable	Not checkable	–
LMFI of PSE	L1–L2	31.66 ± 7.76	22.39 ± 5.06	**0.001**
	L2–L3	32.74 ± 8.95	23.13 ± 5.55	**0.001**
	L3–L4	29.71 ± 7.52	23.97 ± 5.52	**0.001**
	L4–L5	32.61 ± 6.88	26.91 ± 6.24	**0.002**
	L5–S1	38.10 ± 8.86	29.62 ± 7.81	**< 0.001**
TMFI of PSE	L1–L2	45.60 ± 8.46	31.45 ± 7.22	**< 0.001**
	L2–L3	49.93 ± 10.63	34.73 ± 8.75	**< 0.001**
	L3–L4	47.64 ± 10.33	36.86 ± 9.02	**< 0.001**
	L4–L5	53.87 ± 8.71	43.04 ± 11.62	**0.001**
	L5–S1	58.88 ± 8.18	47.57 ± 10.23	**< 0.001**

Bold represents statistically significant

PJK proximal junctional kyphosis; *LMFI* lean muscle–fat index; *PS* Psoas; *QL* quadratus lumborum; *PSE* paraspinal extensor muscle; *TMFI* total muscle–fat index

The values are given as mean ± standard deviation. A *P* value of < 0.05 was considered to indicate statistical significance

patients have worse results in back pain, self-image and function.

It is clear that varied pathogenic mechanisms may influence the development and progression of PJK, several patient-related, surgery-related and radiographic risk factors have been identified in the literature [16]. Age, BMI and osteoporosis are patient-related risk factors. Bridwell et al. [19] reported that older age and obesity were associated with a development of PJK ≥ 20° in primary adult idiopathic/degenerative scoliosis. Kim et al. [20] also found patients with PJK requiring revision were older. However, the age and BMI of the patients enrolled are similar in our study. We found preexisting low BMD and *T*-score were the independent risk factor of PJK, which was consistent with the results by Yagi et al. [22] and Kim et al. [14].

Paraspinal muscles, including flexor and extensors, produce trunk movements and maintain body balance. Hyun and his colleague [21] demonstrated that patients with PJK after stopping at the thoracolumbar junction had lower ES muscularity and higher ES and MF fatty degeneration at the T10 to L2 level. Another study, including 49 cases of ASD patients, also found that mean back muscle volume in the thoracolumbar area was significantly lower in the PJK group [14]. The current study found PJK group had higher SI of total and lean muscle and reduced FCSA of PSE, demonstrating that PSE degeneration was related to the occurrence of PJK. In multivariate regression analysis, PSE muscularity and fatty degeneration at lumbar were independent risk factors for PJK in DLS patients having multilevel spinal instrumented fusion stopping at the thoracolumbar junction.

Ogon et al.'s study [29] showed intramyocellular lipids of MF had a significantly negative correlation with LL and a significantly positive correlation with SVA in the chronic low back pain patients. However, there was no significant correlation between extramyocellular lipids of the multifidus with LL or SVA. Jun et al. [30] demonstrated that increasing in fatty degeneration ratio and decreasing in lumbar muscularity in the paraspinal muscle were correlated with a decrease in LL, which in turn was correlated with a decrease in TK and then an increase in SVA. Our results showed an LL loss at the final follow-up in both groups, but the PJK group had much larger LL loss, which may result from a severely lower muscularity and higher fatty degeneration in the PJK group. Less LL was observed preoperatively in the PJK group, though there was no statistical significance (22.26 ± 18.34 vs. 29.94 ± 17.5, $P = 0.139$). As PSE condition was more severe preoperatively, additionally, iatrogenic denervation, ischemic and thermal damage during posterior

Table 4 Comparison of radiographical parameters between the PJK group and the Non-PJK group

Parameters	PJK group (*n* = 17)	Non-PJK group (*n* = 67)	*P* value
Cobb (°)			
Preoperative	32.31 ± 15.92	28.73 ± 10.37	0.389
Postop < 2 week	13.76 ± 9.05	11.63 ± 5.59	0.366
Final follow-up	14.40 ± 7.22	11.96 ± 5.73	0.141
Change in Cobb	18.55 ± 13.23	17.10 ± 9.05	0.673
AVT (mm)			
Preoperative	25.77 ± 12.59	27.33 ± 14.44	0.811
Postop < 2 week	14.43 ± 6.81	17.41 ± 10.28	0.333
Final follow-up	13.75 ± 10.58	16.41 ± 10.33	0.263
Change in AVT	11.34 ± 10.12	9.92 ± 8.87	0.190
CSVL (mm)			
Preoperative	20.81 ± 16.26	19.02 ± 21.19	0.407
Final follow-up	19.63 ± 13.72	19.54 ± 15.44	0.798
TK (°)			
Preoperative	16.22 ± 12.14	18.11 ± 14.69	0.625
Postop < 2 week	18.48 ± 6.48	20.43 ± 11.44	0.604
Final follow-up	26.75 ± 15.31	22.36 ± 12.85	0.230
Change in TK	2.26 ± 10.95	2.32 ± 10.49	0.564
TLK (°)			
Preoperative	23.95 ± 18.06	8.05 ± 16.71	**0.003**
Postop < 2 week	14.43 ± 9.46	9.23 ± 7.21	**0.018**
Final follow-up	24.44 ± 9.99°	9.14 ± 11.26	**< 0.001**
Change in TLK	− 9.52 ± 16.29	1.18 ± 16.39	**0.012**
LL (°)			
Preoperative	22.26 ± 18.34	29.94 ± 17.51	0.139
Postop < 2 week	38.21 ± 11.01	40.06 ± 9.14	0.477
Final follow-up	28.04 ± 12.11	35.91 ± 12.54	**0.022**
Change in LL	15.94 ± 16.01	10.12 ± 13.97	0.140
PT (°)			
Preoperative	27.29 ± 8.44	24.68 ± 11.04	0.367
Postop < 2 week	15.53 ± 7.49	19.62 ± 8.02	0.061
Final follow-up	25.34 ± 7.75	22.00 ± 8.78	0.156
Change in PT	11.76 ± 8.53	5.09 ± 8.12	**0.004**
PI (°)			
Preoperative	45.79 ± 8.014	51.07 ± 11.00	0.067
Postop < 2 week	45.28 ± 5.12	50.19 ± 10.66	0.142
Final follow-up	46.81 ± 8.28	51.86 ± 10.59	0.071
SS (°)			
Preoperative	18.58 ± 7.84	26.30 ± 10.65	**0.006**
Postop < 2 week	30.58 ± 9.28	30.27 ± 8.08	0.889
Final follow-up	21.58 ± 8.56	29.82 ± 9.12	**0.001**
PI-LL (°)			
Preoperative	23.52 ± 16.96	21.12 ± 17.78	0.617
Postop < 2 week	7.92 ± 11.06	10.29 ± 10.02	0.485
Final follow-up	18.77 ± 12.71	15.95 ± 13.07	0.426
SVA (mm)			
Preoperative	71.16 ± 52.68	39.59 ± 44.70	**0.042**
Postop < 2 week	12.24 ± 24.23	24.20 ± 39.88	0.343
Final follow-up	62.88 ± 33.31	44.59 ± 33.15	**0.046**
Change in SVA	58.92 ± 62.11	15.38 ± 53.36	**0.019**
PJA (°)			

Table 4 (continued)

Parameters	PJK group ($n=17$)	Non-PJK group ($n=67$)	P value
Preoperative	4.30 ± 6.64	4.20 ± 9.27	0.967
Postop < 2 week	10.13 ± 6.19	6.24 ± 7.61	0.055
Final follow-up	22.16 ± 7.61	6.97 ± 8.84	**< 0.001**
Change in PJA	5.83 ± 3.67	2.04 ± 6.61	**0.026**

Bold represents statistically significant

PJK proximal junctional kyphosis; *AVT* apical vertebral translation; *CSVL* coronal vertical axis from the central sacrum vertical line; *TK* thoracic kyphosis; *TLK* thoracolumbar kyphosis; *LL* lumbar lordosis; *PT* pelvic tilt; *PI* pelvic incidence; *SS* sacral slope; *PI-LL* difference between pelvic incidence and lumbar lordosis; *SVA* sagittal vertical axis; *PJA* proximal junctional angle

The values are given as mean ± standard deviation. A P value of < 0.05 was considered to indicate statistical significance

spinal surgery [31] could contribute to increasing PSE atrophy and progression to eventual decreased LL. Decreased LL causes anterior displacement of the center of gravity, and an increased SVA was observed at the final follow-up than immediate postoperative, which may result in PJK. Our data suggest that spine surgeons should evaluate muscularity and fatty degeneration preoperatively. Therefore, antiosteoporosis and fusion up to the upper thoracic, if the low paraspinal muscularity and fatty degeneration are severe, could be considered to prevent PJK in DLS patients.

Approach, choice of UIV, fusion to the sacrum and the magnitude of the correction are common surgical risk factors for PJK. In our study, all patients are instrumented using pedicle screws posteriorly with UIV at the thoracolumbar junction and choose UIV at the stable, neutral, horizontal vertebra with a stable proximal adjacent disc in the coronal plane [32]. UIV at the lower thoracic spine and fusion to the sacrum have been proposed as risk factors for PJK by previous studies [19, 22]. However, there were no statistical differences of PJK incidence according to UIV locations and fusion to the sacrum in our study, which was consistent with Hyun et al.'s study [21]. Recently, studies have shown greater SVA, and LL correction may contribute to PJK [17, 21, 22]. In our study, we found a change of SVA in the PJK group was larger than the non-PJK group (58.92 ± 62.11 mm vs. 15.38 ± 53.36 mm, $P=0.019$), but the change in SVA was not significant in multivariate analysis. In a previous study [33] of our institution, it was reported that average PI value of asymptomatic Chinese adult (46.4 ± 9.6°) was lower than that of Caucasian adults (51.7° to 55.0°), and Xu's study [34] found PI was 43.6 ± 11.2° and LL was 48.2 ± 9.6° in asymptomatic Chinese adults. Another Chinese study [35] suggested that the ideal PI-LL may be between 10° and 20° in ADS patients after long posterior instrumentation and fusion. In our clinical practice, we also found it was not proper to restore LL to achieve ideal PI-LL ≤ 10°, especially for older people. The correction of LL was not so much as previous studies reported, which may account for our results.

In our study, higher preoperative SVA and a larger change in PJA were identified as a potential risk factor, and higher preoperative TLK and lower preoperative SS were independent radiographic risk factors. Annis et al. [36] reported that preoperative sagittal vertical axis > 5 cm and postoperative PJA > 5° were risk factors for proximal junctional failure. We found immediate postoperative PJA in PJK was larger, but there was no significant difference(10.13 ± 6.19° vs. 6.24 ± 7.16°, $P=0.055$). Disruption of the posterior soft tissues, such as the posterior tension band and intervertebral elements, may contribute to the local sagittal alignment change. Zhao et al. [15] lately also reported preoperative larger TLK and smaller SS in the PJK group. Simultaneous to the development of PJK, the SS was reduced to values similar to the pre-operative average and was smaller than that of the non-PJK patients. Pelvis rotation involving increasing PT and decreasing SS is a compensatory mechanism for hypolordotic deformity of the lumbar spine and compensates for the forward incline of sagittal alignment caused by PJK [15, 37, 38]. It was also reported Ankylosing spondylitis patients with PJK had a larger TLK preoperatively than those without PJK [39]. Greater preoperative TLK might result in a sagittal imbalance, and the occurrence of PJK after correction surgery would be a compensatory mechanism for sagittal malalignment [15].

Many studies showed there were no significant clinical differences between PJK patients and non-PJK [19, 22]. Kim et al. [40] reported that pain was more prevalent in PJK patients with a lower improvement in the SRS pain domain. No differences were seen in other SRS domains, total SRS score or ODI. However, Hassanzadeh et al. [41] noted that PJK patients had significantly lower scores in all SRS-22 domains except satisfaction and significantly higher ODI scores. Our study suggested that PJK patients had worse clinical results in back pain, self-image and function in SRS-22, while VAS score for leg pain, ODI and JOA score were not different between the two groups, which might result from that PJK usually occurs in the thoracic spine.

Table 5 Comparison of health-related quality-of-life outcomes between the PJK group and the Non-PJK group

Parameters	PJK group (*n* = 17)	Non-PJK group (*n* = 67)	*P* value
VAS back pain			
Preoperative	6.07 ± 1.71	6.09 ± 1.86	0.966
Final follow-up	3.60 ± 1.99	2.24 ± 1.66	**0.015**
Change in VAS	2.47 ± 2.07	3.85 ± 2.33	**0.036**
VAS leg pain			
Preoperative	5.53 ± 2.13	5.30 ± 2.32	0.848
Final follow-up	2.27 ± 2.12	1.83 ± 2.02	0.405
Change in VAS	3.27 ± 2.49	3.47 ± 2.89	0.801
ODI			
Preoperative	62.40 ± 18.20	58.35 ± 16.80	0.408
Final follow-up	24.83 ± 15.20	20.73 ± 15.33	0.291
Change in ODI	37.57 ± 19.45	37.62 ± 19.94	0.992
JOA			
Preoperative	13.00 ± 4.19	13.28 ± 4.62	0.830
Final follow-up	21.40 ± 3.60	22.78 ± 4.43	0.264
Change in JOA	8.40 ± 4.34	9.50 ± 5.08	0.439
SRS-22 domain			
Pain			
Preoperative	2.29 ± 0.63	2.35 ± 0.67	0.755
Final follow-up	3.52 ± 0.71	4.12 ± 0.72	**0.005**
Change in pain	1.23 ± 0.83	1.77 ± 0.95	**0.044**
Function			
Preoperative	1.71 ± 0.47	2.02 ± 0.55	0.051
Final follow-up	2.79 ± 0.56	3.35 ± 0.68	**0.004**
Change in function	1.09 ± 0.33	1.33 ± 0.85	0.077
Self-image			
Preoperative	2.27 ± 0.68	2.26 ± 0.58	0.939
Final follow-up	3.57 ± 0.70	3.94 ± 0.63	**0.048**
Change	1.29 ± 1.17	1.68 ± 0.75	0.051
Mental health			
Preoperative	2.84 ± 0.98	2.88 ± 0.72	0.934
Final follow-up	3.82 ± 1.01	4.19 ± 0.61	0.132
Change	0.98 ± 0.90	1.31 ± 0.71	0.059
Satisfaction			
Final follow-up	3.80 ± 0.94	4.24 ± 0.75	0.104
Total			
Preoperative	2.28 ± 0.47	2.38 ± 0.39	0.395
Final follow-up	3.50 ± 0.60	3.97 ± 0.55	**0.008**
Change	1.22 ± 0.68	1.59 ± 0.66	**0.028**

Bold represents statistically significant

PJK proximal junctional kyphosis; *VAS* visual analogue scale; *ODI* Oswestry disability index; *JOA* Japanese Orthopedic Association; *SRS* Scoliosis Research Society

The values are given as mean ± standard deviation. A *P* value of < 0.05 was considered to indicate statistical significance

There are many methods to prevent PJK occurrences, such as using hooks, vertebral cement augmentation and sublaminar bands. As a preventive measure, various trials to reduce the prevalence of PJK using hooks have been reported. Hassanzadeh et al. [41] used the transverse process hook and pedicle screws at the UIV for patients who had already undergone more than five levels of instrumentation surgeries. None of the 20 patients in the hook group versus 8 of 27 patients in the screw group (29.6%) developed PJK at a 2-year follow-up. Hart et al. [42] reported that the use of prophylactic vertebroplasty of the UIV and UIV + 1 levels not only reduced the risk of proximal junctional acute collapse but was also a cost-effective intervention in elderly female patients undergoing extended lumbar fusions. Besides, damage to parts of the posterior column, such as the facet joint capsule or interspinous ligament during the operation, must be minimized to allow it to function as a posterior tension band [43]. Sublaminar bands provide an effective alternative to pedicle screws and sublaminar wires in posterior spinal fusion while reducing the rate of PJK [44].

This study has several limitations. First, the number of patients was relatively small, and the follow-up was relatively short, and the study may be underpowered to detect the significance of some risk factors. Second, only pedicle screws were used in the surgery rather than other types of instruments, such as hooks, which have also been reported to play a key role in the prevention of PJK. Third, we didn't take into account measurements on muscles at thoracolumbar levels (T10–T12), restricting measurements at the lumbar level. And paraspinal muscles are commonly affected during spine surgery, postoperative variations of paraspinal muscles and their correlation with PJK were not analyzed.

Conclusion

Osteoporosis, larger preoperative TLK, smaller preoperative SS, lower lumbar muscularity and higher fatty degeneration of PSE were the independent risk factors contributing to the occurrence of PJK in DLS patients following long-level posterior instrumented spinal fusion. And PJK patients have a worse clinical result in back pain, self-image and function.

Compliance with ethical standards

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

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