European Spine Journal (2022) 31:267–274
https://doi.org/10.1007/s00586-021-07090-x

ORIGINAL ARTICLE

Correlation between lordosis distribution index, lordosis tilt, and occurrence of proximal junctional kyphosis following surgery for adult degenerative scoliosis

Fei Xu[1,2,3,4] · Zhuoran Sun[1,3,4] · Weishi Li[1,3,4] · Xiangyu Hou[1,2,4] · Shuai Jiang[1,3,4] · Siyu Zhou[1,3,4] · Da Zou[1,3,4] · Zhuofu Li[1,2,3,4]

Received: 9 May 2021 / Revised: 25 October 2021 / Accepted: 10 December 2021 / Published online: 25 January 2022

Abstract

Purpose This study aimed to evaluate the effect of postoperative reciprocal progression of Lordosis tilt (LT), Lordosis distribution index (LDI) and occurrence of Proximal junctional kyphosis (PJK) following surgery for Degenerative lumbar scoliosis (DLS).

Methods A total of 122 consecutive patients with ADS were treated with correction of deformity and followed up for a minimum of 2 years. Spinopelvic parameters were measured preoperatively, postoperatively, and at the latest follow-up. The Japanese Orthopaedic Association score, Oswestry Disability Index, and visual analog scale scores were measured at the latest follow-up. Associations between LT, LDI, and PJK were analyzed using receiver operating characteristic analyses.

Results The prevalence of PJK in the present study was 24.6%. The outcomes of patients with PJK were significantly worse than those of patients without PJK. Postoperative reciprocal progression in LT and LDI with lumbar lordosis restorative surgery was observed. Preoperative risk factors for PJK were older age, larger LT, and larger Cobb angle of the curves. Postoperative risk factors for PJK included postoperative LT and postoperative Cobb angle of the curves, which were smaller than those preoperatively. We found a strong correlation between postoperative LT and Cobb angle of the curves resulting in PJK. Patients with LT < − 8° were at a higher risk of PJK.

Conclusions LT can be used to predict the occurrence of PJK in patients undergoing surgery for DLS. Appropriate postoperative LT is crucial for preventing the progression of PJK.

Keywords Adult degenerative scoliosis · Cobb angle of the curves · Lordosis distribution index · Lordosis tilt · Proximal junctional kyphosis

Introduction

Degenerative lumbar scoliosis (DLS) is highly prevalent in individuals aged > 65 years, affecting between 8.3 and 68% of the population [1–4]. DLS is a chronic condition that results from degenerative bone and soft tissue changes. Degeneration ultimately leads to pathological changes in load-bearing at the intervertebral and facet joints, resulting in spinal deformity [5]. DLS often leads to radiculopathy or ultimately instability (via spondylolisthesis or rotatory subluxation) that results in spinal stenosis and low back pain [6]. Posterior instrumentation and fusion for DLS have become the mainstay of operative treatment [7]. One of the most prevalent complications following surgical correction of DLS is Proximal junctional kyphosis (PJK) [8]. The prevalence rates of PJK after DLS surgery vary widely, which

Fei Xu and Zhuoran Sun contributed equally to this work.

✉ Weishi Li
puh3liweishi@163.com

1 Orthopaedic Department, Peking University Third Hospital, Haidian District, No. 49 North Garden Road, Beijing 100191, China

2 Peking University Health Science Center, Haidian District, No. 38 Xueyuan Road, Beijing 100191, China

3 Beijing Key Laboratory of Spinal Disease Reasearch, Beijing, China

4 Engineering Research Center of Bone and Joint Precision Medicine, Ministry of Education, Beijing, China

have been reported to range between 20 and 40% [9, 10]. The current literature evaluating sagittal alignment in the management of spinal deformity and the risk radiological factors and outcomes associated with proximal PJK have been largely based on the Schwab criteria [11] and GAP score [12]. Although the etiology of PJK is multifactorial, some radiological risk factors are still not fully understood.

An influential and widely employed classification system for the lumbo-pelvic profile in the sagittal plane has been proposed by Roussouly et al. [13]. Taking into consideration the apex of the lumbar curve and the Sacral slope (SS) in the standing position, the method allows defining four different lumbo-pelvic types, which have recently been extended to 5 by accounting for the presence of pelvic anteversion [14]. Under the Roussouly classification, two concepts deserve attention. First, the Lordosis tilt (LT) is an important positional parameter. LT is defined as the angle between the line of the anterior upper edge of L1 and S1 vertebrae and the plumb line, which indicates the inclines of the total lordosis. Second, as the lower arc of lordosis is the main portion, extending to the concept of Lordosis distribution index (LDI), defined as L4–S1 lordosis/L1–S1 lordosis × 100%, determines the lower-arc lordosis [12]. LDI is a Pelvic incidence (PI)-based proportional radiographic paralordosis, which is important because it alters the distribution of the load [15, 16]. With the same amount of Lumbar lordosis (LL), there may be different forms of LT and LDI. In the past, we paid more attention to the amount of lumbar lordosis correction. The significance of LT and LDI in DLS correction has not been fully studied.

This study aimed to investigate the potential value of LT and LDI in the occurrence of PJK following DLS correction surgery, and provide practical guidance on surgical strategies to improve clinical outcomes.

Methods

This was a single-center, retrospective study that included consecutive patients with DLS who underwent posterior instrumentation and fusion treatment at our institution between 2009 and 2018. Institutional review board approval was obtained from all the participants. The inclusion criteria for patients were as follows: (1) Cobb angle of lumbar curves ≥ 10°; (2) age > 45 years at the time of surgery; (3) long instrumentation from thoracolumbar to L5 or the sacrum with a minimum of four vertebral segments of fusion; (4) complete preoperative and postoperative radiographic data and functional evaluation forms; and (5) at least a 2-year follow-up. The exclusion criteria were as follows: (1) history of previous lumbar spine surgery and (2) other types of scoliosis.

Radiographic measurements and clinical outcomes.

Radiological evaluations were performed using the entire standing spine. X-ray and all radiological measurements were performed by two experienced surgeons who were not involved in the operations. Radiographic data collection consisted of full-length lateral radiographs obtained preoperatively, postoperatively, and at the latest follow-up. The following radiographic parameters were measured: (1) pelvic parameters: PI, pelvic tilt, and SS. (2) Local curvature: Cobb angle; LL; LDI was defined as L4–S1 lordosis/L1–S1 lordosis × 100%; thoracic kyphosis (TK). (3) Global parameters: sagittal vertical axis; LT, the angle formed by the vertical line and the line through the anterior superior edge of S1 and the first lumbar (L1) vertebra. LT is expressed as a negative value if L1 is posterior to the anterior aspect of S1 and positive if it is anterior to S1 (Fig. 1).

PJK was defined as ≥ 10° increase in kyphosis between the Upper instrumented vertebra (UIV) and the UIV + 2 between early postoperative and follow-up radiographs. Proximal junctional failure was defined as fracture of the UIV or UIV + 1, pullout of instrumentation at the UIV, and/or presence of sagittal subluxation.

Clinical outcomes were evaluated using the Japanese orthopedic association (JOA) score, Oswestry disability index (ODI), and Visual analog scale (VAS) scores at the final follow-up. These are valid and rigorous functional measures used to assess spinal disorders.

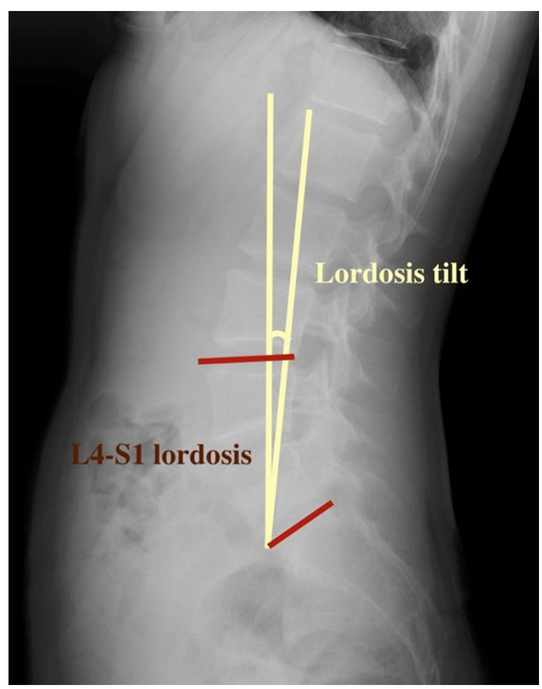

Fig. 1 Schematic diagram of measured parameters

Preoperative clinical function questionnaires, including the VAS of low back pain, JOA, and ODI scores for patients were completed on admission for surgery without assistance. All enrolled patients were followed up for at least 2 years from the date of surgery. Questionnaires were completed in the outpatient department at the final follow-up.

Statistical analysis

Statistical analysis was performed using SPSS version 23.0. All continuous data are expressed as the mean and standard deviation. The normality of continuous data was tested using the Kolmogorov–Smirnov test. Normally distributed values were compared using Student's t-test, while values with skewed distribution were compared using the Kruskal–Wallis test. Categorical data were presented as numbers, and statistical significance was performed using the $\chi 2$-test. Pearson correlation analysis was performed to investigate the relationship between postoperative radiographic parameters. ROC curve estimation was performed to predict PJK using postoperative parameters. Statistical significance was set at $p<0.05$.

Results

Patient population

A total of 122 patients were enrolled in this study; 24 were men and 98 were women, with an average age of 63.5 ± 6.3 years. The patient demographics were shown in Table 1. They underwent 6.1 ± 1.6 levels of fusions. Postoperatively, the spinopelvic alignment of patients improved significantly, and the mean preoperative and postoperative alignments were summarized in Table 1. LDI, LT, ODI, JOA, VAS in the preoperative periods were 107.4 ± 107.2%, 6.0 ± 11.7°, 58.3 ± 15.4, 11.4 ± 3.8, and 6.4 ± 1.7, respectively. The postoperative LDI and LT were 83.7% ± 20.3% and − 2.8 ± 7.4°, respectively. LDI, LT, ODI, JOA, and VAS at final follow-up were 85.9 ± 36.3%, -4.2 ± 8.0°, 27.4 ± 18.9, 20.2 ± 5.5, and 3.5 ± 2.4, respectively.

Relationship between distal fusion level and clinical outcomes

All patients were divided into floating and lumbosacral groups. We compared the clinical outcomes between the two groups and found no significant differences. The results revealed no significant difference in Cobb angle of the curves at the final follow-up time ($p=0.766$), ODI at final follow-up ($p=0.963$), JOA at final follow-up time ($p=0.379$), final VAS ($p=0.103$), and rate of PJK ($p=0.9$), which were shown in Table 2. These results confirmed that the distal fusion level does not influence the next steps of the analysis in this study.

Table 1 Patient demographics

Number of cases	122
Gender (male/female)	24/98
Age at surgery (y/o)	63.5 ± 6.3
Levels of fusion (n)	6.1 ± 1.6
Follow-up time (m)	40.1 ± 19.0
Preoperative LDI (%)	107.4 ± 107.2
Preoperative LT (°)	− 6.0 ± 11.7
Preoperative PJA (°)	4.7 ± 9.2
Preoperative Cobb angle of the curves(°)	29.6 ± 11.4
Preoperative ODI	58.3 ± 15.4
Preoperative JOA (LBP)	11.4 ± 3.8
Preoperative VAS (LBP)	6.4 ± 1.7
Postoperative LDI (%)	83.7 ± 20.3*
Postoperative LT (°)	− 2.8 ± 7.4*
Postoperative PJA (°)	8.4 ± 8.1*
Postoperative Cobb angle of the curves(°)	11.8 ± 6.8
LDI (%) at last follow-up	85.9 ± 36.3*
LT (°) at last follow-up	− 4.2 ± 8.0*
PJA (°) at last follow-up	11.1 ± 9.5*
Cobb angle of the curves(°) at last follow-up	11.2 ± 6.7
ODI at last follow-up	27.4 ± 18.9*
JOA at last follow-up (LBP)	20.2 ± 5.5*
VAS at last follow-up (LBP)	3.5 ± 2.4*

Value is expressed as the mean ± standard deviation or number

*$p<.05$, compared with preoperative result

Table 2 Comparison of therapeutic effects or complications between groups with long instrumentation and fusion with lumbar vertebra or S1

Variables	Group 1	Group 2	*P* value
Number of cases	50	72	–
Cobb angle of the curves at last follow-up (°)	10.9 ± 5.8	11.3 ± 7.4	0.766
ODI at last follow-up	27.3 ± 19.8	27.5 ± 18.3	0.963
JOA at last follow-up (LBP)	20.8 ± 5.4	19.9 ± 5.6	0.379
VAS at last follow-up (LBP)	3.1 ± 2.2	3.8 ± 2.6	0.103
PJK	92	30	0.9

Value is expressed as the mean ± standard deviation or number

*$p<.05$, compared with preoperative result

Incidence and clinical importance of PJK at final follow-up

Thirty patients (24.6%) had PJK at the final follow-up. Eighteen patients had PJK grade A (PJA < 20°), 10 patients had grade B (PJA increase from 20° to 29°), and two patients

Table 3 Comparison of clinical outcome in non-PJK group and different PJK group

Variables	Non PJK	PJK A	PJK B	PJKC
ODI at last follow-up	23.9 ± 17.8	38.4 ± 18.7*	37.0 ± 18.3*	45.0 ± 0
JOA at last follow-up (LBP)	20.9 ± 5.4	18.2 ± 5.4*	19.9 ± 4.0	5.0 ± 0*
VAS at last follow-up (LBP)	3.3 ± 2.5	4.0 ± 1.9	4.1 ± 2.2	10.0 ± 0*
SRS at last follow-up (LBP)	4.1 ± 0.8	3.5 ± 0.9*	3.3 ± 0.8*	1.0 ± 0*

*$p < .05$, compared with Non PJK group

Table 4 Preoperative characteristics of patients in non-PJK group and PJK group

Variables	Non-PJK	PJK	*P* value
Age(y)	62.7 ± 6.2	65.9 ± 6.5	0.015*
Gender(male/female)	18/74	6/24	0.959
BMI	25.7 ± 3.7	27.0 ± 5.2	0.14
Osteoporosis(Yes/No)	17/61	6/17	0.666
Fixed levels	5.9 ± 1.3	6.7 ± 2.3	0.076
LT(°)	-4.5 ± 11.7	-10.4 ± 10.5	0.016*
LDI (%)	115.3 ± 118.3	83.0 ± 56.8	0.152
Cobb angle of the curves(°)	27.9 ± 9.8	34.6 ± 14.3	0.005*
TK(°)	18.9 ± 14.6	21.7 ± 15.4	0.378
LL(°)	28.9 ± 18.4	27.0 ± 20.2	0.643
PI(°)	51.3 ± 11.6	46.8 ± 9.1	0.055
PT(°)	24.6 ± 9.9	23.5 ± 9.5	0.567
SS(°)	26.3 ± 10.8	23.4 ± 11.8	0.200
PI-LL(°)	22.4 ± 15.9	19.8 ± 18.3	0.447
|PI-LL| < 10–20° (No/Yes)	68/24	23/7	0.764
SVA (mm)	48.2 ± 49.7	63.3 ± 51.7	0.155

Value is expressed as the mean ± standard deviation or number

*$p < .05$, compared with Non-PJK group

had grade C (PJA increase > 30°). Besides, there were 7 patients (23.3%) got PJF in the patients with PJK. As shown in Table 3, ODI, JOA, and VAS scores at the final follow-up were worse in the PJK (–) group than in the PJK (+) group.

Comparison of PJK and Non-PJK

PJK patients were significantly older and had larger preoperative LT and Cobb angles. Comparison of PJK (–) and PJK (+) patients did not reveal any other differences in preoperative sagittal parameters. No significant differences in sex or body mass index were observed between PJK (+) and PJK (–) patients (Table 4). Postoperative sagittal spinopelvic alignment in patients with and without PJK is summarized in Table 5. The PJK (–) patients had a significantly smaller angle LT (− 1.6 ± 7.2 vs. − 6.2 ± 6.6°; $p = 0.002$) and Cobb

Table 5 Summary of postoperative parameters comparing patients in non-PJK group and PJK group

Variables	Non-PJK	PJK	*P* value
LT(°)	− 1.6 ± 7.2	− 6.2 ± 6.6	0.003*
LDI(°)	85.7 ± 16.8	77.8 ± 28.1	0.062
Cobb angle of the curves(°)	10.9 ± 6.1	14.3 ± 8.0	0.017*
TK(°)	21.3 ± 11.5	25.3 ± 10.8	0.095
LL(°)	39.8 ± 11.2	40.2 ± 13.7	0.845
PI(°)	48.0 ± 10.8	44.3 ± 7.7	0.059
PT(°)	19.7 ± 9.2	17.0 ± 7.8	0.141
SS(°)	31.7 ± 8.7	29.6 ± 9.6	0.270
PI-LL(°)	14.8 ± 13.8	18.1 ± 17.5	0.728
− 10 − (− 20)° < PI-LL < 10–20° (No/Yes)	74/18	21/9	0.232
SVA (mm)	23.6 ± 51.8	13.5 ± 28.3	0.313

Value is expressed as the mean ± standard deviation or number

*$p < .05$, compared with Non-PJK group

Table 6 Parameters of patients in non-PJK group and PJK group at last follow-up

Variables	Non-PJK	PJK	*P* value
LT(°)	− 3.2 ± 8.4	− 7.4 ± 5.3	0.002*
LDI(°)	90.0 ± 38.4	73.3 ± 25.5	0.028*
Cobb angle of the curves(°)	10.2 ± 5.9	14.1 ± 8.3	0.021*
TK(°)	20.0 ± 13.4	31.8 ± 15.2	< 0.001*
LL(°)	34.7 ± 14.1	32.5 ± 15.2	0.476
PI(°)	49.3 ± 10.6	48.2 ± 11.1	0.653
PT(°)	21.1 ± 10.6	22.6 ± 10.8	0.493
SS(°)	28.6 ± 10.1	23.1 ± 11.1	0.014*
PI-LL(°)	20.6 ± 14.2	18.1 ± 17.5	0.485
|PI-LL| < 10–20° (No/Yes)	69/23	22/8	0.856
SVA (mm)	47.2 ± 45.9	55.7 ± 32.3	0.351

Value is expressed as the mean ± standard deviation or number

*$p < .05$, compared with Non-PJK group

angle of the curves (10.9 ± 6.1 vs. 14.3 ± 8.0; $p = 0.017$). At final follow-up, the PJK (–) patients had a significantly smaller LT, TK and Cobb angle of the curves and significantly larger LDI and SS, which were shown in Table 6.

Postoperative reciprocal change (RC) of LT, LL and LDI

LL was significantly increased postoperatively in patients with DLS ($p < 0.001$). LT was also significantly increased in patients with dynamic light scattering ($p = 0.001$). LDI was also significantly increased in patients with DLS ($p = 0.013$). In addition, there was a significant positive correlation between increased LL angles and increased LT angles ($p = 0.006$) (Fig. 2). These results indicate that postoperative RC in LT occurred with LL corrective surgery. In contrast, there were no significant correlations between the increased LT angles and increased LDI angles.

ROC curve analysis of postoperative parameters to predict PJK

We established an ROC curve to predict PJK by including factors that were < 0.05, such as age, postoperative LT, postoperative LDI, postoperative Cobb angle, and PI-LL, which have been proven to be related to PJK [17]. This is shown in Table 7. We concluded that the Cobb angle of the curve and LT were independent risk factors for PJK in patients with DLS. According to the You Den Index of ROC analysis, the threshold (integer) for identifying patients at high risk of PJK was set at 8.0, and patients with postoperative LT < – 8° were more likely to develop PJK (43.8% vs. 18.0%, $p < 0.05$).

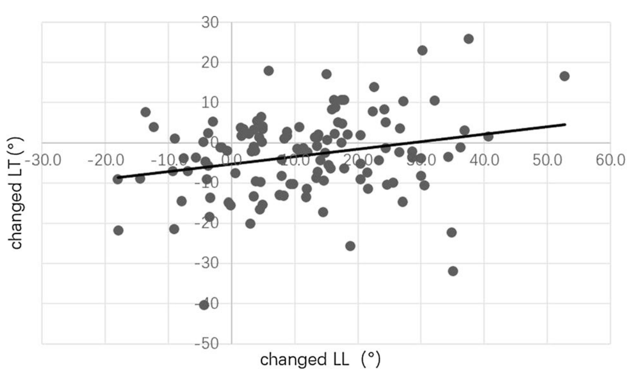

Fig. 2 Relationship between the changed LT and changed LL of preoperative and postoperative

Discussion

This study showed a correlation between postoperative LT, LDI, and clinical outcomes. There was also a significant difference in the Cobb angle of the curves in the postoperative time and last follow-up time among the groups, which indicated the great effectiveness in coronal realignment.

In the present study, the prevalence of PJK was 24.6%. Consistent with previous reports [18, 19], the clinical outcomes of patients with PJK were significantly worse than those of patients without PJK. The relationship between spinopelvic parameters and quality of life remains controversial. A previous study showed that flat-back syndrome was an indication of unsatisfactory clinical outcomes after lumbar fusion surgery [20]. Mac-Thiong [21] demonstrated that sagittal spinal and global balance was strongly associated with ODI in adults with scoliosis. In our study, there was no significant difference in clinical outcomes between the two groups when fused to S1. Therefore, the position of distal vertebral fixation was not different in these patients. We found that patients with PJK had worse clinical outcomes, which indicated the important role of sagittal balance in clinical outcomes.

Preoperative risk factors for PJK were older age, larger LT, and larger Cobb angle of the curves. The postoperative risk factors for PJK were LT and Cobb angle of the curves (Fig. 3). Previous studies indicated that patients with worse preoperative spinopelvic alignment and a large correction in LL are more likely to develop PJK [19, 22–24]. The distribution of lordosis is also important [16]. In our study, we used the age, postoperative LT, postoperative LDI, postoperative Cobb angle of the curves, and PI-LL, which have been proven to be related to PJK [17], in ROC analysis. According to the ROC curves, we found a strong correlation between postoperative LT and PJK without a relationship with LDI. LT is a spinopelvic parameter for analyzing the relationship between the relative positions of the spine and pelvis,

Table 7 ROC curve of postoperative parameters to predict PJK

Variables	B	Exp (B)	95% IC	*P* value
Age	0.072	1.075	0.999–1.156	0.051
Postoperative |PI-LL|< 10–20°(No/Yes)	0.501	1.650	0.591–4.608	0.339
postoperative LT	-0.088	0.916	0.851–0.986	0.019*
postoperative LDI	0.132	1.141	0.238–5.477	0.869
postoperative Cobb angle of the curves	0.074	1.077	1.006–1.152	0.032*

*$p < .05$, compared with preoperative result

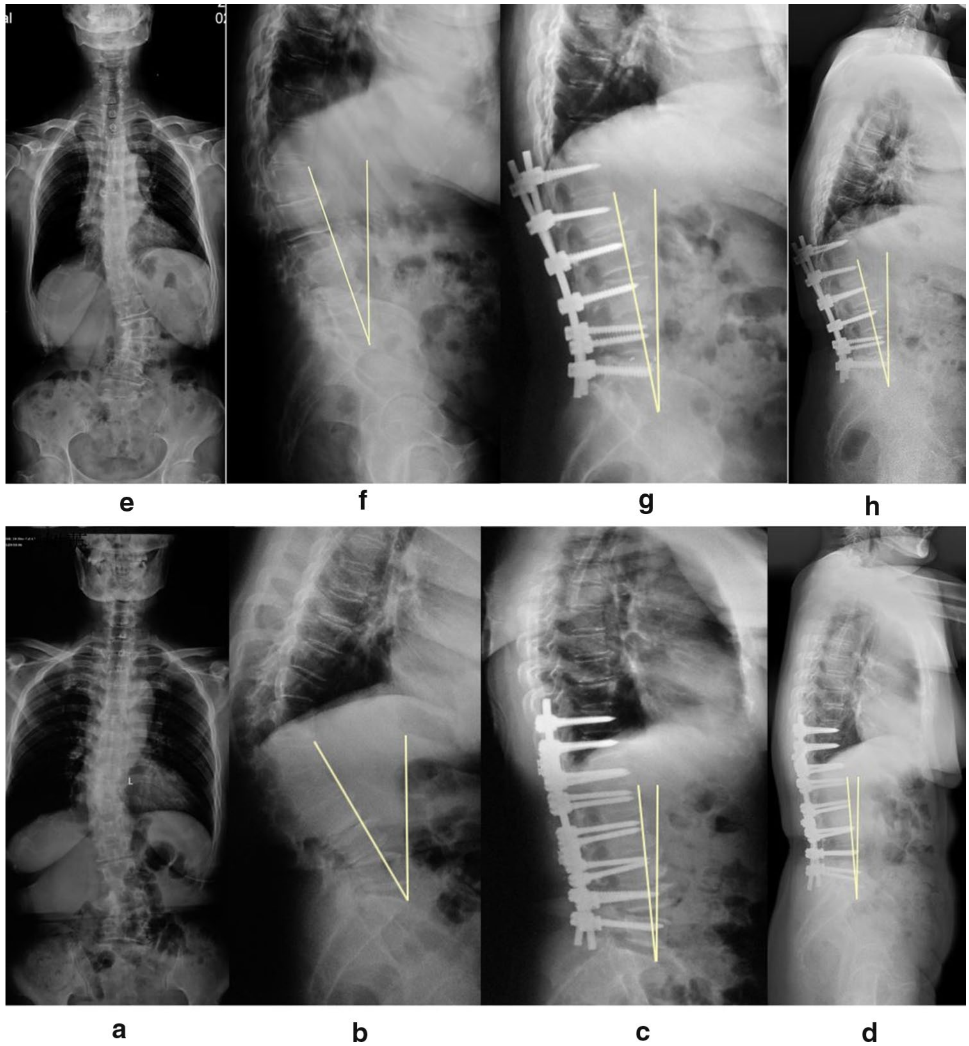

Fig. 3 The relationship between the postoperative risk factors and PJK. In the pictures, patient without PJK was shown in a, b, c and d. LDI, LT and LL in the preoperative period were 849.0%, − 26.2° and 5.1° (**a** and **b**). LDI, LT and LL in the postoperative period were 84.3%, − 3.9° and 40° (**c**). LDI, LT and LL in the preoperative period were 115.2%, − 6.9° and 24.3°(**d**). Patient with PJK was shown in e, f, g and h. LDI, LT and LL in the preoperative period were 146.6%, − 19.1° and 17.8° (**e** and **f**). LDI, LT and LL in the postoperative period were 65.1%, − 20.4° and 31.5°(**g**). LDI, LT and LL in the preoperative period were 54.4%, − 18° and 37.3° (**h**).

which indicates the inclines of the total lordosis. In total, it reflects the total LL position. In addition, we also found a positive relationship between LL and LT. Thus, attention should be paid to both LT and LL. LT had no effect on LDI. The distribution of the lordosis was considered to be aligned if the LDI was within the range 50–80%. Almost all the patients met the criteria in this study. Therefore, we believe that the relationship between LDI and PJK remains uncertain. It is still controversial whether small LDI is essential in severe deformity as a risk factor for PJK in patients with DLS using the method that was concluded by other studies [25–27]. According to the Yuden index of the ROC curve, we concluded that patients with LT < − 8° were at a higher risk of PJK.

To our knowledge, this is the first report showing a critical correlation between postoperative LT and lordosis distribution and consequent PJK. Importantly, LT is a modifiable factor depending on the surgical technique, and we can apply this knowledge to surgical strategies. In contrast with previous reports, a smaller postoperative LT was not found to be a risk factor for PJK. This is because in the previous study, they did not pay attention to this parameter. Recent reports have focused on the impact of UIV orientation on the development of PJK [28, 29]. We can control LT by adjusting the rod curvature of the position between L1 and S1 in our operation.

This study has some limitations. First, this was a retrospective study that may have caused selection bias. Second, the sample size was limited in a single-center study. Because of these limitations, a multicenter, prospective randomized study is needed to determine the ideal LT in Chinese patients.

Conclusions

Preoperative risk factors for PJK were older age, larger LT, and larger Cobb angle of the curves. Postoperative risk factors for PJK included postoperative LT and postoperative Cobb angle of the curves, which were smaller than those preoperatively. LT is a spinopelvic parameter for analyzing the relationship between the relative positions of the spine and pelvis, which indicates the incline of the total lordosis. Control of postoperative LT is crucial for preventing PJK.

Funding This article is supported by the National Natural Science Foundation of China (Grant No. 8187090666).

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 There is no conflict of interest.

Ethics approval This study was approved by the institutional review board of the hospital. For this type of study formal consent is not required.

References

1. Carter OD, Haynes SG (1987) Prevalence rates for scoliosis in US adults: results from the first National Health and Nutrition Examination Survey. Int J Epidemiol 16(4):537–544. https://doi.org/10.1093/ije/16.4.537
2. Hong JY, Suh SW, Modi HN et al (2010) The prevalence and radiological findings in 1347 elderly patients with scoliosis. J Bone Joint Surg Br 92(7):980–983. https://doi.org/10.1302/0301-620x.92b7.23331
3. Schwab F, Dubey A, Gamez L, A.B, et al (2005) Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. Spine 30(9):1082–1085
4. Pritchett JW, Bortel DT (1993) Degenerative symptomatic lumbar scoliosis. Spine 18(6):700–703
5. Glassman SD, Bridwell K, Dimar JR et al (2005) The impact of positive sagittal balance in adult spinal deformity. Spine 30(18):2024–2049
6. Pellisé F, Vila-Casademunt A, Ferrer M et al (2015) Impact on health related quality of life of adult spinal deformity (ASD) compared with other chronic conditions. Eur Spine J 24(1):3–11. https://doi.org/10.1007/s00586-014-3542-1
7. Cho KJ, Kim YT, Shin SH et al (2014) Surgical treatment of adult degenerative scoliosis. Asian Spine J 8(3):371–381. https://doi.org/10.4184/asj.2014.8.3.371
8. Schwab F, Ungar B, Blondel B et al (2012) Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine 37(12):1077–82
9. Hyun SJ, Lee BH, Park JH et al (2017) Proximal junctional kyphosis and proximal junctional failure following adult spinal deformity surgery. Korean J Spine 14(4):126–132. https://doi.org/10.14245/kjs.2017.14.4.126
10. Diebo BG, Shah NV, Stroud SG et al (2018) Realignment surgery in adult spinal deformity: prevalence and risk fac- tors for proximal junctional kyphosis. Orthopade 47(4):301–309. https://doi.org/10.1007/s00132-018-3536-5
11. Schwab F, Ungar B, Blondel B et al (2012) Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine 37(12):1077–82
12. Yilgor C, Sogunmez N, Boissiere L et al (2017) Global Alignment and Proportion (GAP) Score: Development and Validation of a New Method of Analyzing Spinopelvic Alignment to Predict Mechanical Complications After Adult Spinal Deformity Surgery. J Bone Joint Surg Am 99(19):1661–1672. https://doi.org/10.2106/JBJS.16.01594
13. Roussouly P, Gollogly S, Berthonnaud E et al (2005) Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. Spine 30:346–353
14. Laouissat F, Sebaaly A, Gehrchen M et al (2018) Classification of normal sagittal spine alignment: refounding the Roussouly classification. Eur Spine J 27:2002–2011. https://doi.org/10.1007/s00586-017-5111-x
15. Roussouly P, Nnadi C (2010) Sagittal plane deformity: an overview of interpretation and management. Eur Spine J 19(11):1824–1836. https://doi.org/10.1007/s00586-010-1476-9
16. Roussouly P, Pinheiro-Franco JL (2011) Sagittal parameters of the spine: biomechanical approach. Eur Spine J 5:578–85
17. Im SK, Lee JH, Kang KC et al (2020) Proximal Junctional Kyphosis in Degenerative Sagittal Deformity After Under- and Overcorrection of Lumbar Lordosis: Does Overcorrection of Lumbar Lordosis Instigate PJK? Spine 45(15):933–942
18. Kim HJ, Bridwell KH, Lenke LG et al (2013) Proximal junctional kyphosis results in inferior SRS pain subscores in adult deformity patients. Spine 38(11):896–901
19. Kim HJ, Bridwell KH, Lenke LG et al (2014) Patients with proximal junctional kyphosis requiring revision surgery have higher postoperative lumbar lordosis and larger sagittal balance corrections. Spine 39(9):E576-80
20. Kostuik JP, Maurais GR, Richardson WJ et al (1988) Combined single stage anterior and posterior osteotomy for correction of iatrogenic lumbar kyphosis. Spine 13(3):257–66
21. Mac-Thiong JM, Transfeldt EE, Mehbod AA et al (2009) Can c7 plumbline and gravity line predict health related quality of life in adult scoliosis? Spine 34(15):519–27
22. Hyun SJ, Kim YJ, Rhim SC (2016) Patients with proximal junctional kyphosis after stopping at thoracolumbar junction have lower muscularity, fatty degeneration at the thoracolumbar area. Spine J 16(9):1095–1101. https://doi.org/10.1016/j.spinee.2016.05.008
23. Maruo K, Ha Y, Inoue S, Samuel S et al (2013) Predictive factors for proximal junctional kyphosis in long fusions to the sacrum in adult spinal deformity. Spine 38(23):1469–7146
24. McClendon J Jr, Smith TR, Sugrue PA et al (2016) Spinal Implant Density and Postoperative Lumbar Lordosis as Predictors for the Development of Proximal Junctional Kyphosis in Adult Spinal Deformity. World Neurosurg 95:419–424. https://doi.org/10.1016/j.wneu.2016.08.008
25. Hasegawa K, Okamoto M, Hatsushikano S et al (2016) Normative values of spino-pelvic sagittal alignment, balance, age, and health-related quality of life in a cohort of healthy adult subjects. Eur Spine J 25(11):3675–3686. https://doi.org/10.1007/s00586-016-4702-2
26. Inami S, Moridaira H, Takeuchi D et al (2016) Optimum pelvic incidence minus lumbar lordosis value can be determined by individual pelvic incidence. Eur Spine J 25(11):3638–3643. https://doi.org/10.1007/s00586-016-4563-8
27. Yamato Y, Hasegawa T, Kobayashi S et al (2016) Calculation of the Target Lumbar Lordosis Angle for Restoring an Optimal

Pelvic Tilt in Elderly Patients With Adult Spinal Deformity. Spine 41(4):211–7
28. Hey HWD, Tan KA, Neo CS et al (2017) T9 versus T10 as the upper instrumented vertebra for correction of adult deformity-rationale and recommendations. Spine J 17(5):615–621. https://doi.org/10.1016/j.spinee.2016.11.008
29. Lafage R, Line BG, Gupta S et al (2017) Orientation of the Uppermost Instrumented Segment Influences Proximal Junctional Disease Following Adult Spinal Deformity Surgery. Spine 42(20):1570–1577