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CLINICAL ARTICLE

Junctional Kyphosis after Correction with Long Instrumentation for Late Posttraumatic Thoracolumbar Kyphosis: Characteristics and Risk Factors

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Objective: Junctional kyphosis is a common complication after corrective long spinal fusion for adult spinal deformity. Whereas there is still a paucity of data on junctional kyphosis, specifically among late posttraumatic thoracolumbar kyphosis (LPTK) patients. Thus, the aim of this study was to investigate the characteristics and risk factors of junctional kyphosis in LPTK patients receiving long segmental instrumented fusion.

Methods: We retrospectively reviewed a cohort of LPTK patients who had received long segmental instrumented fusion (>4 segments) in our center between January 2012 and January 2019. Radiographic assessments included the sagittal alignment, pelvic parameters, bone quality on CT images, and measurements of the cross-sectional area (CSA, cross-sectional area of muscle-vertebral body ratio × 100) and fat saturation fraction (FSF, cross-sectional area of fat-muscle body ratio × 100) of paraspinal muscles. Patients in this study were divided into those with junctional kyphosis or failure (Group J) and those without (Group NJ) during follow-up. Group J included patients with junctional kyphosis (Group JK) and patients with junctional failure (Group JF).

Results: A total of 65 patients (16 males and 49 females, average age 56.5 ± 23.4 years) were enrolled in this study. After (32.7 ± 8.5) months follow-up, 15 patients (23.1%) experienced junctional kyphosis, and four of them deteriorated into junctional failure. Eighty percent (12/15) of junctional kyphosis was identified within 6 months after surgery. In comparison with Group NJ, Group J were older ($P = 0.026$), longer fusion levels ($P < 0.001$), greater thoracic kyphosis ($P = 0.01$), greater global kyphosis ($P = 0.023$), lower bone quality ($P < 0.001$), less CSA ($P = 0.005$) and higher FSF (P <0.001) of paraspinal muscles. Preoperative global kyphosis more than 48.5° ($P = 0.001$, odds ratio 1.793) and FSF more than 48.4 ($P = 0.010$, odds ratio 2.916) were identified as independent risk factors of junctional kyphosis. Based on the statistical differences among Group NJ, Group JK and Group JF ($P < 0.001$), Group JF had lower bone quality than Group NJ ($P < 0.001$) and Group JK ($P = 0.015$). In terms of patient-reported outcomes, patients in Group JF had worse outcomes in ODI and VAS scores, and PCS and MCS of SF-36 than Group NJ and group JK

Conclusion: The prevalence of junctional kyphosis was 23.1% in LPTK patients after long segmental instrumented fusion. Preoperative hyperkyphosis and advanced fatty degeneration of paraspinal muscles were independent risk factors of junctional kyphosis. Patients with lower bone quality were more likely to develop junctional failure.

Key words: Junctional failure; Junctional kyphosis; Late posttraumatic thoracolumbar kyphosis; Long instrumentation

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Introduction

Late posttraumatic thoracolumbar kyphosis (LPTK) is a common complication of unstable spinal injuries due to failed conservative management or inappropriate surgical intervention.[1,2] Internal fixation surgery is usually required in LPTK patients with serve intractable back pain, progressive kyphosis, or increasing neurological deficits. Although good results can be expected with surgical treatment, the complication rate has been reported to be as high as 30.8%.[3–5] To date, general surgical complications have been reported, however, spine-specific complications, such as implantation complications and junctional kyphosis or failure, have not been extensively documented in patients with LPTK.

Junctional kyphosis is a common complication after long segmental fusion surgeries characterized with focal kyphosis formation at the proximal or distal end of the instrumentation. Junctional failure is a distinct entity in the spectrum of junctional kyphosis with structural failure of the vertebral body and/or the implants. Patients with junctional failure usually present with intractable pain, neurologic deficit and ambulatory difficulties.[6–8] Additional surgical intervention is required for severe junctional kyphosis and junctional failure. It is essential to identify the risk factors of junctional kyphosis or failure. Several risk factors of junctional kyphosis such as sagittal malalignment,[9] greater curvature correction,[9–12] and low bone mineral density,[11,13] have been reported in patients with adult spinal deformity, however, patients with LPTK were usually excluded due to specific pathogenesis.[10,14,15] The characteristics and risk factors of junctional kyphosis in patients with LPTK after long segmental instrumented fusion surgery are still unclear.

To the best of our knowledge, there is a paucity of data on risk factors of junctional kyphosis in patients with LPTK. Therefore, this study was performed to investigate the characteristics and risk factors of junctional kyphosis after long segmental instrumented fusion in patients with LPTK.

Materials and Methods

Study Sample

This study was approved by the Institution Review Board at our institution (No. 2021–398-01). We retrospectively reviewed the clinical and radiological data of patients who had undergone long segetal instrumented fusion for LPTK at our center between January 2012 and January 2019. The inclusion criteria of this study were as follows: (i) late kyphosis secondary to thoracolumbar fracture (local kyphosis ≥30°); (ii) fusion levels longer than four segments; (iii) at least 2-year follow-up after surgery; and (iv) complete set of imaging data, including preoperative full length standard X-ray of the whole spine, CT and MRI, postoperative and follow-up full length standard X-ray of the whole spine. Patients were excluded for any of the following criteria: (i) metastatic fracture; (ii) hooks used at anchors; and (3) with neuromuscular disease. Patient's demographic data, including age, gender and body mass index (BMI) were recorded.

Surgical Technique

Patients enrolled in this study were all treated with long posterior spinal segmental fusion and osteotomy. All surgical procedures were performed with monitoring of somatosensory-evoked potentials and motor-evoked potentials. The patient was placed in the prone position and given intravenous anesthesia. After standard posterior exposure, pedicle screws were inserted into the adjacent segments above and below the fractured vertebra. The vertebrae to be included in fusion span were determined on a case-to-case basis by evaluations of sagittal alignment and location of osteotomy vertebra. Bone cements were used in some patients with severe osteoporosis to strengthen the vertebral body or enhance the pullout resistance of pedicle screws. One unilateral temporary rod was fixed to maintain the spinal stability during the advanced-grade osteotomy procedures.[16,17] After the osteotomy procedure, the osteotomy gap was gently closed with compression forces and a permanent rod was placed. Lastly, autologous bone grafts obtained from the osteotomy combined with allografts were placed over the instrumented levels after decortication. All patients were instructed to avoid bending, lifting, and twisting motions for the first 3 months postoperatively to help promote fusion.

Radiological and Clinical Evaluation

All radiological measurement was independently completed by three senior spinal surgeons, and the average value was taken as the final result. Standing posteroanterior full-length standard X-ray films of the whole spine were used for measurements of the following parameters: (i) thoracic kyphosis (TK), defined as the angle between the superior endplate of T5 and the inferior endplate of T12; (ii) global kyphosis (GK), the angle between the superior endplate of the most tilted vertebra cranially and the inferior endplate of the vertebra tilted most caudally; (iii) local kyphosis (LK), the angle between the superior endplate of the super-adjacent segment of the fractured vertebra and the inferior endplate of the infer-adjacent one of the fractured vertebra; (iv) lumbar lordosis (LL), the angle between the upper endplate of the L1 vertebra and the upper endplate of S1; (v) sagittal vertical axis (SVA), the distance between a plumb line from the center of the C7 vertebral body and posterior superior corner of S1; (vi) pelvic parameters, including pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS);and (vii) proximal junctional angle (PJA), the angle between the lower endplate of the UIV and the upper endplate of the second supra-adjacent vertebra.

In this study, bone quality was evaluated by preoperative CT images at the axial plane from L4 vertebral body on a standard radiology picture archiving and communication system (PACS) workstation.[2,18,19] We placed a single oval click-and-drag region of interest (ROI) in the trabecular bone space of the vertebral body to assess the mean CT attenuation in Hounsfield units (HU).[20] The ROI should be as large as possible and avoid the vertebral cortex, spinal hemangiomas, posterior venous plexus, dense bone islands, and compression fracture to eliminate distortion of attenuation measurements. If it cannot be measured on the L4 vertebral body, an alternative measurement was obtained on L3 vertebral body. DEXA results were also collected if the patients had undergone DEXA examinations before surgery.

The cross-sectional area (CSA) of paraspinal muscles (cross-sectional area of muscle-vertebral body ratio × 100) and the fat saturation fraction (FSF) of paraspinal muscles (cross-sectional area of fat-muscle ratio × 100) were measured on axial T2-weighted MR images at the inferior endplate of T7 to L3 endplate levels, and the average value was calculated to represent the final CSA and FSF, using ImageJ software (ImageJ version 1.51 e, the National Institutes of Health, Bethesda, MD, USA).[21]

In this study, proximal junctional kyphosis was defined as a proximal junctional angle (PJA) of >10° that is at least 10° greater than the preoperative value.[18] Distal junctional kyphosis was defined as the angle between the superior endplate of the lowest instrumented vertebra and the inferior endplate of the adjacent distal vertebra when increased ≥10 degrees in relation to preoperative angle.[22,23] Junctional failure was defined as a vertebral fracture or implant failure of the UIV/LIV or the adjacent level, including screw/nut cut-out or pull-out.[18] The following clinical data were recorded: the types and time of junctional disorders occurrence, accompanied symptoms and history of revision surgery.

The enrolled patients were divided into those with junctional kyphosis or failure (Group J) and those without (Group NJ) during follow-up. Further, patients in Group J were subdivided into the group with junctional kyphosis (Group JK) and the group with junctional failure (Group JF).

Patient-reported outcomes were assessed using the SF-36 questionnaire, Oswestry disability index (ODI) scales and visual analogue scales (VAS).

Statistical Analysis

The statistical analyses were performed using the software of SPSS version 18.0 (SPSS, Chicago, IL, USA). The mean and standard deviation were calculated for continuous variables. The unpaired *t*-test and was used for normally distributed variables, and Mann–Whitney test was used for skewed-distributed variables between Group NJ and Group J. Differences among Group NJ, Group JK and Group JF were evaluated by Fisher's least significant difference (LSD) multiple comparison method after the analysis of variance (ANOVA). Logistic regression analysis was performed to identify the independent risk factors.

First, we performed an analysis of the demographic data for each experimental group. Second, comparison analysis of radiographic parameters was performed between Group J and Group NJ, and among Group NJ, Group JK and Group JF. Next, logistic regression analysis was performed with use of univariate analysis on all predictor variables between Group J and Group NJ. Multivariate logistic regression analysis was performed using a stepwise regression model with an inclusion criterion of $P < 0.10$ on univariate analysis to identify the independent risk factors. In addition, cutoff values to dichotomize the risk factors were calculated with receiver operating characteristics (ROC) curve analysis, with the best cutoff value selected from the point of the ROC curve with the shorter orthogonal distance to the optimum cutoff value. And the odds ratio was used to determine the score of an independent risk factor and construct a prediction model. The inter-observer consistency between the three senior spinal surgeons were analyzed using the intra-class correlation coefficient (ICC). ICC >0.75 was regarded as excellent, ICC 0.40–0.75 was fair to good, and ICC <0.40 was poor. Statistical difference was set at $P < 0.05$.

Results

General Data

A total of 65 patients (16 males, 49 females) with mean age of (56.5 ± 23.4) years at the time of surgery were included in the final analysis. The number of segments included in the fusion span was (7.2 ± 2.7) levels. The radiologic measurements showed excellent inter-observer consistency across the three observers (Supplementary Table S1).

Thirteen patients received SPO, 10 patients received PSO, and 52 patients received grade IV osteotomy. The mean preoperative and postoperative local Cobb angle of the kyphosis was (41.7° ± 18.5°) and (3.8° ± 2.1°), with an average correction rate of 90.9%. There was a 1.8° correction loss at a mean follow-up of 32.7 months. Eight (12.3%) patients suffered from perioperative complications. Cerebrospinal fluid leakage was encountered in three patients, which was relieved after pressure dressing. Two patients experienced transient neurologic deficits and recovered completely after a period of conservative treatment. Three patients suffered from superficial infection and recovered after local wound care and antibiotic treatment. All patients who had undergone PSO or grade IV osteotomy got solid bone-on-bone fusion at the last follow-up.

Characteristics of Junctional Kyphosis in LPTK *Patients*

Junctional kyphosis was detected in 15 (23.1%) patients, including 10 proximal junctional kyphosis, two proximal junctional failure (fracture at the superjacent level), one distal junctional kyphosis, and two distal junctional failure (one screw pull-out and the other with distal junctional fracture and screw pull-out). Among these patients, five patients experienced junctional problems at 3-month follow-up, seven patients at 6-month follow-up and three patients at 1-year follow-up. None demonstrated a newly onset of PJK 1-year later after surgery. At the latest visit, nine (18%) patients in Group NJ and 8 (60%) patients in Group J had back pain. Among four patients with junctional failure received brace treatments, three of them had symptomatic relief, but one resorted to revision surgery due to distal junctional fracture and cauda equine syndrome (Fig. 1).

Comparisons between Groups

Patients in Group J were statistically older (63.5 ± 11.2 *vs* 54.5 ± 10.3, p = 0.026) at surgery and lower *t* scores (−2.1 ± 1.8 *vs* -0.8 ± 1.0, P = 0.013) than patients in Group NJ (Table 1). Patients in Group J had statistical longer fusion length than patients in Group NJ (8.1 ± 3.2 *vs* 6.8 ± 3.1, $P < 0.001$). No statistical differences were observed in terms of gender, BMI, follow-up period, location of the upper or lower instrumented vertebra, osteotomy method, use of bone cement, application of sacropelvic fixation, and use of additional rods (all *P*s > 0.05). None of the patients included in this study underwent interbody fusion.

Patients in Group J were demonstrated with higher preoperative thoracic kyphosis (48.5° ± 13.4° *vs* 30.2° ± 19.1°, P = 0.01) and higher global kyphosis (53.2° ± 20.3° *vs* 42.1° ± 10.3°, P = 0.023) than patients in group NJ (Table 2). Also, the bone quality on CT images was statistically lower in Group J than in Group NJ (106.4 ± 29.8 Hu *vs* 153.5 ± 30.1 Hu, P = 0.012). In the paraspinal muscles assessment, patients in Group J had statistically less CSA (179.2 ± 41.3 *vs* 202.6 ± 34.8, P <0.001) and higher FSF (53.8 ± 12.4 *vs* 40.5 ± 10.3, P <0.001) than patients in Group NJ.

ANOVA revealed that *t* scores and bone quality on CT images had statistic differences among Group NJ, Group JK and Group JF (all *P*s < 0.001, Table 3). In detail, Group JF had statistically lower *t* scores than Group JK (−3.5 ± 1.1 *vs* -1.8 ± 1.7, $P < 0.001$) and Group NJ (−3.5 ± 1.1 *vs* -0.8 ± 1.0, $P < 0.001$). Similarly, the bone quality on CT images was also significantly lower in Group JF than in Group JK (92.2 ± 30.6 Hu *vs* 108.7 ± 25.6 Hu, P = 0.015) and Group NJ (92.2 ± 30.6 Hu *vs* 153.5 ± 30.1 Hu, $P < 0.001$).

Regression Analysis

Multivariate logistic regression analysis revealed preoperative global kyphosis more than 48.5° (P = 0.001, odds ratio 1.793) and the FSF of paraspinal muscles higher than 48.4 (P = 0.010, odds ratio 2.916) were significantly independent risk factors associated with junctional kyphosis or failure (Table 4).

Quality of Life

Based on ANOVA results on ODI and VAS scores at the latest follow-up, we found that Group JF had statistically worse ODI scores than Group NJ (28.7 ± 6.4 *vs* 19.4 ± 9.5, $P < 0.001$) and Group JK (28.7 ± 6.4 *vs* 20.1 ± 7.4, P = 0.005), VAS scores were also worse in Group JF than Group NJ (3.1 ± 1.7 *vs* 2.3 ± 1.2, P = 0.003) and Group JK (3.1 ± 1.7 *vs* 2.3 ± 1.8, p < 0.001) (Table 5). The PCS of SF-36 was also worse in Group JF than Group NJ (46.3 ± 13.7 *vs* 48.6 ± 13.2, P = 0.023) and Group JK (46.3 ± 13.7 *vs*

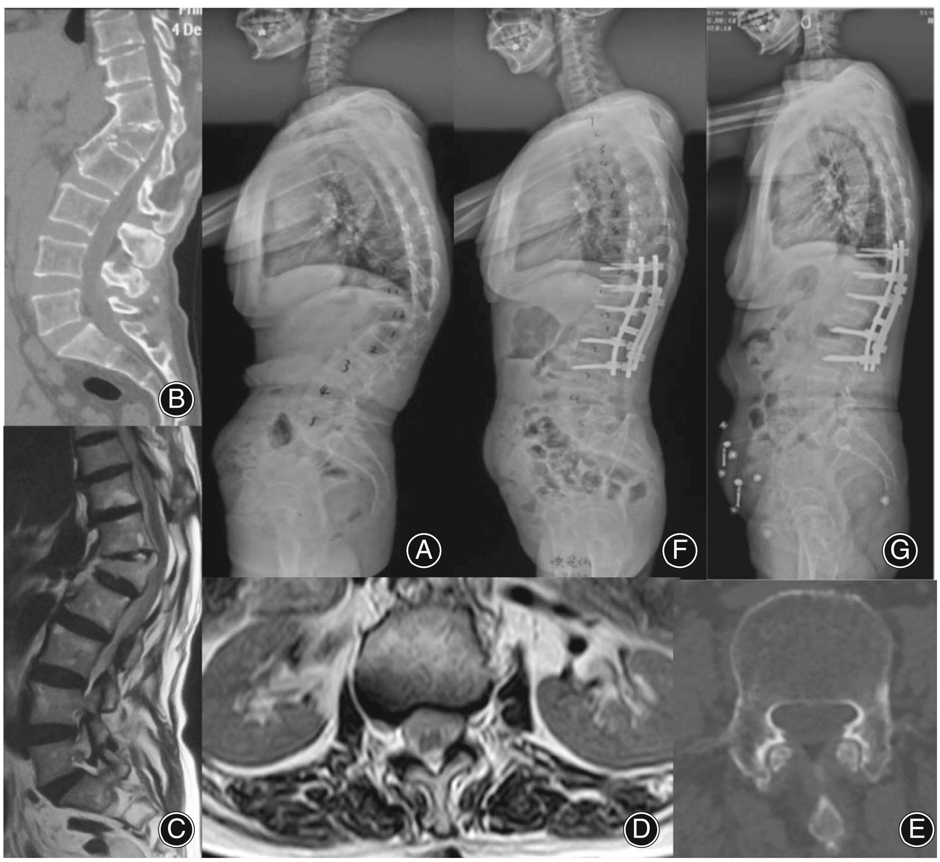

Fig. 1 Posttraumatic kyphosis secondary to old fracture at L1 in a 63-year-old female patient (a). She was noticed with highly wedging deformation of fractured vertebral body (b, c), normal paraspinal muscles (d) and normal bone quality (e; CT attenuation: 168.0 HU). Then she received instrumented fusion from T10 to L3 and Grade IV osteotomy at L1(f). The kyphosis correction maintained well till 4 years follow-up (g).

TABLE 1 Summary of patient demographics

Parameters	Group NJ	Group J			Group JK *vs* total Group J		Group JK *vs* Group NJ		Group JF *vs* Group NJ		Group JF *vs* Group JK	
		Total	Group JK	Group JF	*t*	*P* value	*t*	*P* value	*t*	*P* value	*t*	*P* value
Gender (M/F)	15/35	1/14	1/10	0/4	1.638	0.114	1.147	0.257	0.27	0.788	0.639	0.533
Age (years)	54.5±10.3	63.5±11.2*	63.0±13.8*	64.5±9.8 *	2.787	0.010	2.937	0.005	3.484	0.001	1.299	0.215
BMI (kg/m^2)	23.3±3.8	24.2±4.2	24.1±5.2	24.5±12.1	1.39	0.177	0.918	0.363	0.656	0.515	0.029	0.977
Follow-up (mo)	32.6±12.0	33.2±14.2	33.8±10.6	31.6±12.0	0.375	0.711	0.966	0.339	0.753	0.455	0.8	0.437
No. of fixed segments	6.8±3.1	8.1±3.2*	8.0±2.5*	8.3±3.6*	3.725	0.001	2.576	0.013	3.489	<0.001	0.673	0.512
t score	-0.8±1.0	-2.1±1.8	-1.8±1.7*	-3.5±1.1*#	2.069	0.049	2.678	0.010	3.489	<0.001	3.438	0.004
Osteotomy method												
SPO	8	5	4	1	0.834	0.412	0.853	0.398	1.368	0.177	1.314	0.210
PSO	7	3	2	1								
Grade IV osteotomy	40	12	9	3								
Bone cement												
Yes	3	1	0	1	1.136	0.267	0.367	0.715	1.331	0.189	1.045	0.314
No	47	14	11	3								
Sacropelvic fixation												
Yes	3	1	0	1	0.678	0.504	1.267	0.211	0.802	0.426	0.665	0.517
No	47	14	11	3								
Additional rods												
Yes	18	5	4	1	0.667	0.511	1.094	0.279	0.941	0.351	0.445	0.663
No	32	10	7	3								

Note: "*" means comparing with Group NJ, $p < 0.05$; "#" means comparing with Group JK, $P < 0.05$.; Abbreviations: BMI, body mass index; J, junctional kyphosis and failure; JF junctional failure; JK, junctional kyphosis; M/F, male/female; NJ, none junctional kyphosis.

48.9 ± 12.2, P = 0.006). The MCS of SF-36 was worse in Group JF than Group NJ (50.7 ± 11.6 *vs* 52.6 ± 17.2, P = 0.010) and Group JK (50.7 ± 11.6 *vs* 52.9 ± 14.4, P = 0.001). No statistical differences were founded between Group NJ and Group JK in ODI ($P > 0.05$) and VAS scores ($P > 0.05$) and SF-36 ($P > 0.05$)

TABLE 2 Comparison of radiographic parameters between Group NJ and Group J

Parameters	Group NJ	Group J	*t*	*P* value
TK (°)				
Preoperative	30.2 ± 19.1	48.5 ± 13.4	2.655	0.010
Postoperative	26.8 ± 9.2	27.7 ± 6.9	0.942	0.350
Follow-up	28.8 ± 13.9	29.6 ± 21.2	1.104	0.274
GK (°)				
Preoperative	42.1 ± 10.3	53.2 ± 20.3	2.33	0.023
Postoperative	30.6 ± 16.2	32.0 ± 18.7	1.645	0.105
Follow-up	34.6 ± 17.8	36.2 ± 20.6	1.559	0.124
LK (°)				
Preoperative	35.4 ± 17.4	43.3 ± 15.0	3.449	<0.001
Postoperative	3.8 ± 2.6	4.3 ± 2.3	0.464	0.644
Follow-up	5.8 ± 3.2	6.2 ± 2.7	0.265	0.792
LL (°)				
Preoperative	−36.1 ± 25.0	−37.6 ± 24.6	0.638	0.526
Postoperative	−37.0 ± 25.4	−38.9 ± 8.0	1.013	0.315
Follow-up	−36.3 ± 21.3	−37.7 ± 16.3	0.464	0.644
SVA (mm)				
Preoperative	22.9 ± 44.9	28.1 ± 47.5	1.645	0.105
Postoperative	12.8 ± 30.5	12.0 ± 25.3	1.122	0.266
Follow-up	11.6 ± 25.6	12.3 ± 27.1	0.368	0.714
PI (°)				
Preoperative	50.3 ± 15.6	53.6 ± 12.9	0.577	0.566
Postoperative	47.3 ± 13.2	48.5 ± 12.9	0.386	0.701
Follow-up	49.8 ± 15.9	50.2 ± 16.4	1.097	0.277
PT (°)				
Preoperative	23.9 ± 13.2	24.8 ± 10.9	1.202	0.234
Postoperative	16.9 ± 9.2	16.0 ± 8.4	0.817	0.417
Follow-up	18.7 ± 6.3	18.5 ± 9.1	0.954	0.344
SS (°)				
Preoperative	26.5 ± 12.9	28.7 ± 13.8	1.127	0.264
Postoperative	30.9 ± 9.8	30.5 ± 6.0	1.253	0.215
Follow-up	28.7 ± 11.2	29.2 ± 14.3	1.365	0.177
PJA (°)				
Preoperative	6.2 ± 7.1	5.4 ± 6.9	1.052	0.297
Postoperative	9.1 ± 7.9	10.3 ± 7.2	0.324	0.747
Follow-up	15.4 ± 7.1	25.3 ± 10.4	3.449	0.001
CSA	202.6 ± 34.8	179.2 ± 41.3	2.908	0.005
FSF	40.5 ± 10.3	53.8 ± 14.7	3.449	<0.001
Bone quality (Hu)	153.5 ± 30.1	106.4 ± 29.8	2.586	0.012

Discussion

In our study, the incidence of junctional kyphosis or failure was 23.1% in patients with LPTK after long segmental instrumented fusion over an average 32.7 months of follow-up, and junctional kyphosis mainly occurred within 6 months after surgery. Larger preoperative global kyphosis and higher fatty degeneration of paraspinal muscles were independent risk factors of junctional kyphosis. Patients with lower bone quality were more likely to develop junctional failure. Junctional failure patients had worse patients reported outcomes than patients with or without junctional kyphosis.

Characteristics of Junctional Kyphosis

This study demonstrated a 23.1% incidence of junctional kyphosis in patients with LPTK. Previous studies reported that the incidence of junctional kyphosis ranged from 20% to 40% in adult spinal deformity.[4,11,24–27] Nevertheless, the incidence of junctional kyphosis in the single pathology of LPTK is still unclear. This study specifically discussed the incidence of junctional kyphosis in patients with LPTK, and found that the incidence was similar to that in ASD patients.

In this study, 80% of junctional kyphosis and failure occurred within 6 months after surgery (Fig. 2). As was

TABLE 4 Summary of multivariate logistic regression for predicting junctional problems

Variables	Odds ratio	*P* value
Preoperative GK > 48.5°	1.793	0.001
Bone quality on CT < 119.4 Hu	0.693	0.065
FSF > 48.4	2.916	0.010

Abbreviations: GK, global kyphosis; FSF, fat saturation fraction.

TABLE 3 Comparison of radiographic parameters among Group NJ, Group JK and Group JF

Parameters	Group NJ	Group JK	Group JF	ANOVA	Group JK *vs* Group NJ	Group JF *vs* Group NJ	Group JF *vs* Group JK
Preoperative TK (°)	30.2 ± 19.1	49.1 ± 17.2	46.9 ± 18.1	<0.001	0.001	<0.001	0.603
Preoperative LK (°)	35.4 ± 17.4	43.5 ± 15.3	42.4 ± 10.6	0.326	/	/	/
Preoperative GK (°)	42.1 ± 10.3	53.5 ± 16.4	52.0 ± 13.2	0.178	/	/	/
CSA	202.6 ± 34.8	181.0 ± 43.2	178.0 ± 37.4	0.015	<0.001	<0.001	0.272
FSF	40.5 ± 10.3	53.4 ± 15.2	54.9 ± 10.4	0.348	/	/	/
Bone quality (Hu)	153.5 ± 30.1	108.7 ± 25.6	92.2 ± 30.6	<0.001	<0.001	<0.001	0.015

Abbreviations: CSA, cross-sectional area; FSF, fat saturation fraction; GK, global kyphosis; JF junctional failure; JK, junctional kyphosis; LK, local kyphosis; NJ, none junctional kyphosis; TK, thoracic kyphosis.

TABLE 5 Patient-reported outcomes

Parameters	Group NJ	Group J			Group JK vs total Group J		Group JK vs Group NJ		Group JF vs Group NJ		Group JF vs Group JK	
		Total	Group JK	Group JF	*t*	*P* value	*t*	*P* value	*t*	*P* value	*t*	*P* value
ODI scores												
Pre-operation	59.3 ± 18.9	58.6 ± 22.4	58.9 ± 17.4	57.8 ± 20.1	1.267	0.217	0.741	0.462	0.971	0.336	0.373	0.715
Follow-up	19.4 ± 9.5	22.4 ± 8.2	20.1 ± 7.4	28.7 ± 6.4*#	1.39	0.177	1.215	0.230	2.93	0.005	2.772	0.015
VAS back pain												
Pre-operation	6.7 ± 2.0	6.4 ± 1.6	6.3 ± 2.1	6.5 ± 1.9	0.571	0.573	1.273	0.209	1.375	0.175	0.663	0.518
Follow up	2.3 ± 1.2	2.5 ± 1.5	2.3 ± 1.8	3.1 ± 1.7*#	0.975	0.339	1.437	0.157	2.542	0.014	4.141	0.001
PCS of SF-36												
Pre-operation	40.7 ± 14.1	41.2 ± 11.5	41.4 ± 13.9	40.7 ± 15.6	1.272	0.215	0.493	0.624	0.256	0.799	0.827	0.422
Follow up	48.6 ± 13.2	48.2 ± 15.6	48.9 ± 12.2	46.3 ± 13.7*#	1.348	0.190	1.473	0.147	2.342	0.023	3.234	0.006
MCS of SF-36												
Pre-operation	46.1 ± 15.7	46.3 ± 18.4	46.4 ± 18.3	46.0 ± 17.2	0.107	0.916	0.207	0.837	1.163	0.250	1.131	0.277
Follow up	52.6 ± 17.2	52.3 ± 16.4	52.9 ± 14.4	50.7 ± 11.6*#	0.408	0.687	0.611	0.544	2.672	0.010	4.141	0.001

Note: "*" means comparing with Group NJ, $P < 0.05$; "#" means comparing with Group JK, $P < 0.05$.; Abbreviations: J, junctional kyphosis and failure; JF junctional failure; JK, junctional kyphosis; MCS, Mental Component Score; NJ, none junctional kyphosis; ODI, Oswestry disability index; PCS, Physical Component Score; VAS, Visual Analogue Scale.

shown by a previous study, 59% of patients developed junctional kyphosis as early as 8 weeks postoperatively.[4] Another study also reported early onset of junctional kyphosis, in which 66% of PJK appeared within 3 months postoperatively.[11] The early onset of junctional kyphosis could be explained by the immediately collapse of the intervertebral space adjacent to the upper or lower instrumented vertebra due to severe age-related disc, musculoligamentous degeneration. In addition, intraoperative dissection of paraspinal musculature and destruction of integrity of ligaments would increase the weakness of posterior tension band, thus accelerate the occurrence of junctional kyphosis. These comprehensive factors ultimately contribute to the early onset of junctional kyphosis in this study.

Risk Factor of Junctional Kyphosis

Larger preoperative global kyphosis and higher fatty degeneration of paraspinal muscles were identified as independent predictors of junction kyphosis (Fig. 1). According to previous studies,[28–32] preoperative hyperkyphosis was significantly associated with proximal junctional kyphosis. Several studies had demonstrated that thoracic kyphosis greater than 40° was a significant risk factor for PJK.[28–30] Shin *et al.*[31] also reported that preoperative hypokyphosis and excessive kyphotic deformity correction were independent risk factors associated with PJK in ASD patients. Patients who underwent substantial reduction of hyperkyphotic through osteotomy procedure usually led to an acute change in the sagittal alignment, which might contribute to postoperative reciprocal kyphosis at the junction area.[33] Also, in order to restore the physiological thoracic or thoracolumbar kyphosis, greater force was applied on the instrumentation, which subjected the junctions to excessive force. In this condition, hyperkyphosis significantly increased the risk for junctional kyphosis in patients with LPTK.

Severe fatty degeneration of paraspinal muscles was the other risk factor of junctional kyphosis or failure in patients with LPTK. According to Hyun *et al.*,[10] decreased thoracolumbar muscularity and extensive fatty degeneration were significantly risk factors for PJK. Extensive fatty degeneration could lead to poor muscle strength, which was disadvantageous to maintain the natural curvature of spine. Poor muscle strength could lead to a reduce in lumbar lordosis and an increase in thoracic kyphosis, which could significantly increase the flexional forces on the proximal or distal junction, thereby increasing the risk of junctional kyphosis. In addition, intraoperative muscles dissection could significantly weaken the paraspinal muscle strength and lead to the early onset of junctional kyphosis. Thus, surgeons should reduce intraoperative musculoligamentous dissection at the proximal or distal junction, as extensive dissection can decrease flexion stiffness at the dissected segment.[25,26] Furthermore, if atrophy of the paraspinal muscularity and fatty degeneration was severe, extension of the fusion segment might be considered.

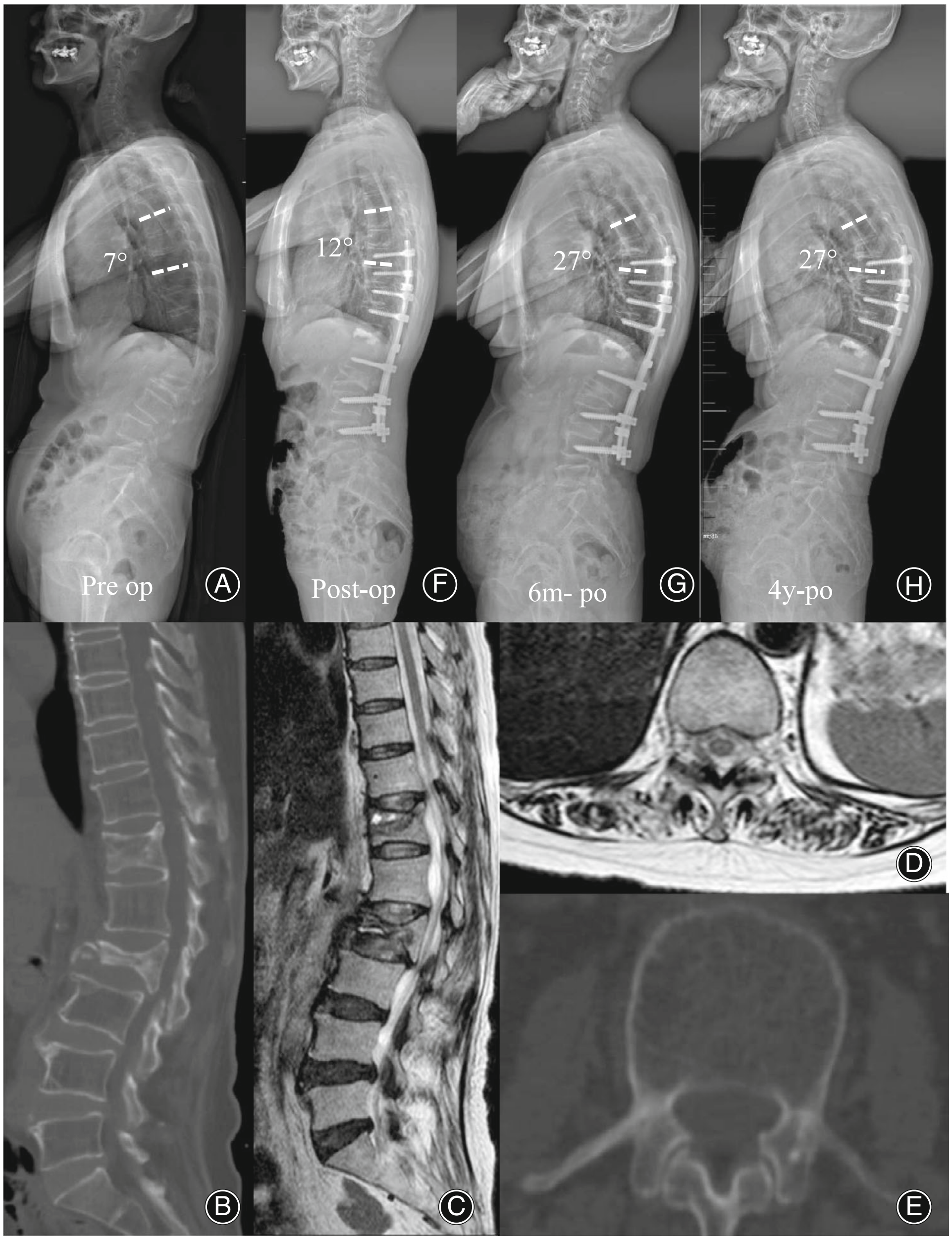

Fig. 2 Posttraumatic kyphosis (a) secondary to old fractures at T12 and L2 in a 65-year-old female patient, with Kummell diseases noticed at both fractured vertebrae and highly wedging deformation at L2 (b, c). She was detected with advanced fatty degeneration of paraspinal muscles (d) and poor bone quality (e; CT attenuation at L4 body: 103.0 HU). She received correction surgery with fusion from T8 to L4, Grade IV osteotomy at L2 and vertebraplasty at T12 (f). Six months later, she was observed with occurrence of asymptomatic PJK (g). After brace treatment and anti-osteoporosis medications, her PJK remained steady till 4 years follow-up (h).

Risk Factor of Junctional Failure

As revealed in this study, junctional failure patients had significantly lower bone quality than junctional kyphosis patients and non-junctional kyphosis patients. One previous study with a 2-year follow-up demonstrated that low bone mineral density was a significant risk factor for proximal junctional failure.[13] Low bone mineral density could significantly reduce the rigidity of vertebral and ultimately result in junctional fracture and looseness of internal fixation.[34,35] Junctional failures in our study were all caused by junctional fracture and implant/bone interface failure, which were closely associated with low bone mineral density (Fig. 3). Our results suggested that patients with low bone mineral density were more likely to develop junctional failure. Hence, perioperative anti-osteoporosis treatment might be useful to prevent junctional failure and spare patients from revision surgery.

Patient Reported Quality of Life

Junctional failure patients had worse ODI and VAS scores than junctional kyphosis patients and non-junctional kyphosis patients. Several studies have reported that there were no significant differences in patients reported outcomes between patients with junctional kyphosis and those without.[24,36] Nevertheless, junctional failure patients usually experienced pain, neurologic deficit and/or ambulatory difficulties.[37] This

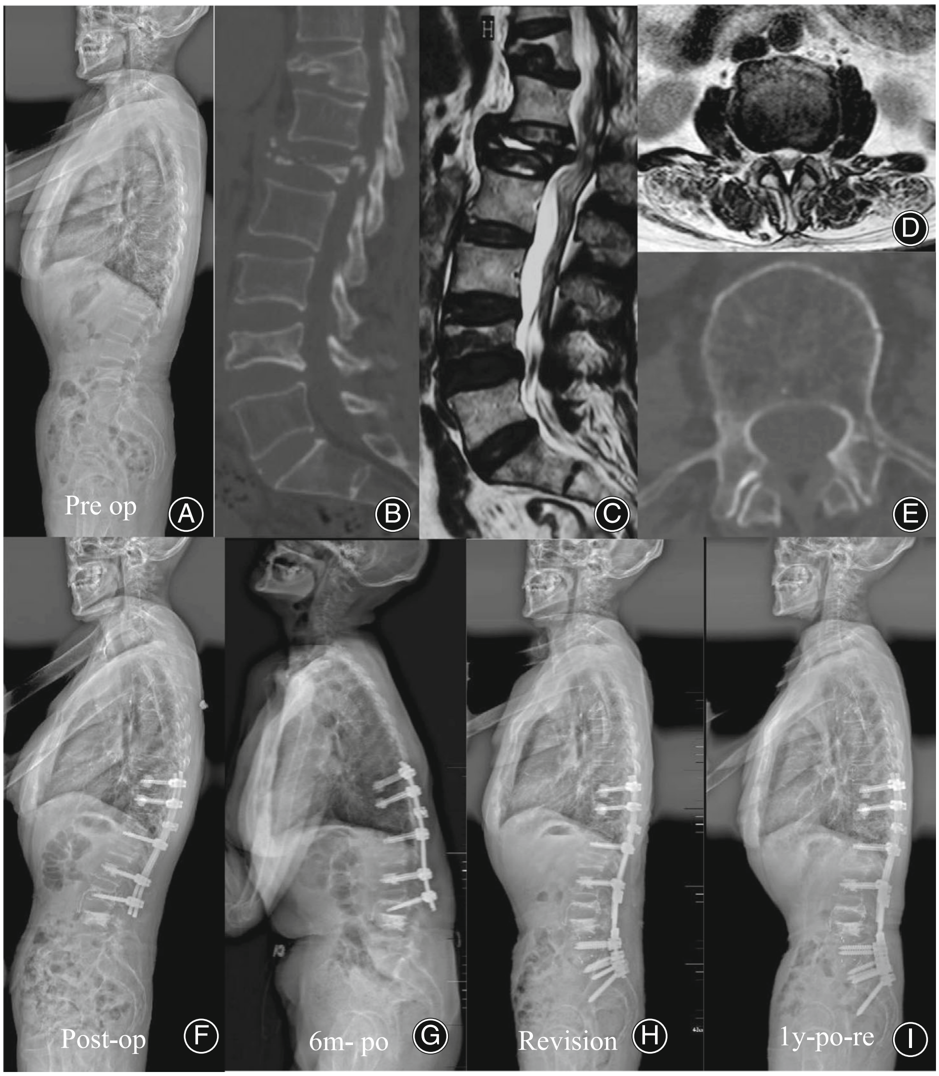

Fig. 3 A 64-year-old female patient with posttraumatic kyphosis secondary to old fractures at T11, L1 and L4 (a). She was observed with Kummell diseases at L1 and L4, significant canal encroachment due to unhealed bony fragment at L1(b, c), advanced fatty degeneration of paraspinal muscles (d) and poor bone quality (e; CT attenuation at L3 body: 95.0 HU). Then, she had undergone instrumented fusion from T9 to L3 with cement-augmented screws, Grade IV osteotomy at L1 and vertebraplasty at L4(f). Six months later, unfortunately, she developed distal junctional failure (including L3 fracture and instrumentation failure) and cauda equina syndrome (g). Thus, a decompressive revision surgery was performed with fusion extended to the pelvis (h). The revised correction maintained well at 1 year follow-up (i).

study revealed that junctional kyphosis tended to be simple radiographic findings, while patients with junctional failures were usually symptomatic and required further medical intervention. In this study, three patients (3/4) achieved symptomatic relief and spared from revision surgery after brace treatment. Brace treatment seems to be a good strategy for symptomatic junctional failure.

Clinical Relevance

To the best of our knowledge, this is the first study specifically focused on junctional kyphosis in LPTK patients. The clinical relevance in this study relates to preventing the occurrence of postoperative junctional kyphosis in LPTK patients after long segmental fusion. First, for patients with large preoperative global kyphosis and severe degeneration of paraspinal muscles, surgeons must carefully design the operative plan, and consider extending the length of internal fixation if necessary. Second, perioperative anti-osteoporosis treatment and bone cement reinforced pedicle screws may be good strategies to prevent screws pull-out or junction vertebra fracture caused by poor bone quality, as recommended by Kolz *et al.*[38]

Limitations

This study has several limitations. First, this is a retrospective study conducted by a single center. Second, the follow-up period was relatively short and variable among patients, making it difficult to assess the natural course of junctional kyphosis or failure. Third, the location of the upper and lower instrumented vertebra varied significantly among patients. Last, because of the relatively small number of patients in our study, a future study with a larger sample size is nevertheless needed.

Conclusion

Junctional kyphosis occurs in approximately 23.1% of LPTK patients after long segments fusion. It mainly occurs within 6 months after surgery and it is usually asymptomatic. Large preoperative global kyphosis and severe fatty degeneration of paraspinal muscles are independent risk factors for postoperative junctional kyphosis, and poor bone quality is associated with junctional failure, so each should be carefully evaluated during the treatment of LPTK patients.

Author Contributions

XP, QZ and LX reviewed radiographs. XP performed statistical analysis and drafted the manuscript. YY, ZL, BP, BW and ZZ gave administrative and intellectual support. XS and YQ conceived the study, finalized the manuscript and is responsible. All authors read and approved the final manuscript.

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Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Table S1. Comparison of inter-observer consistency in Radiologic measurements problems.

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