Risk Factors for PJK After Posterior Long-Segment Internal Fixation for Chronic Symptomatic Osteoporotic Thoracolumbar Fractures with Kyphosis

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Research Article

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Abstract

Background: This study aimed to analyze the risk factors for proximal junctional kyphosis (PJK) for patients with chronic symptomatic osteoporotic thoracolumbar fractures (CSOTLF) and kyphosis who underwent long-segment internal fixation.

Methods: We retrospectively reviewed the records of patients with CSOTLF complicated with kyphosis who underwent posterior multilevel internal fixation in our hospital between January 2013 and June 2018. The patients' age, sex, body mass index (BMI), bone mineral density (BMD), smoking status, cause of injury, comorbidities, injury segments, and American Spinal Injury Association (ASIA) grading non-surgical data; posterior ligament complex (PLC) injury, upper and lower instrumented vertebral position (UIV and LIV, respectively), number of fixed segments surgical data, proximal junctional angle (PJA), sagittal vertebral axis (SVA), pelvic incidence (PI), lumbar lordosis (LL), pelvic incidence-lumbar lordosis mismatch (PI-LL), pelvic tilt (PT), and sacral slope (SS) surgical indicators were collected. Patients were divided into postoperative PJK and non-PJK groups.

Results: This study included 90 patients; among them, 30 (31.58%) developed PJK postoperatively. All patients were followed up for >24 months (mean 32.5 months). Univariate analysis showed significant differences in age, BMI, BMD, PLC injury, UIV, and LIV fixation position, number of fixation stages, and preoperative PJA, SVA, PI-LL, and SS between the two groups ($P < 0.05$). Additionally, no significant differences were observed in sex, smoking, cause of injury, complications, injury segment ASIA grade, and preoperative PT between the two groups ($P > 0.05$). Multifactorial logistic regression analysis showed that age >70 years (OR=32.279, $P<0.05$), BMI >28 kg/m^2 (OR=7.876, $P<0.05$), BMD T value <-3.5 SD (OR=20.836, $P<0.05$), PLC injury (OR=13.981, $P<0.05$), and preoperative PI-LL >20° (OR=13.301, $P<0.05$) were risk factors for PJK after posterior long-segment internal fixation in elderly patients with CSOTLF complicated with kyphosis.

Conclusions: Elderly patients with CSOTLF and kyphosis aged >70 years with BMI >28 kg/m^2, BMD <3.5 SD, preoperative PI-LL >20°, and PLC injury have increased risk of PJK after posterior long-segment internal fixation. Considering these findings, weight control, osteoporosis treatment, soft tissue protection, and spinal sagittal balance restoration are important to prevent PJK.

Background

The increasing age of the population has highlighted osteoporosis and associated fractures as major health concerns.[1] However, elderly patients are unresponsive to pain, which fails to attract sufficient attention; these often lead to the progression of acute fractures to chronic symptomatic osteoporotic thoracolumbar fractures (CSOTLF).[2] Increased patient age, osteoporosis, and progressive vertebral collapse lead to progressive aggravation of thoracolumbar kyphosis, which severely affects the quality of life of patients. However, bed rest, wearing braces, anti-osteoporosis medications, and other non-surgical treatments are ineffective for some patients. Long-segment internal fixation is effective in stabilizing the spine, correcting deformities, reestablishing spinal balance, and relieving neuro spinal compression; however, patients with older age, poor bone conditions, or medical comorbidities are at an increased risk of surgical complications.[3] One common complication of long-segment internal fixation of the spine is the proximal junctional kyphosis (PJK), whose progression can cause intractable low back pain,[4] severe cosmetic deformity, and neurological compression symptoms, which may require revision surgery.[5] The incidence of PJK in elderly patients with spinal deformity after orthopedic surgery is 15-40%.[6–8] However, no studies have identified the risk factors associated with the development of PJK after posterior long-segment internal fixation for patients with CSOTLF, and PJK is associated with a complex pathogenesis involving both surgical and non-surgical factors. This retrospective study aimed to determine the risk factors and prevention methods of PJK in patients who underwent recent long-segment internal fixation. Additionally, it aimed to provide clinical suggestions regarding the prevention and reduction of postoperative PJK.

Methods

This retrospective cohort study included inpatients with CSOTLF who underwent posterior long-segment fixation in our hospital between January 2013 and June 2018. We reviewed the clinical records of each patient and extracted the information into a pre-arranged database.

Inclusion Criteria

This study included patients with the following characteristics: 1) definitive diagnosis of single-segment CSOTLF (Cobb >30° on both flexion radiographs and sagittal CT in the supine position)[9]; 2) collapse of the posterior wall of the vertebral body protruding into the first ≤1/3 of the spinal canal; 3) treatment with posterior long-segment (≥5 motor segments) internal fixation; 4) ineffective conservative management for >3 months, including the administration of non-steroidal anti-inflammatory painkillers and anti-osteoporosis drugs; 5) age ≥ 60 years; and 6) bone mineral density (BMD) T-value ≤ -2.5SD.

Exclusion Criteria

Patients with the following characteristics were excluded: 1) history of thoracolumbar spine surgery; 2) comorbid idiopathic or congenital spinal deformity; 3) history of severe spinal cord injury; 4) pathological fractures caused by tumors, infections, tuberculosis, and other causes; 5) history of lower extremity surgery, such as the knee and hip, which may affect the measurement of imaging data; and 6) < 24 months of postoperative follow-up or incomplete imaging data.

Full-length frontal and lateral radiographs, and pelvic parameters of the spine were collected preoperatively, before discharge, 6 months postoperatively, during postoperative PJK complications, and during the final follow-up. Postoperative PJK was defined as the angle formed between the lower endplate of the upper instrumented vertebra (UIV) and the upper endplate of UIV+2 is postoperative ≥10° and > 10° greater than the preoperative angle.[10]

Non-surgical factors included age, sex, body mass index (BMI), BMD, smoking history, injury cause, comorbidities (hypertension, diabetes, heart disease, stroke), injury segment, and American Spinal Injury Association (ASIA). Surgical information included posterior ligament complex (PLC) injury, UIV position, lower instrumented vertebral (LIV) position, and the fixation stages number.

Surgical factors included: 1) PJA (the angle between the upper endplate of the UIV+2 and the lower endplate of the UIV); 2) sagittal vertebral axis (SVA) (the vertical distance between the plumb line at the center of the C7 vertebral body and the posterior edge of the supra-sacral endplate); 3) pelvic incidence-lumbar lordosis mismatch (PI-LL) corresponded to the compatibility between the lumbar curve and pelvic morphology (PI is the angle between the line from the center of the femoral head to the center of the superior sacral endplate and the vertical line of the superior sacral endplate; on the other hand, LL is the angle between the parallel line formed by the T_{12} superior endplate and the S_1 superior endplate); 4) pelvic tilt (PT) is the angle between the straight line and the plumb line at the end of the superior sacral endplate and the midpoint of the central line of the bilateral femoral heads; 5) sacral slope (SS) is the angle between the S1 upper-end plate and horizontal line.

Statistical analysis

All statistical analyses were performed using SPSS software (version 23.0; IBM Corp, Armonk, NY, USA). Continuous data were expressed as *mean ±SD*, which were analyzed using independent samples *t-test*. Categorical data were expressed as frequency (percentage), which were analyzed using the chi-square test or Fisher's exact probability method. Univariate analysis was used to identify potential factors influencing PJK after posterior long-segment internal fixation. Statistically significant variables in the univariate analysis were further analyzed using multivariate logistic regression analysis. Statistical significance was set at $P < 0.05$.

Results

In this study, 136 elderly patients with CSOTLF were admitted; among them, 15 patients were lost to follow-up, 26 cases were followed up for less than 24 months. Finally, 95 patients with a mean age of 73 (range 60–85) years were included in this study since they were followed up for at least 24 months with an average follow-up time of 32.5 months. Among them, 32 were men and 63 were women; additionally, the injury was due to sprain and falls in 31 and 64 patients, respectively. Additionally, the location of the fractured vertebrae were as follows: T_{11} vertebrae in 17 patients; T_{12} vertebrae, 37 patients; L_1 vertebrae, 30 patients; and L_2 vertebrae, 11 patients. All patients with CSOLTF were treated with posterior long segment internal fixation. Additionally, the patients were divided into the PJK group (n=30) and the non-PJK group (n=65), according to the postoperative development of PJK. The patients' demographic details are presented in Table 1.

Table 1
Patients demographic data

Groups	Sex		Age	BMD T value	Injury		Level				Time from injury to surgery
	Male	Female	(years)	(SD)	sprain	fall	T_{11}	T_{12}	L_1	L_2	(years)
PJK Group(n=30)	12	18	73.6±5.3	-4.5±0.4	6	24	5	12	10	3	5.8±2.2
Non-PJK Group(n=65)	20	45	64.5±5.2	-3.5±0.4	25	40	12	25	20	8	6.1±2.8
χ^2/t value	0.783		7.858	12.164	0.038		0.187				0.396
P value	0.376		0.000	0.000	0.845		0.980				0.652

Abbreviations: PJK, proximal junctional kyphosis; BMD, bone mineral density;

Univariate Analysis

The results of the univariate analysis are shown in Table 2. No significant differences were observed in the sex, smoking history, injury cause, comorbidity, injured segments, ASIA grading, and pre-PT, between the two groups. The proportion of patients aged >70 was significantly higher in the PJK group (66.7%) than in the non-PJK group (10.8%; $\chi^2 = 34.257$, $P<0.0001$). The proportion of patients with BMI >28 was significantly higher in the PJK group (70.0%) than in the non-PJK group (12.3%; $\chi^2 = 33.035$, $P<0.001$). The percentage of patients with BMD <3.5 SD was significantly higher in the PJK group (76.7%) than in the non-PJK group (21.5%; $\chi^2 = 26.235$, $P<0.0001$). The percentage of patients with PLC injury in the PJK group (76.7%) was significantly higher than in the non-PJK group (23.1%; $\chi^2 = 24.562$, $P<0.001$). The percentage of patients whose UIV was positioned at T_{10}-T_{12} was significantly higher in the PJK group (70.0%) than in the non-PJK group (35.4%; $\chi^2 = 9.982$, $P=0.002$). The percentage of patients with LIV positioned at S_1 was significantly higher in the PJK group (63.3%) than in the non-PJK group (36.9%; $\chi^2 = 5.779$, $P=0.016$). The percentage of patients with fixed segments>7 in the PJK group (63.3%) was higher than that in the non-PJK group (40.0%; $\chi^2 = 4.483$, $P=0.034$). The percentage of patients with pre-PJA>5° was significantly higher in the PJK group (43.3%) than in the non-PJK group (23.1%;$\chi^2 = 4.052$, $P=0.044$). The percentage of patients with Pre-SVA>50 mm in the PJK group (60.0%) was higher than that in the non-PJK group (33.8%; $\chi^2 = 5.760$, $P=0.016$). The percentage of patients with PI-LL >20° was significantly higher in the PJK group (70.0%) than in the non-PJK group (26.2%; $\chi^2 = 16.442$, $P<0.001$), and the percentage of patients with Pre-SS <25° was significantly higher in the PJK group (56.7%) than in the non-PJK group (32.3%; $\chi^2 = 2.526$, $P=0.112$).

Table 2
Univariate Analysis of PJK After Posterior Long-segment Internal Fixation

Factors	All patients(n=95)	PJK Group(n=30)	Non-PJK Group(n=65)	χ^2 value	P value
Age(%)	28(29.5)	1(3.3)	27(41.5)	34.257	0.000
60~65 years	40(42.1)	9(30.0)	31(47.7)		
65~70 years	27(28.4)	20(66.7)	7(10.8)		
>70 years					
BMI(%)	27(28.4)	2(6.7)	25(38.5)	33.035	0.000
<24.0 kg/m^2	39(41.1)	7(23.3)	32(49.2)		
24.0~28.0 kg/m^2	29(30.5)	21(70.0)	8(12.3)		
>28.0 kg/m^2					
BMD(%)	58(61.1)	7(23.3)	51(78.5)	26.235	0.000
-3.5SD≤T value≤-2.5SD	37(38.9)	23(76.7)	14(21.5)		
T value<-3.5SD					
Smoking(%)	62(65.3)	20(66.7)	42(64.6)	0.038	0.845
No	33(34.7)	10(33.3)	23(35.4)		
Yes					
Combined Diseases(%)	35(36.8)	10(33.3)	25(38.5)	0.232	0.630
Hypertension	42(44.2)	14(46.7)	28(66.7)	0.107	0.743
Diabetes	23(24.2)	8(26.7)	15(23.1)	0.144	0.704
Heart Diseases	26(27.4)	9(30.0)	17(26.2)	0.153	0.696
Strokes					
ASIA Grading(%)	19(20.0)	8(26.7)	11(16.9)	1.218	0.270
D	76(80.0)	22(73.3)	54(83.1)		
E					
PLC Injury(%)	57(60.0)	7(23.3)	50(76.9)	24.562	0.000
No	38(40.0)	23(76.7)	15(23.1)		
Yes					

Factors	All patients(n=95)	PJK Group(n=30)	Non-PJK Group(n=65)	χ^2 value	P value
UIV(%)	51(52.6)	9(30.0)	42(64.6)	9.892	0.002
T_{10} or higher	44(47.4)	21(70.0)	23(35.4)		
T_{10}-T_{12}					
LIV(%)	52(54.7)	11(36.7)	41(63.1)	5.779	0.016
L_5 or higher	43(45.3)	19(63.3)	24(36.9)		
S_1					
Fixed Segments(%)	50(52.6)	11(36.7)	39(60.0)	4.483	0.034
≤7	45(47.4)	19(63.3)	26(40.0)		
>7					
Pre-PJA(%)	67(70.5)	17(56.7)	50(76.9)	4.052	0.044
≤5°	28(29.5)	13(43.3)	15(23.1)		
>5°					
Pre-SVA(%)	55(57.9)	12(40.0)	43(66.2)	5.760	0.016
≤50mm	40(42.1)	18(60.0)	22(33.8)		
>50mm					
Pre-PI-LL(%)	57(60.0)	9(30.0)	48(73.8)	16.442	0.000
≤20°	38(40.0)	21(70.0)	17(26.2)		
>20°					
Pre-PT(%)	26(27.4)	5(16.7)	21(32.3)	2.526	0.112
≤30°	69(72.6)	25(83.3)	44(67.7)		
>30°					
Pre-SS(%)	38(40.0)	17(56.7)	21(32.3)	5.075	0.024
≤25°	57(60.0)	13(43.3)	44(67.7)		
>25°					

Abbreviations: PJK, proximal junctional kyphosis; BMI, body mass index; BMD, bone mineral density; ASIA, American Spinal Injury Association; PLC, posterior ligament complex; UIV, upper instrumented vertebral; LIV, lower instrumented vertebral; Pre, preoperative; PJA, proximal junctional angle; SVA, sagittal vertebral axis; PI, pelvic incidence; LL, lumbar lordosis; PI-LL, pelvic incidence-lumbar lordosis mismatch; PT, pelvic tilt; SS, sacral slope.

Multivariate Analysis

Among the variables that were positive in the univariate analysis, the independent risk factors that were positively correlated with PJK after posterior long-segment internal fixation for CSOTLF were as follows: age >70 years (odds ratio [OR]=32.279, 95% confidence interval [CI] =3.827–272.291, P=0.001), BMI> 28 kg/m^2 (OR=7.876, 95% CI=1.633–37.993, P=0.010), BMD T-value <-3.5SD (OR=20.836, 95% CI=2.360–183.928, P=0.006), PLC injury (OR=13.981, 95%CI=1.373–142.344, P=0.026), and PI-LL>20°(OR=13.301,95% CI=1.544–113.869, P=0.018). Table 3 and Figure 1show the results of multivariate analysis.

Table 3
Multivariate Logistic Regression Analysis of PJK After Posterior Long-segment Internal Fixation

Variable	Partial Regression Coefficient	Standard Error	Wald value	P value	OR value	95%CI
Age > 70 years	3.474	1.088	10.198	0.001	32.279	3.827-272.291
BMI > 28kg/m^2	2.064	0.803	6.608	0.010	7.876	1.633-37.993
BMD T value <-3.5SD	3.037	1.111	7.469	0.006	20.836	2.360-183.928
PLC injury	2.638	1.184	4.963	0.026	13.981	1.373-142.344
PI-LL>20°	2.588	1.096	5.580	0.018	13.301	1.544-113.869

Abbreviations: PJK, proximal junctional kyphosis; BMI, body mass index; BMD, bone mineral density; PLC, posterior ligament complex; PI-LL, pelvic incidence-lumbar lordosis mismatch; OR, odds ratio; CI, confidence interval.

Discussion

In elderly patients, the diagnosis and treatment of CSOTLF is often delayed. Additionally, increasing age leads to worsening of degree of osteoporosis and thoracolumbar kyphosis; these factors lead to intractable low back pain and eventual bilateral lower extremity paralysis, which severely affects the quality of life of patients.[9] Non-surgical treatment methods are often unsuccessful; however, long-segment internal fixation is effective in maintaining spinal stability, correcting posterior convexity deformity, and preventing injured spine collapse and progression of the posterior convexity Cobb angle.[11] However, long segment internal fixation can cause several segmental complications. Among them, PJK is the most common affecting 6%-40% of patients depending on disease type, surgical approach, and follow-up time.[12-14] PJK evaluation criteria are often different for patients with advanced age and excessive deformities.[15] Studies have emphasized that advanced age, BMI, BMD, UIV/LIV fixed position, PJA, LL, SVA, and fixed segments are the main risk factors for developing PJK.[16-18] Clinical observation shows that most patients with PJK develop mild symptoms, requiring only regular check-ups; on the other hand, a few patients may progress to PJF or even neurological damage, which severely affects patients' postoperative functional recovery. Therefore, when using posterior long-segment internal fixation for CSOLTF, active detection of high-risk factors for PJK is important for improving patient prognosis.

Non-Surgical Factors

(1) Age: Advanced age is a risk factor for developing PJK. Particularly, previous studies found that individuals aged >55 years have the highest incidence of PJK, and the risk increases with age.[19] Kim et al[20] and Yang et al[21] also confirmed that PJK is more prevalent and has a higher incidence in people aged ≥60 years. Patients with PJK can be aggravated by spinal deformities, which leads to changes in paravertebral muscle tissue; furthermore, uneven stresses on the intervertebral discs and small spinal joints can accelerate degeneration. In addition, advanced age is considered to be an important risk factor for revision surgery for PJK.[13]

(2) BMI: Currently, patients with BMI >25 kg/m^2 are believed to have high susceptibility to PJK. This relationship may be attributed to the increased load placed on the spine and internal fixation in overweight and obese patients and the forward shift of the body's center of gravity, resulting in increased stress on adjacent segments. Simultaneously, obese and overweight patients have significantly weakened low back muscles, which increases the risk of osteoporosis.[22]

(3) BMD: O'Leary et al[23] showed that patients with osteoporosis are more prone to PJK. Additionally, reduced bone mass and bone microarchitecture disruption reduce screw holding power, which increases the risk of screw loosening and extraction. In addition, lower bone density is associated with reduced muscle tissue in the thoracolumbar segment, which may lead to spinal instability and accelerate the development of PJK.[24]

The results of this study showed that age >70 years, BMI >28 kg/m^2, and BMD with T value <3.5 SD, were risk factors for PJK in patients who underwent posterior long segment internal fixation for CSOTLF. This study suggests that strict postoperative weight control and standardized anti-osteoporosis treatment reduce the occurrence of postoperative PJK in elderly patients aged >70 years.

Surgical Factors

(1) PLC: Posterior spinal surgery may damage the proximal soft tissues, including the supraspinous and interosseous ligaments; furthermore, small joint capsule injuries can lead to decreased local stability and PJK.[25]

(2) Imaging parameters: Iyer et al[26] found that SVA and LL increases and decreases, respectively, with age. When the sagittal sequence is artificially corrected, the organism continues to return to its natural state. In contrast, overcorrection of the deformity increases stress in the proximal-distal junction area and the incidence of PJK. Therefore, the maximum correction of SVA to 0 may not be ideal for the patient. The retrospective study of ANNIS et al[27] found that postoperative PJA >5° and LL correction >30° were independent risk factors for PJK in 135 patients. PI-LL reflects the compatibility between the lumbar curve and pelvic morphology and suggests a compensatory state of sagittal balance of the spine. Senteler et al[28] found a direct relationship between PI-LL and the risk of degeneration of adjacent segments.

(3) UIV/LIV: Additionally, the choice of UIV/LIV is related to the occurrence of PJK; therefore, the apex of posterior convexity and segments with degenerative instability should be avoided as much as possible. UIV fixation to the thoracolumbar segment increases the risk of PJK, which may be attributed to the fixation of the UIV at the transition from thoracic kyphosis to the anterior lumbar convexity. This area is the junctional zone of stress transmission and is relatively less stable due to the lack of thoracic protection, which increases the

susceptibly for PJK. When the UIV is fixed above T_{10}, stable rib support exists, which can protect the stability of the adjacent vertebrae and reduce the occurrence of degenerative diseases in the proximal adjacent segments. However, this can cause increased intraoperative bleeding; furthermore, no significant advantages have been found regarding other complications and revision rates. The literature states that LIV fixation fusion to the sacrum/pelvis/iliac bone is twice as effective as preserving lumbosacral motion for PJK.[29] The author believes that fusion to S_1 results in a concentration of proximal stresses due to long segment fixation, a weakened sagittal balance of pelvic regulation, and a higher incidence of both postoperative pseudarthrosis and sagittal imbalance. Adult spinal deformities often have structural changes and deformities at the $L_{4/5}$ segment; therefore, fixation at L_5 avoids iliac screws, preserves lumbosacral motion, and reduces sacroiliac joint stresses. However, extended fixation to the ilium can effectively increase fixation strength and stability in the following patients: patients with coronal/sagittal imbalance of the trunk who require orthopedics; those who require three-column osteotomy in the lumbosacral region; those with repeated nail placement or poor stability of S_1 screws found intraoperatively; and those with significant lumbosacral instability or revision surgery. However, it should be noted that the choice of UIV/LIV is not absolute fixation; particularly, the patient's spinal balance should be considered in the decision.

(4) Fixed segments: Internal fixation with long segmental pedicle screws increases the incidence of PJK since it can damage more paravertebral muscles and small intervertebral joints while exposing the nail placement point, which affects spinal stability and stress, especially at the proximal junction, the junction that generates lateral stress and causes displacement of the adjacent vertebrae. Kim et al[7] found that patients were at an increased risk for PJK if the number of fixed vertebral bodies was >5. This may be attributed to the significant concentration of stress in the adjacent vertebral body, making the adjacent vertebral body more susceptible to degeneration and displacement.

This study showed that PLC injury, UIV fixation at T_{10}-T_{12}, LIV fixation at S_1, preoperative PJA >5°, preoperative SVA >50 mm, preoperative PT >30°, preoperative SS ≤25°, and fixation stages >7 were risk factors for developing postoperative PJK. Therefore, preoperative interventions for high-risk groups and individualized surgical plans can be formulated by identifying risk factors to reduce the incidence of postoperative PJK.

PJK Complication Management

For non-surgical factors, CSOLTF disease mostly occurs in elderly patients with numerous medical comorbidities. Patients with advanced age (>70 years), increased BMI (>28.0 kg/m^2), and severe osteoporosis (BMD <3.5 SD) warrant increased preoperative attention to adjust the patient's general comprehensive condition to reduce the incidence of PJK.

(1) Functional exercise of the lumbar back muscles: As patients age, paravertebral muscle atrophy and severe paravertebral fat infiltration lead to decreased paravertebral muscle strength, which significantly increases the risk of postoperative PJK.[30] Therefore, appropriate preoperative muscle exercises can help reduce the occurrence of PJK. (2) Weight reduction: Reducing a patient's weight can lower the physical stress of the musculoskeletal system in the proximal junction area, which reduces the incidence of PJK. (3) Anti-osteoporosis treatment: Standardized anti-osteoporosis treatment can improve bone calcium content and bone strength, which can help maintain the stability of the internal fixation system and reduce loosening and extraction.

Therefore, it can reduce the development of vertebral fractures and collapse in the junction area, which reduce the incidence of mechanical complications.

For surgical factors: (1) Soft tissue protection: Anatomical exposure of the upper end of the vertebral region minimizes the damage to the supra- and interspinous ligaments. Fine separation of the paravertebral muscles in the junctional area, maximum possible preservation of the midline ligament structure, and muscle attachment. (2) Ligamentous strengthening of the junctional area: ligamentous strengthening through tendon grafting or silk wire reinforcement can reduce the stress in the junctional area and increase the strength of the PLC. (3) Non-strength fixation: the use of a plate hook in the proximal fixed vertebrae can provide a relatively non-strength fixation structure, which can help protect the small joints and discs of the adjacent segments, prevent excessive stress concentration in the junctional zone, and reduce the occurrence of PJK or PJF. (4) UIV/LIV selection: in the apex of the lordosis and the segment of degenerative disability, proximal and distal fixed vertebrae should be avoided; on the other hand, proximal fixed vertebrae should be avoided in the thoracolumbar junction area. Regarding distal fixed vertebrae, advantages and disadvantages of fixation in L_5, S_1, or skeleton should be considered in an individual basis. (5) Bone cement reinforcement: preventive application of bone cement reinforcement to both fixed and adjacent vertebrae to increase the strength of the vertebral body can, to a certain extent, avoid internal fixation failure and adjacent vertebrae fracture. (6) Sagittal restoration: moderate deformity correction while considering overall balance should be performed according to the adult spinal deformity sagittal evaluation standard SRS-Schwab staging requirements[31] and spinal sagittal sequence score (global alignment and proportion score)[32].

Limitations

This was a single-center retrospective study with a small number of enrolled patients and selection bias. Most of the relevant clinical evaluation information during the follow-up period was provided by the patient through telephone interview or outpatient follow-up, which may have caused errors. Future multicenter prospective studies with large sample sizes are warranted to understand the relationship of PJK with different imaging parameters, and fixed segments. This is to guide the surgical strategy of long segment fixed fusion, minimize the risk of postoperative PJK, and provide guidance on the strategy of revision surgery.

Conclusion

Advanced age (age >70 years), obesity (BMI >28.0 kg/m^2), severe osteoporosis (BMD T value <-3.5 SD), PLC injury, and preoperative PI-LL (>20°) are high-risk factors for the occurrence of PJK after posterior long-segment internal fixation in patients with CSOLTF. It is suggested that for elderly patients with CSOLTF, a detailed preoperative evaluation should be performed to develop a reasonable surgical plan to avoid a greater degree of kyphosis correction. Intraoperative soft tissue protection, preservation of PLC, and UIV/LIV avoidance in the thoracolumbar segment and sacrum should be emphasized. For patients with significant sagittal imbalance, targeted measures should be administered preoperatively; furthermore, postoperative follow-up and testing should be increased to emphasize the postoperative recovery of sagittal balance and reduce the risk of PJK.

Abbreviations

CSOLTF, chronic symptomatic osteoporotic thoracolumbar fractures; PJK, proximal junctional kyphosis; BMI, body mass index; BMD, bone mineral density; ASIA, American Spinal Injury Association; PLC, posterior ligament complex; UIV, upper instrumented vertebral; LIV, lower instrumented vertebral; Pre, preoperative; PJA, proximal junctional angle; SVA, sagittal vertebral axis; PI, pelvic incidence; LL, lumbar lordosis; PI-LL, pelvic incidence-lumbar lordosis mismatch; PT, pelvic tilt; SS, sacral slope; OR, odds ratio; CI, confidence interval.

Declarations

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Authors contributions

All the authors participated in surgical treatment for the patients in this study. QDL drafted the manuscript. JSY, BRH and TJL conceived the study design. JSY, LG, XC and XT supervised the data collection and analysis. YJS and BRH contributed to the revision. DJH is responsible for this article. All authors read and approved the final manuscript.

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Availability of data and materials

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

Ethics approval and consent to participate

The study was conducted in agreement with the Declaration of Helsinki and was approved by the Ethics Committee of the Honghui Hospital in China (202110004). All participants gave written informed consent.

Consent for publication

Consent to publish was obtained from the patient detailed in this study.

Competing interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

1. Compston JE, McClung MR, Leslie WD: Osteoporosis. Lancet 2019, **393**(10169):364–376.
2. Lamartina C, Berjano P, Petruzzi M, Sinigaglia A, Casero G, Cecchinato R, Damilano M, Bassani R: **Criteria to restore the sagittal balance in deformity and degenerative spondylolisthesis**. Eur Spine J 2012, **21 Suppl 1**(Suppl 1):S27-31.
3. Doodkorte RJP, Vercoulen TFG, Roth AK, de Bie RA, Willems PC: **Instrumentation techniques to prevent proximal junctional kyphosis and proximal junctional failure in adult spinal deformity correction-a systematic review of biomechanical studies**. Spine J 2021, **21**(5):842–854.
4. Wu Y, Chen CH, Tsuang FY, Lin YC, Chiang CJ, Kuo YJ: **The stability of long-segment and short-segment fixation for treating severe burst fractures at the thoracolumbar junction in osteoporotic bone: A finite element analysis**. PLoS One 2019, **14**(2):e0211676.
5. Cerpa M, Sardar Z, Lenke L: **Revision surgery in proximal junctional kyphosis**. Eur Spine J 2020, **29**(Suppl 1):78–85.
6. Glattes RC, Bridwell KH, Lenke LG, Kim YJ, Rinella A, Edwards C, 2nd: **Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: incidence, outcomes, and risk factor analysis**. Spine (Phila Pa 1976) 2005, **30**(14):1643–1649.
7. Kim YJ, Bridwell KH, Lenke LG, Glattes CR, Rhim S, Cheh G: **Proximal junctional kyphosis in adult spinal deformity after segmental posterior spinal instrumentation and fusion**: **minimum five-year follow-up**. *Spine (Phila Pa 1976)* 2008, **33**(20):2179-2184.
8. Ferrero E, Bocahut N, Lefevre Y, Roussouly P, Pesenti S, Lakhal W, Odent T, Morin C, Clement JL, Compagnon R *et al*: **Proximal junctional kyphosis in thoracic adolescent idiopathic scoliosis: risk factors and compensatory mechanisms in a multicenter national cohort**. Eur Spine J 2018, **27**(9):2241–2250.
9. Hao DJ, Yang JS, Tuo Y, Ge CY, He BR, Liu TJ, Huang DG, Jia SJ, Liu P, Zhang JN *et al*: **Reliability and application of the new morphological classification system for chronic symptomatic osteoporotic thoracolumbar fracture**. J Orthop Surg Res 2020, **15**(1):348.
10. Kim HJ, Iyer S: **Proximal Junctional Kyphosis**. J Am Acad Orthop Surg 2016, **24**(5):318–326.
11. Ishikawa Y, Watanabe K, Katsumi K, Ohashi M, Shibuya Y, Izumi T, Hirano T, Endo N, Kaito T, Yamashita T *et al*: **Short- versus long-segment posterior spinal fusion with vertebroplasty for osteoporotic vertebral collapse with neurological impairment in thoracolumbar spine: a multicenter study**. BMC Musculoskelet Disord 2020, **21**(1):513.
12. Scheer JK, Fakurnejad S, Lau D, Daubs MD, Coe JD, Paonessa KJ, LaGrone MO, Amaral RA, Trobisch PD, Lee JH *et al*: **Results of the 2014 SRS Survey on PJK/PJF: A Report on Variation of Select SRS Member Practice Patterns, Treatment Indications, and Opinions on Classification Development**. Spine (Phila Pa 1976) 2015, **40**(11):829–840.
13. Kim HJ, Bridwell KH, Lenke LG, Park MS, Song KS, Piyaskulkaew C, Chuntarapas T: **Patients with proximal junctional kyphosis requiring revision surgery have higher postoperative lumbar lordosis and larger sagittal balance corrections**. Spine (Phila Pa 1976) 2014, **39**(9):E576-580.
14. Sebaaly A, Riouallon G, Obeid I, Grobost P, Rizkallah M, Laouissat F, Charles YP, Roussouly P: **Proximal junctional kyphosis in adult scoliosis: comparison of four radiological predictor models**. Eur Spine J 2018,

27(3):613–621.

15. Lafage R, Schwab F, Glassman S, Bess S, Harris B, Sheer J, Hart R, Line B, Henry J, Burton D *et al*: **Age-Adjusted Alignment Goals Have the Potential to Reduce PJK**. Spine (Phila Pa 1976) 2017, **42**(17):1275–1282.
16. Im SK, Lee JH, Kang KC, Shin SJ, Lee KY, Park JJ, Kim MH: **Proximal Junctional Kyphosis in Degenerative Sagittal Deformity After Under- and Overcorrection of Lumbar Lordosis: Does Overcorrection of Lumbar Lordosis Instigate PJK?** Spine (Phila Pa 1976) 2020, **45**(15):E933-e942.
17. Zhao J, Chen K, Zhai X, Chen K, Li M, Lu Y: **Incidence and risk factors of proximal junctional kyphosis after internal fixation for adult spinal deformity: a systematic evaluation and meta-analysis**. Neurosurg Rev 2021, **44**(2):855–866.
18. Zou L, Liu J, Lu H: **Characteristics and risk factors for proximal junctional kyphosis in adult spinal deformity after correction surgery: a systematic review and meta-analysis**. Neurosurg Rev 2019, **42**(3):671–682.
19. Bridwell KH, Lenke LG, Cho SK, Pahys JM, Zebala LP, Dorward IG, Cho W, Baldus C, Hill BW, Kang MM: **Proximal junctional kyphosis in primary adult deformity surgery: evaluation of 20 degrees as a critical angle**. Neurosurgery 2013, **72**(6):899–906.
20. Kim HJ, Bridwell KH, Lenke LG, Park MS, Ahmad A, Song KS, Piyaskulkaew C, Hershman S, Fogelson J, Mesfin A: **Proximal junctional kyphosis results in inferior SRS pain subscores in adult deformity patients**. Spine (Phila Pa 1976) 2013, **38**(11):896–901.
21. Yang J, Khalifé M, Lafage R, Kim HJ, Smith J, Shaffrey CI, Burton DC, Ames CP, Mundis GM, Jr., Hostin R *et al*: **What Factors Predict the Risk of Proximal Junctional Failure in the Long Term, Demographic, Surgical, or Radiographic?: Results From a Time-dependent ROC Curve**. Spine (Phila Pa 1976) 2019, **44**(11):777–784.
22. Yagi M, Fujita N, Okada E, Tsuji O, Nagoshi N, Asazuma T, Ishii K, Nakamura M, Matsumoto M, Watanabe K: **Fine-tuning the Predictive Model for Proximal Junctional Failure in Surgically Treated Patients With Adult Spinal Deformity**. Spine (Phila Pa 1976) 2018, **43**(11):767–773.
23. O'Leary PT, Bridwell KH, Lenke LG, Good CR, Pichelmann MA, Buchowski JM, Kim YJ, Flynn J: **Risk factors and outcomes for catastrophic failures at the top of long pedicle screw constructs: a matched cohort analysis performed at a single center**. Spine (Phila Pa 1976) 2009, **34**(20):2134–2139.
24. Kim DK, Kim JY, Kim DY, Rhim SC, Yoon SH: **Risk Factors of Proximal Junctional Kyphosis after Multilevel Fusion Surgery: More Than 2 Years Follow-Up Data**. J Korean Neurosurg Soc 2017, **60**(2):174–180.
25. Hostin R, McCarthy I, O'Brien M, Bess S, Line B, Boachie-Adjei O, Burton D, Gupta M, Ames C, Deviren V *et al*: **Incidence, mode, and location of acute proximal junctional failures after surgical treatment of adult spinal deformity**. Spine (Phila Pa 1976) 2013, **38**(12):1008–1015.
26. Iyer S, Lenke LG, Nemani VM, Albert TJ, Sides BA, Metz LN, Cunningham ME, Kim HJ: **Variations in Sagittal Alignment Parameters Based on Age: A Prospective Study of Asymptomatic Volunteers Using Full-Body Radiographs**. Spine (Phila Pa 1976) 2016, **41**(23):1826–1836.
27. Annis P, Lawrence BD, Spiker WR, Zhang Y, Chen W, Daubs MD, Brodke DS: **Predictive factors for acute proximal junctional failure after adult deformity surgery with upper instrumented vertebrae in the thoracolumbar spine**. Evid Based Spine Care J 2014, **5**(2):160–162.

28. Senteler M, Weisse B, Snedeker JG, Rothenfluh DA: **Pelvic incidence-lumbar lordosis mismatch results in increased segmental joint loads in the unfused and fused lumbar spine**. Eur Spine J 2014, **23**(7):1384–1393.
29. Wang T, Zhao Y, Liang Y, Zhang H, Wang Z, Wang Y: **Risk factor analysis of proximal junctional kyphosis after posterior osteotomy in patients with ankylosing spondylitis**. J Neurosurg Spine 2018, **29**(1):75–80.
30. Jun HS, Kim JH, Ahn JH, Chang IB, Song JH, Kim TH, Park MS, Chan Kim Y, Kim SW, Oh JK *et al*: **The Effect of Lumbar Spinal Muscle on Spinal Sagittal Alignment: Evaluating Muscle Quantity and Quality**. Neurosurgery 2016, **79**(6):847–855.
31. Schwab F, Ungar B, Blondel B, Buchowski J, Coe J, Deinlein D, DeWald C, Mehdian H, Shaffrey C, Tribus C *et al*: **Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study**. Spine (Phila Pa 1976) 2012, **37**(12):1077–1082.
32. Yilgor C, Sogunmez N, Boissiere L, Yavuz Y, Obeid I, Kleinstück F, Pérez-Grueso FJS, Acaroglu E, Haddad S, Mannion AF *et al*: **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 2017, **99**(19):1661–1672.

Figures

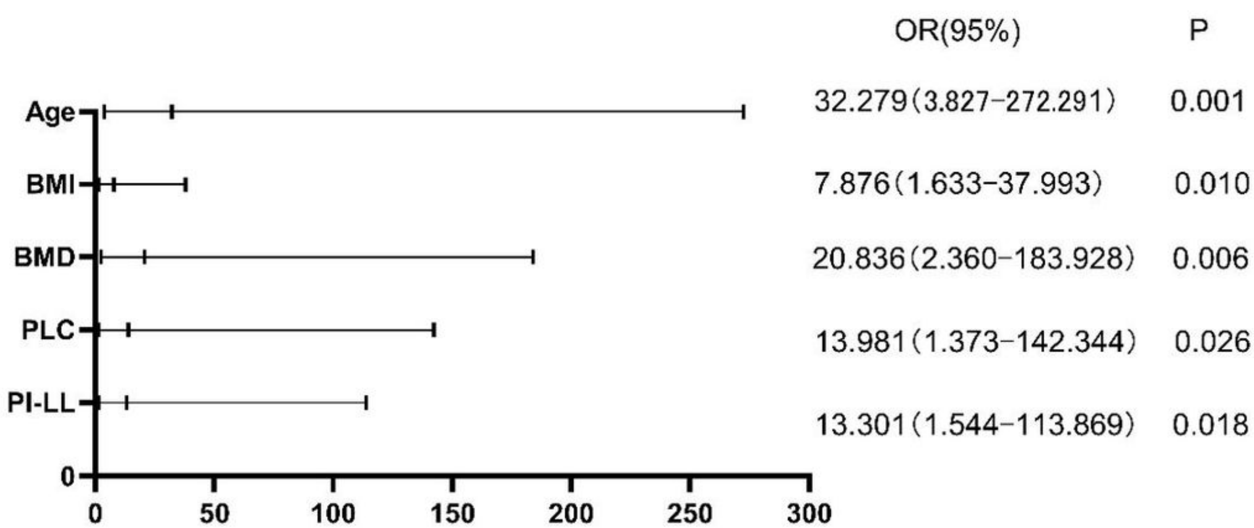

Figure 1

Risk factors of PJK after posterior long-segment internal fixation for CSOTLF.