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Research Paper

Impact of Body Mass Index on Early and Late Proximal Junctional Kyphosis After Long Spinal Fusion

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ABSTRACT

Background: Proximal junctional kyphosis (PJK) is a common complication of long spinal fusion. The relationship between body mass index (BMI) and PJK is controversial.

Objectives: This study aimed to evaluate the relationship between patient BMI and PJK prevalence in patients undergoing long spinal fusion.

Methods: This retrospective study included 76 patients who underwent long spinal fusion (≥5 levels or pelvic fixation) for degenerative canal stenosis with a minimum 24-month follow-up. PJK was defined as ≥10° increase in Cobb angle between the UIV inferior endplate and the UIV+2 superior endplate.

Results: PJK occurred in 26 patients (34.2%) at early follow-up (≤6 months) and in 18 patients (23.7%) at late follow-up (>6 months). Mean BMI was significantly higher in the early PJK group (29.6 vs 23.4 kg/m², P<0.001). BMI was an independent predictor of early PJK (OR=1.32, 95% CI, 1.18%, 1.48%, P<0.001). Overweight patients (BMI>25) had a 69.6% early PJK rate vs 20.5% in normal-weight patients. Surgically treated early PJK patients had higher mean BMI (30.8 vs 28.4 kg/m², P=0.023).

Conclusion: Higher BMI is significantly associated with early PJK following long spinal fusion, particularly in the first 6 months postoperatively.

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Introduction

Proximal junctional kyphosis (PJK) remains a prevalent and challenging complication following long-segment spinal fusion for adult spinal deformity, with reported incidence rates varying widely from 5% to 46% across the literature [1, 2]. This heterogeneity in reported prevalence is largely attributed to variations in diagnostic definitions, patient demographics, and radiographic protocols. Clinically, PJK can lead to significant patient morbidity, ranging from localized pain and sagittal malalignment to proximal junctional failure (PJF) and neurological deficits in severe cases, necessitating revision surgery [3, 4].

The etiology of PJK is multifactorial, resulting from an intricate interplay between patient-specific characteristics, surgical techniques (e.g. upper instrumented vertebra selection and sagittal alignment restoration), and postoperative biomechanical forces [2, 5]. Among patient-related risk factors, body mass index (BMI) has garnered significant attention in recent years. High BMI is associated with increased mechanical load on the spinal construct and technical intraoperative challenges, which may predispose patients to junctional complications [5, 6]. However, the association between BMI and the development of PJK remains a matter of ongoing controversy. While some studies have identified high BMI as an independent risk factor, others have reported no significant correlation [1, 7]. This inconsistency likely arises from methodological differences, including differences in PJK classification, the inclusion of confounding variables such as bone mineral density and sarcopenia, and heterogeneous follow-up durations [2]. Given these conflicting findings, further investigation into the predictive value of BMI is warranted. Therefore, the purpose of this study is to evaluate the relationship between BMI and the prevalence of PJK in patients undergoing long spinal fusion for degenerative canal stenosis. Furthermore, this study provides a detailed analysis of the prevalence of PJK across temporal phases—specifically early and late onset—to elucidate whether BMI exerts a differential influence on the timing of this complication

Methods

Study design and patient population

This retrospective study was conducted at ShafaYahyaeian Hospital, Tehran, Iran, between January 2018 and December 2021. The study included patients who underwent long spinal fusion for degenerative canal stenosis with a minimum 24-month follow-up. Long spinal fusion was defined as fusion involving ≥5 moving segments or fusion extending to the pelvis with iliac fixation (iliac or S2 alar-iliac screws).

Inclusion and exclusion criteria

Patients were included if they

1) Underwent long spinal fusion for degenerative canal stenosis; 2) Had a minimum 24-month follow-up; 3) Had available preoperative and follow-up radiographic images.

Patients were excluded if they had

1) Preoperative kyphotic deformity at the proximal junctional region; 2) Significant BMI change (>5 units) during follow-up; 3) Previous spinal surgery at fused levels; 4) Primary spinal deformity as a surgical indication; 5) Incomplete medical records or radiographic data.

Initially, 129 patients were identified; 35 were excluded due to BMI changes, leaving 94 patients. Of these, 76 completed a minimum 24-month follow-up and were included in the final analysis.

Data collection

Demographic data, including age, sex, weight, and height, were collected from medical records. BMI was calculated as weight (kg) divided by height (m^2).

Radiographic assessment

All radiographic measurements were performed on standing full-spine lateral radiographs by two independent observers blinded to clinical outcomes. PJK was defined as an increase in Cobb angle between the UIV inferior endplate and the UIV+2 superior endplate of >10° compared to the preoperative measurement [8].

1) Early PJK: Developing within 6 months postoperatively; 2) Late PJK: Developing after 6 months postoperatively

Statistical analysis

Descriptive statistics were expressed as Mean±SD for continuous variables and frequencies (percentages) for categorical variables. Comparisons between groups were performed using independent-samples t tests or the Mann-Whitney U test for continuous variables, and the chi-square test for categorical variables. Logistic regression was performed for multivariate analysis. Statistical significance was set at $P<0.05$.

Results

Patient demographics: The study included 76 patients (52 women, 24 men) with a mean age of 60.2 years (range: 43-78 years). The mean follow-up duration was 38.4 months (range: 24-51 months). The mean BMI was 27.6 kg/m² (range: 18.3-34.8 kg/m²) (Table 1); PJK prevalence: PJK occurred in 34 patients (44.7%) overall. Early PJK occurred in 26 patients (34.2%) and late PJK in 18 patients (23.7%); BMI and PJK: In early PJK, mean BMI was significantly higher in the PJK group (29.6 vs 23.4 kg/m², P<0.001) (Table 2). No significant difference was found for late PJK; BMI categories and PJK risk (Table 3); Multivariate analysis (Table 4); Surgical intervention: Among early PJK patients, 16(61.5%) required surgical intervention. Mean BMI was significantly higher in surgically treated patients (30.8 vs 28.4 kg/m², P=0.023).

Discussion

This study identifies a significant association between higher BMI and the development of PJK following long-segment spinal fusion for degenerative lumbar disease. Patients with early PJK had a significantly higher mean BMI than those without PJK, and multivariate analysis identified BMI as an independent predictor of early PJK (odds ratio: 1.32 per 1 kg/m² increase) [8, 9].

The overall PJK prevalence in our study (44.7%) is consistent with what is reported in the literature for long fusions, which ranges from 5-46% depending on the definition and patient cohort [1, 8] . This high rate in our study may be attributed to strict radiographic monitoring and the inclusion of patients with advanced degenerative pathology requiring long-segment constructs. Crucially, the rate of early PJK (occurring within 6 months postoperatively; 34.2%) exceeded that of late PJK (23.7%). This temporal pattern supports prior findings indicating that the majority of PJK cases develop in the early postoperative period, primarily driven by immediate mechanical failure or junctional segment overload rather than long-term degenerative changes [10, 11].

The strong association between elevated BMI and early PJK observed in this study is consistent with several clinical cohorts [8, 9, 12]. Biomechanically, a higher BMI contributes to increased mechanical loading on the upper instrumented vertebra (UIV) and adjacent segments through several interconnected pathways. Obesity increases the axial load and gravity-line displacement, causing greater rotational bending moments at the transition zone between the rigid instrumented construct and the upper segments [12, 13]. Second, patients with obesity often exhibit postural compensations, such as an anteriorly shifted sagittal vertical axis, which increases the

Table 1. Patient demographics (n=76)

Characteristic		Mean±SD/No. (%)
Age (y)		60.2±9.8
Gender	Female	52(68.4)
	Male	24(31.6)
BMI (kg/m²)		27.6±4.2
Follow-up (months)		38.4±8.2
Fusion levels		7.2±2.1
Pelvic fixation		68(89.5)

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Table 2. BMI comparison between PJK and non-PJK groups

Period	Mean±SD		Difference	P
	PJK Group BMI	Non-PJK Group BMI		
Early (≤6 months)	29.6±3.8	23.4±4.1	6.2	<0.001*
Late (>6 months)	27.3±4	26.7±4.3	0.6	0.412

*Statistically significant.

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Table 3. Early PJK rate by BMI category

BMI Category	Patients	Early PJK	Rate (%)
Underweight (<20)	14	2	14.3
Normal (20-25)	39	8	20.5
Overweight (>25)	23	16	69.6

Note: Overweight patients had significantly higher early PJK rates (69.6%) than normal-weight (20.5%) and underweight (14.3%) patients.

Table 4. Multivariate analysis for early PJK

Variables	Odds Ratio	95% CI	P
BMI (unit increase)	1.32	1.18, 1.48	<0.001*
Age (year increase)	1.04	0.98, 1.1	0.186
Sex (female vs male)	1.68	0.72, 3.92	0.231
Fusion length (level)	1.12	0.89, 1.41	0.342

BMI: Body mass index; CI: Confidence interval.

*Statistically significant.

Note: BMI was identified as an independent predictor of early PJK (OR=1.32, P<0.001).

mechanical demand on the posterior ligamentous complex [13, 14]. The technical challenge of surgical exposure in patients with high BMI may lead to unintended damage to the posterior tension band (interspinous ligaments and facet capsules) at the UIV level, compromising structural integrity [15]. Obesity-related systemic inflammation and impaired microvascular circulation have been shown to delay bone healing and ligamentous recovery, increasing susceptibility to early mechanical failure [16].

In our sample, 61.5% of patients who developed early PJK required revision surgery, and these patients had a significantly higher mean BMI than those managed conservatively. This implies that a higher BMI not only increases the risk of developing PJK but also predisposes patients to severe or symptomatic forms such as PJF that necessitate surgical reoperation [9, 1].

While many studies agree that obesity is a risk factor for mechanical failure, some review studies have reported conflicting results regarding the direct correlation between BMI and PJK. This inconsistency is likely due to heterogeneity in surgical techniques, different definitions of PJK, and varying follow-up periods across cohorts [1, 12]. However, when focusing specifically on early mechanical complications rather than late degenerative progression, the impact of body weight becomes more pronounced, as demonstrated in our findings.

Based on the findings, we propose several clinical strategies to mitigate the risk of early PJK in patients with high BMI:

• Preoperative optimization: Whenever clinically feasible, weight reduction and physical conditioning should be encouraged prior to elective surgery to reduce early mechanical demands on the constructs [12, 16].

• Surgical construct adjustments: In patients with high BMI, surgeons should consider preventive strategies such as soft-tissue preservation at the UIV, prophylactic vertebral augmentation (cementing the UIV/UIV+1), or using transition rods (tapered rods) to graduate the stiffness at the junction [11, 15].

• Sagittal alignment planning: Avoiding overcorrection of lumbar lordosis in obese patients is critical, as matching their natural, slightly more kyphotic or compensated alignment can lower junctional stress [13, 14].

• Postoperative monitoring: Patients with a BMI >25 kg/m² should undergo more frequent and careful radiographic follow-up during the first 6 months to detect early junctional changes before they progress to catastrophic failure.

Conclusion

High BMI is an independent predictor of early PJK (≤6 months) following long spinal fusion, with every unit increase in BMI raising the risk by 32%. High BMI is also associated with a greater likelihood of requiring surgical revision for early PJK. In contrast, BMI does not significantly influence late-onset PJK (>6 months). Preoperative weight optimization and tailored protective surgical strategies at the UIV level are recommended to mitigate the risk of early mechanical failure in patients with high BMI

Strengths and limitation

Our study had several strengths. First, we specifically focused on patients undergoing long spinal fusion (≥5

levels or pelvic fixation) for degenerative canal stenosis, which is a well-defined population. Second, we distinguished between early and late PJK, which allowed us to identify the time-dependent relationship between BMI and PJK. Third, we analyzed the relationship between BMI and the need for surgical intervention, which provided additional information beyond the presence of radiographic PJK. Fourth, we used standardized definitions for PJK and long spinal fusion. However, our study had some limitations. First, the retrospective design introduced potential biases as noted by O'Neill et al. [17]. Second, our sample size (76 patients) may have been insufficient to detect smaller differences in subgroup analyses. Third, the study was conducted at a single center, which may limit generalizability. Fourth, we excluded patients with >5 unit change in BMI during follow-up, which may have removed some informative patients. Fifth, we did not collect data on bone mineral density, a known risk factor for PJK, as discussed by Line et al. (2020). Sixth, interobserver and intraobserver reliability for radiographic measurements as not formally assessed.

Future research

Future studies should focus on several areas. First, prospective studies with larger sample sizes are needed to confirm our findings, as recommended by Cho et al. [18]. Second, biomechanical studies using finite element analysis could help elucidate the mechanisms by which increased BMI leads to PJK. Third, intervention studies evaluating the effect of preoperative weight loss on PJK rates would be valuable. Fourth, multi-centerstudies would increase sample sizes and improve generalizability. Fifth, longer follow-up studies (5-10 years) would help determine if the relationship between BMI and PJK persists over time. BMI is an independent predictor of early PJK (OR=1.32, 95% CI, 1.18%, 1.48%, P<0.001) Higher BMI is significantly associated with increased prevalence of early PJK following long spinal fusion. Overweight patients have a substantially higher risk and should be counseled preoperatively. Weight optimization and modified surgical techniques should be considered in high-risk patients.

Ethical Considerations

Compliance with ethical guidelines

The ethical principles observed in the article, such as the informed consent of the participants, the confidentiality of information, the permission of the participants to cancel their participation in the research.

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Authors' contributions

Conceptualization and supervision: Ebrahim Ameri and Hassan Ghandhari; Methodology: Farshad Nikoii and Ehsan Ghavidel; Formal analysis: Ehsan Ghavidel and Javad Moeini; Data curation and Data collection: Javad Moeini, Mohammad Reza Shakeri, and Ehsan Ghavidel; Data analysis: Ehsan Ghavidel and Mohammad Reza Chehrasan; Project administration: Ebrahim Ameri, Hassan Ghandhari, and Farshad Nikoii; Investigation and writing: All authors.

Conflict of interest

The authors declared no conflict of interest.

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