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Risk Factors for Failure of Minimally Invasive PFNA Internal Fixation in Elderly Patients with Intertrochanteric Femoral Fractures

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Abstract

Objective: To investigate the risk factors for failure of minimally invasive proximal femoral nail antirotation internal fixation in elderly patients with intertrochanteric femoral fractures, and to provide evidence for reducing the surgical failure rate and improving prognosis. **Methods:** A total of 230 elderly patients with intertrochanteric femoral fractures who underwent PFNA internal fixation at Zhanjiang First Hospital of Traditional Chinese Medicine from January 2019 to April 2024 were retrospectively included. According to whether internal fixation failure occurred postoperatively, the patients were divided into a control group (successful fixation, $n = 199$) and an observation group (fixation failure, $n = 31$). Univariate analysis was used to compare clinical data between the two groups. Variables with $P < 0.05$ were included in a multivariable logistic regression model to identify independent risk factors. A nomogram prediction model was constructed based on the regression results, and its discrimination, calibration, and clinical utility were evaluated using receiver operating characteristic curves, calibration curves, and decision curve analysis. **Results:** Univariate analysis showed significant differences between the two groups in age, AO fracture classification, reduction status, diabetes mellitus, and smoking history ($P < 0.05$). Multivariable logistic regression analysis, using AO type 1 fractures and grade I reduction as the reference categories, showed that increasing age, AO type 3 fractures, and concomitant diabetes mellitus were independent risk factors for PFNA fixation failure, whereas good reduction quality (grade III) was a protective factor associated with lower odds of fixation failure (all $P < 0.05$). Each additional year of age was associated with an approximately 13.4% increase in the odds of fixation failure. The nomogram model constructed using these four factors yielded an AUC of 0.911 in

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the training set and 0.885 in the validation set, with Brier scores of 0.067 in both sets. The calibration curves closely approximated the ideal reference line, and decision curve analysis showed that the model provided favorable clinical net benefit across a broad range of threshold probabilities. **Conclusion:** Age, AO type 3 fracture, diabetes mellitus, and reduction quality are key factors influencing PFNA internal fixation failure in elderly patients with intertrochanteric femoral fractures. The nomogram prediction model based on these factors demonstrates good discrimination and calibration and may be used to identify high-risk patients preoperatively and guide individualized treatment decisions.

Keywords

Intertrochanteric Femoral Fracture, PFNA Internal Fixation, Risk Factors

1. Introduction

As population aging continues to intensify, the annual incidence of hip fractures among older adults is increasing. These fractures carry high risks of disability and mortality and represent an important public health issue in current geriatric orthopedics. Intertrochanteric femoral fracture is the most common type of hip fracture in older adults, accounting for more than 50% of hip fractures [1]. The 1-year mortality rate after this type of fracture reaches 20% - 30% [2], and approximately half of patients are left with varying degrees of hip dysfunction and are unable to regain their pre-fracture level of activity. Therefore, identifying safe and effective treatment strategies to improve patient prognosis is a critical clinical challenge that must be addressed.

At present, the proximal femoral nail anti-rotation (PFNA) is the preferred internal fixation method for treatment of intertrochanteric femoral fractures. PFNA provides central intramedullary fixation and offers advantages such as a short lever arm, low bending moment, reduced postoperative pain, and the ability to initiate early functional exercise. However, with the widespread use of PFNA, increasing attention has been directed to the problem of internal fixation failure. The failure rate of PFNA internal fixation can reach 13.3% - 20.5%. The primary manifestations of internal fixation failure include helical blade cut-out, loosening and back-out of the implant, main nail breakage, and fracture nonunion or malunion [3]-[5]. These complications not only cause substantial suffering and severely impair recovery of hip joint function but also increase the medical burden associated with revision surgery. Therefore, identifying risk factors for PFNA internal fixation failure and achieving accurate preoperative risk stratification are of great clinical significance for reducing failure rates and improving patient outcomes.

Previous studies have examined risk factors for PFNA fixation failure at multiple levels. At the patient level, advanced age, severe osteoporosis, and comorbid

medical conditions such as diabetes have been considered closely associated with fixation failure. At the fracture level, factors such as unstable fracture patterns, poor integrity of the lateral wall, and discontinuity of the medial cortex may significantly increase the risk of failure. At the surgical level, technical factors, including suboptimal reduction quality, excessive tip-apex distance, and improper positioning of the helical blade, have also been identified as important risk factors. However, most existing studies are single-center, small-sample retrospective analyses; their findings are not entirely consistent, and most are limited to identifying individual risk factors. Systematic integration and quantitative assessment of multiple factors remain lacking, as do risk prediction tools that can be directly applied in clinical practice.

Against this background, the present study retrospectively analyzes the clinical data of elderly patients with intertrochanteric femoral fractures treated with PFNA internal fixation who were admitted to Zhanjiang First Hospital of Traditional Chinese Medicine between January 2019 and April 2024. It systematically evaluates the risk factors for internal fixation failure, with the aim of providing evidence-based support for preoperative risk assessment, optimization of surgical strategies, and the development of individualized prevention and treatment approaches in clinical practice.

2. Materials and Methods

2.1. General Information

With approval from the hospital ethics committee (ethics approval No. 2024027), this study randomly selected 230 elderly patients with intertrochanteric femoral fractures who underwent PFNA internal fixationfrom January 2019 to April 2024 at Zhanjiang First Hospital of Traditional Chinese Medicine. The mean age of the patients was80.57 ± 9.32 years; 87 were male and 143 were female.

Inclusion criteria: (1) age ≥ 60 years; (2) acute unilateral femoral intertrochanteric fracture confirmed by X-ray and/or CT, meeting the AO/OTA classification criteria; (3) treatment with PFNA internal fixation; (4) complete clinical and imaging data, with postoperative follow-up ≥ 6 months; (5) no other surgical treatment within 1 month before surgery.

Exclusion criteria were as follows: (1) pathological fracture or concomitant fractures at other sites; (2) multiple trauma (ISS ≥ 16); (3) history of previous ipsilateral hip surgery; (4) severe dysfunction of vital organs, such as the liver or kidneys; and (5) missing preoperative imaging data or loss to postoperative follow-up.

2.2. Methods

This retrospective case-control study classified patients into a control group (successful fixation, n = 199) and a case group (fixation failure, n = 31) according to whether postoperative internal fixation failure occurred. Fixation failure was defined as helical blade cut-out or cut-through of the femoral head, implant loosen-

ing or backing out, varus deformity of the hip, fracture nonunion or delayed union, or revision surgery for any of these reasons. To control for confounding, propensity scores were estimated using logistic regression, with age, sex, medical history, and the presence of underlying diseases as matching variables. Univariate analyses were performed to compare clinical characteristics between the two groups, and multivariable logistic regression was used to identify independent risk factors for PFNA fixation failure. The variables analyzed included demographic and clinical characteristics (age, sex, AO fracture classification, surgical history, smoking history, and comorbidities, including hypertension, diabetes mellitus, renal insufficiency, and coronary artery disease) and laboratory parameters (white blood cell count and serum calcium).

2.3. Statistical Methods

Statistical analyses were performed using SPSS 26.0 and R packages. Measurement data were described as ($\bar{\chi}$ ± s) and analyzed using the t test, whereas count data were described as cases (%) and analyzed using the χ^2 test. Univariate and multivariate logistic regression analyses were used to identify risk factors for failure of minimally invasive PFNA internal fixation in elderly patients with intertrochanteric femoral fractures, and a nomogram model for these risk factors was constructed. Its predictive performance was evaluated using the receiver operating characteristic (ROC) curve, internal validation was performed using the bootstrap method, and model calibration and goodness of fit were assessed using the goodness-of-fit test and calibration curves. A value of $P < 0.05$ was considered statistically significant.

3. Results

3.1. Comparison of Clinical Characteristics between the Control and Observation Groups

The incidence of failure after minimally invasive PFNA internal fixation for intertrochanteric fractures in older adults was approximately 13.48% (31/230). Significant differences were observed between the two groups of patients in age, AO fracture classification, reduction quality, comorbid diabetes mellitus, smoking history, and other factors ($P < 0.05$) (Table 1).

Table 1. Univariate analysis of failure after minimally invasive PFNA internal fixation for intertrochanteric fractures in elderly patients.

Factors	Control group (n = 199)	Observation group (n = 31)	X^2/t	*P* value
Age ($\bar{\chi}$ ± s, years)	79.29 ± 9.22	88.81 ± 4.51	5.640	0.001
Sex (*n*/%)			3.541	0.06
Male	80/40.2	7/22.6		
Female	119/59.8	24/77.4		

Continued

AO fracture classification (*n*/%)			7.675	0.022
Type AO1	107	3/9.6		
AO2 type	45	5/16.1		
AO3 type	47	23/74.7		
Reduction status (*n*/%)			10.922	0.004
Reduction status: Grade I	24	21/67.7		
Reduction status: grade II	80	3/9.6		
Reduction status: Grade III	95	7/22.5		
Biochemical indicators				
White blood cell count ($\bar{\chi}$ ± s, $\times 10^9$/L)		8.17 ± 5.31	0.732	0.392
Serum calcium ($\bar{\chi}$ ± s, mmol/L)		2.13 ± 0.19	1.479	0.224
Comorbidities				
Comorbid diabetes (*n*/%)			7.612	0.006
Yes	35	14/45.2		
None	164	17/54.8		
Comorbid hypertension (*n*/%)			1.779	0.182
Yes	23	9/29.0		
None	176	22/71.0		
RI (*n*/%)			1.301	0.254
Yes	17	4/12.9		
None	182	27/87.1		
with concomitant coronary heart disease			0.028	0.866
Yes.	10	5/16.1		
None	189	26/83.8		
Medical history				
Surgical history			0	0.998
Yes	170	31/100		
None	29	0/0		
Smoking history			4.529	0.033
Yes	54	5/16.1		
None	146	26/83.8		

Note: $P < 0.05$ indicates statistical significance.

3.2. Multivariate Logistic Regression Analysis of Failure of Minimally Invasive PFNA Internal Fixation for Intertrochanteric Femoral Fractures in Elderly Patients

Multivariable logistic regression analysis, using AO type 1 fractures and grade I

reduction as the reference categories, showed that increasing age, AO type 3 fractures, and concomitant diabetes mellitus were independent risk factors for fixation failure following minimally invasive PFNA fixation of intertrochanteric femoral fractures in older patients, whereas grade III reduction was a protective factor against fixation failure (all $P < 0.05$) (Table 2).

Table 2. Multivariate logistic regression analysis of failure after minimally invasive PFNA internal fixation for intertrochanteric femoral fractures in older adults.

Risk factors	Regression coefficient	OR value	*P* value	95% CI value	
				Lower bound	Upper limit
Age	0.126	1.134	0.015	1.033	1.270
AO type 3 fracture	2.925	18.630	0.016	2.403	412.100
Concomitant diabetes mellitus	1.488	4.429	0.047	1.067	21.100
Reduction status grade III	−1.823	0.161	0.014	0.033	0.652
Male	−1.517	0.219	0.063	0.036	0.957
AO type 2 fracture	2.041	7.700	0.135	0.651	201.300
Reduction status grade II	−0.564	0.568	0.542	0.084	3.453
Constant	−13.809	0.000	0.003		

Note: $P < 0.05$ indicates statistical significance.

3.3. Construction and Validation of a Nomogram Model for Risk Factors Associated with Failure of Minimally Invasive PFNA Internal Fixation for Intertrochanteric Femoral Fractures in Older Adults

A nomogram prediction model was developed based on four risk factors affecting the outcomes of minimally invasive PFNA internal fixation for intertrochanteric fractures in older adults: age, AO classification, reduction status, and diabetes (Figure 1). The ROC, calibration, and decision curves of the nomogram model are shown in Figure 2. ROC curve analysis showed that the area under the curve (AUC) was 0.911 in the training set, with a sensitivity of 81.8% and a specificity of 92.8% at the optimal cutoff. In the validation set, the AUC was 0.885, with a sensitivity of 66.7% and a specificity of 95.0% at the optimal cutoff. The AUCs of both the training and validation sets were greater than 0.8, with only a small difference between them, indicating that the model was robust. The calibration curves showed that the curves for both the training and validation sets closely approximated the ideal reference line, with Brier scores of 0.067, suggesting a high degree of agreement between the predicted probabilities of the nomogram model and the actual probability of clinical recurrence, and indicating reliable calibration performance. The decision curve for the training set showed that the nomogram model had good clinical predictive value when the probability threshold was within the range of 0 - 0.6; the decision curve for the validation set showed that the model had good clinical predictive value within the probability threshold range of 0 - 0.8. These

results indicate that this nomogram can be used clinically to identify patients at high risk of internal fixation failure after PFNA.

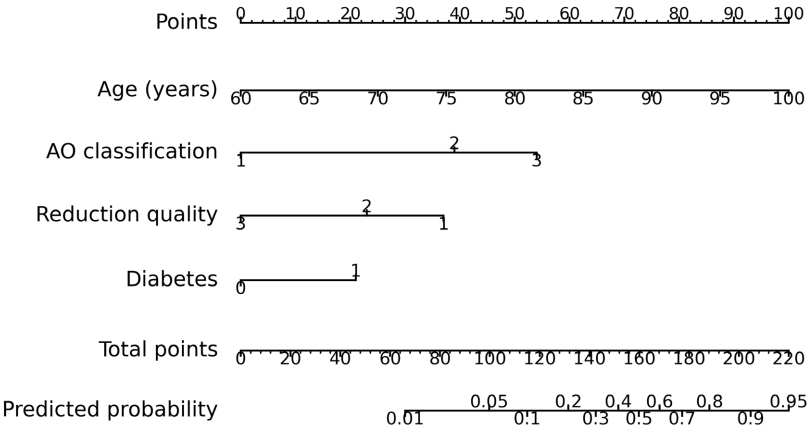


Figure 1. Nomogram for predicting risk factors for failure of minimally invasive PFNA internal fixation in elderly patients with intertrochanteric femoral fractures.

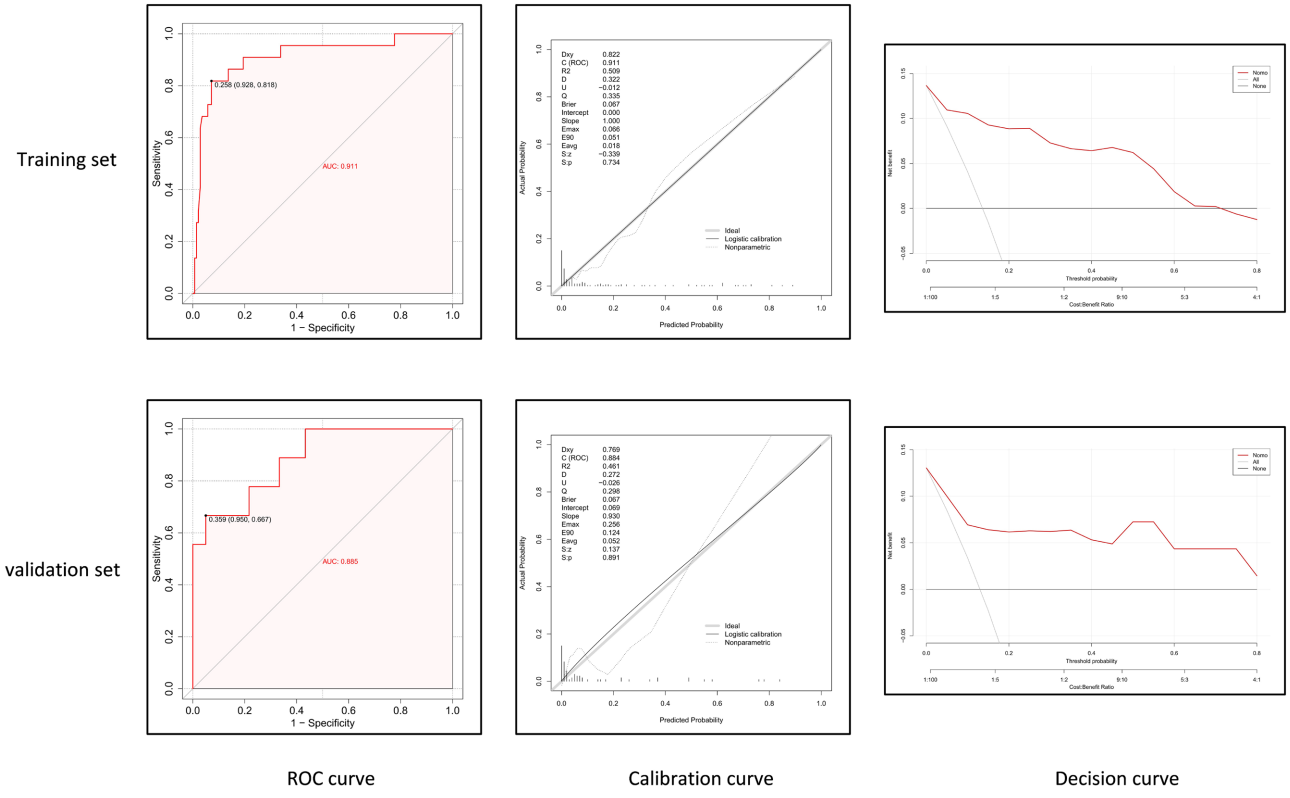


Figure 2. ROC, calibration, and decision curves of the nomogram model.

4. Discussion

Osteoporosis is an important cause of intertrochanteric femoral fractures in the elderly population. Loss of bone mass and reduced biomechanical strength in the proximal femur allow even minor external forces to induce intertrochanteric fem-

oral fractures [6]. In addition, elderly patients often have multiple chronic medical comorbidities, and conservative treatment requires prolonged bed rest, which can readily increase the risk of various complications. Minimally invasive PFNA internal fixation, owing to the biomechanical advantages of central intramedullary fixation and helical blade compression fixation, combines minimal invasiveness, stability, and rapid recovery, and has become the preferred surgical approach for intertrochanteric femoral fractures in older adults [7]. However, failure events such as helical blade cut-out, malunion, and loosening of the internal fixation still occur during clinical follow-up, severely impairing hip joint function. Therefore, this study included relevant clinical indicators for risk factor analysis, aiming to identify high-risk populations and optimize clinical intervention strategies.

This study included 230 elderly patients with intertrochanteric femoral fractures who underwent PFNA internal fixation; the incidence of postoperative internal fixation failure was 13.48%. Univariate and multivariate analyses showed that advanced age, AO type 3 fracture, concomitant diabetes mellitus, and poor reduction quality were independent risk factors for PFNA internal fixation failure. Multivariable analysis showed that increasing age was an independent risk factor for PFNA fixation failure (OR = 1.134, 95% CI: 1.033 - 1.270), indicating that each additional year of age was associated with an approximately 13.4% increase in the odds of fixation failure. The mean age in the failure group was 88.81 years, significantly higher than the 79.29 years observed in the success group. Elderly patients often have severe osteoporosis [8]; degeneration of the trabecular microarchitecture leads to substantial bone loss and a marked reduction in the holding strength at the bone-implant interface [9] [10]. Consequently, the helical blade may have insufficient anchorage in osteoporotic bone, predisposing patients to failure events such as cut-out and backing out [11]. In addition, elderly patients often have an increased burden of comorbidities and poorer adherence to postoperative rehabilitation, both of which may indirectly affect the quality of fracture healing and increase the risk of internal fixation failure.

Among fracture types, AO3 fractures were the strongest independent risk factor for PFNA fixation failure in the present study. AO3 fractures are highly unstable; because the fracture ends lack effective medial support, reduction is difficult, and stable intraoperative fracture alignment is challenging to achieve [12]. In the failure group, AO3 fractures accounted for 74.7%, far higher than the 23.6% in the success group. Multivariable analysis, using AO type 1 fractures as the reference category, yielded an OR of 18.630 (95% CI: 2.403 - 412.100) for AO type 3 fractures, indicating that patients with AO type 3 fractures had approximately 18.6 times the odds of fixation failure compared with those with AO type 1 fractures. In such fractures, PFNA fixation is subjected to substantially increased mechanical loading, with a corresponding increase in the risk of helical blade cut-out or back-out [13]. In addition, the present results indicate that good reduction quality is a protective factor against fixation failure. Poor reduction quality was observed in 67.7% of the failure group, far exceeding the 12.1% in the success group, further

supporting the view that, in unstable fractures, failure to achieve satisfactory reduction markedly increases the risk of fixation failure. Therefore, for AO3 fractures, the feasibility of PFNA fixation should be carefully assessed; when necessary, auxiliary fixation techniques should be used, or alternative options such as arthroplasty should be considered [14].

Regarding comorbidities, this study identified diabetes mellitus as an independent risk factor for PFNA fixation failure (OR = 4.429, 95% CI: 1.067 - 21.100), indicating that patients with diabetes had approximately 4.4 times the odds of fixation failure compared with those without diabetes. The prevalence of diabetes was significantly higher in the failure group than in the success group (45.2% vs. 17.6%). The mechanisms by which diabetes affects fracture healing and fixation stability are multifactorial. Patients with diabetes exhibit abnormal bone metabolism, greater bone loss than age-matched non-diabetic patients, poorer bone quality, and markedly reduced bone mechanical strength [15]. In addition, patients with diabetes often have microvascular disease and peripheral neuropathy, resulting in reduced local blood supply at the fracture ends, which is unfavorable for callus formation and fracture healing [16]. Moreover, diabetes can inhibit osteoblast function and enhance osteoclast activity, leading to increased bone resorption and further weakening the stability of the bone-implant interface [17]. Therefore, for patients with intertrochanteric femoral fractures complicated by diabetes, blood glucose levels should be actively controlled before surgery, perioperative glucose monitoring and management should be strengthened, and standardized postoperative anti-osteoporosis therapy should be combined to improve fracture-healing conditions and reduce the risk of fixation failure.

Reduction quality is another important factor influencing the success of PFNA fixation, with good reduction serving as a protective factor against fixation failure. In this study, grade I, representing the poorest reduction quality, was used as the reference category. The OR for grade III reduction was 0.161 (95% CI: 0.033 - 0.652), indicating that patients with good reduction (grade III) had approximately 83.9% lower odds of fixation failure than those with the poorest reduction quality. In the failure group, patients with the poorest reduction quality accounted for 67.7%, far higher than the 12.1% observed in the success group, whereas patients with the best reduction quality accounted for 47.7% in the success group but only 22.5% in the failure group, intuitively reflecting the close relationship between reduction quality and the prognosis of internal fixation. Good reduction can restore the normal alignment of the proximal femur and provide effective medial cortical support, thereby dispersing the stress borne by the implant and reducing the shear force and bending moment on the helical blade [18]. Poor reduction, resulting in residual varus, rotational malalignment, or a gap at the fracture ends, can concentrate stress in specific regions of the implant and accelerate implant fatigue, loosening, and even breakage. Therefore, achieving anatomical reduction criteria as far as possible during surgery can effectively reduce the failure rate of PFNA fixation [19]-[21].

This study developed a visual nomogram prediction model based on four independent influencing factors: age, AO classification, reduction status, and diabetes

mellitus. The model achieved an AUC of 0.911 in the training set and 0.885 in the validation set, with only a small difference between them, indicating good robustness. The calibration curves for both the training and validation sets were close to the ideal reference line, and the Brier score was 0.067 in both sets, suggesting strong agreement between predicted and observed probabilities. Decision curve analysis showed that, within the threshold range of 0 - 0.6 in the training set and 0 - 0.8 in the validation set, the model provided greater clinical net benefit than the two extreme strategies of treating all patients or treating none, demonstrating its practical applicability. In clinical practice, can use this nomogram preoperatively to rapidly assess the probability of PFNA internal fixation failure in patients and optimize surgical planning.

Failure of PFNA internal fixation in elderly patients with intertrochanteric femoral fractures is one of the major causes of reduced quality of life and increased mortality risk, reducing the failure rate of PFNA internal fixation remains a key challenge in the surgical treatment of fractures in older adults. Advanced age, AO type 3 fracture, concomitant diabetes, and poor reduction quality are independent risk factors affecting the outcomes of PFNA internal fixation in elderly patients with intertrochanteric femoral fractures. For elderly intertrochanteric femoral fractures, improving the ability to screen for risk factors and implementing individualized treatment plans are important measures for increasing surgical success rates and improving patient prognosis. The results of this study showed that the nomogram prediction model constructed on the basis of these four risk factors had good discrimination and calibration, and can be used for rapid preoperative identification of high-risk patients and to assist in formulating individualized treatment strategies, thereby reducing the surgical failure rate and improving prognosis. This study was a single-center retrospective study; the sample source was limited, and selection bias may have been present. The analytical variables included did not cover imaging parameters that may affect the outcomes of PFNA internal fixation, such as bone mineral density T-score, Singh index, lateral wall thickness, and posterior tilt angle; therefore, residual confounding may exist. Further systematic studies are still needed to validate the model's generalizability in external independent cohorts.

Author Contributions

Conceptualization, LGS and FKQ; methodology, LGS; software, GHM; validation, LGS, FKQ, and WXF; formal analysis, GHM; investigation, FKQ and GHM; resources, LGS; data curation, WXF; writing—original draft preparation, WXF; writing—review and editing, LGS; visualization, GHM; supervision, LGS; project administration, FKQ; funding acquisition, LGS. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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