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Original Article

Identification of risk factors and development of a high-performance predictive model for non-healing in elderly patients with intertrochanteric fractures post-internal fixation

Jianyue Wu[1*], Peng Xu[1*], Dong Zhang[1], Yingjie Ni[1], Jijun Zhao[2]

[1]Department of Orthopedics, Wuxi Xishan People's Hospital, Wuxi 214015, Jiangsu, China; [2]Department of Orthopedics, Wuxi People's Hospital, Wuxi 214023, Jiangsu, China. [*]Equal contributors and co-first authors.

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Abstract: Objective: To identify risk factors associated with non-healing in elderly patients with intertrochanteric femoral fractures treated with internal fixation and to develop a predictive model for non-union risk. Methods: We conducted a retrospective analysis of 889 elderly patients treated with internal fixation for intertrochanteric fractures at Wuxi Xishan People's Hospital from March 2021 to December 2024. Patients were classified into healing (n=806) and poor healing groups (n=83) based on radiographic evidence three months post-surgery. Univariate and multivariate logistic regression analyses were used to identify significant risk factors. A predictive model was developed and validated using receiver operating characteristic (ROC) analysis and the area under the curve (AUC). Results: Significant risk factors for poor healing included smoking history (Odds ratio [OR] 1.750, P=0.022), osteoporosis (OR 2.055, P=0.003), posterior or medial wall bone defects (OR 1.964, P=0.005), low postoperative albumin (OR 1.674, P=0.032), and early weight-bearing (OR 1.765, P=0.018). The use of proximal femoral nail antirotation (PFNA) significantly reduced the risk of poor-healing (OR 0.515, P=0.006). The combined predictive model achieved an AUC of 0.949, indicating high predictive value. Conclusions: Our findings highlight key risk factors for non-healing in elderly patients post-internal fixation for intertrochanteric fractures. The developed predictive model, incorporating clinical, biochemical, and surgical factors, offers high accuracy and may help identify high-risk patients for targeted intervention.

Keywords: Intertrochanteric fractures, internal fixation, non-healing risk factors, elderly patients, predictive model, orthopedic surgery

Introduction

Intertrochanteric fractures, occurring between the femur's greater and lesser trochanters, pose a significant threat to elderly patients, with high rates of morbidity and mortality [1]. These fractures account for approximately half of all hip fractures in this age group [2]. As life expectancy increases and the elderly population grows worldwide, the incidence of these fractures is expected to rise [3]. This trend underscores the need for better management strategies for post-surgical care [4].

Internal fixation using devices such as dynamic hip screws (DHS) or intramedullary nails is the standard treatment [5]. The goal of surgery is to restore mobility and function. However, some patients experience non-healing or delayed healing after the procedure [6, 7]. Non-healing refers to the failure of the fracture to unite within an expected timeframe, resulting in prolonged immobility, persistent pain, and an increased risk of complications such as non-union or implant failure [8]. Identifying the causes of non-healing is crucial for improving patient outcomes [9].

Previous studies have identified several factors that may contribute to non-healing in elderly patients following internal fixation for intertrochanteric fractures [10, 11]. These patient-spe-

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cific factors significantly influence the body's response to injury and healing [12].

Fracture-related factors, such as fracture type, displacement of bone fragments, and the degree of comminution, are important for determining the stability of fixation and the biological conditions required for healing [13, 14]. Treatment-related factors, including the choice of fixation device, timing of surgery, and the surgeon's skill, also play a crucial role in healing outcomes [15].

While these risk factors are known, there is a lack of well-established models to predict which patients are most likely to experience non-healing after surgery [15]. Developing such models requires a comprehensive analysis of how these risk factors interact and influence patient outcomes [16]. Advances in statistics and machine learning offer promising opportunities to create robust predictive tools that could greatly enhance clinical decision-making and individualized patient care [16].

Recent studies using predictive analytics in orthopedics have shown promising results, emphasizing the value of integrating various types of data into unified models [17]. These models may assist in identifying high-risk patients prior to surgery, enabling tailored approaches such as closer postoperative monitoring, enhanced nutritional support, or personalized rehabilitation plans. Testing these models on independent datasets is crucial to ensure their reliability across different clinical settings.

This study has two primary objectives: (1) to identify risk factors for non-healing in elderly patients following internal fixation for intertrochanteric fractures, and (2) to develop and validate a predictive model based on these factors. By systematically examining the variables associated with non-healing, this research aims to contribute to existing knowledge and provide clinicians with a practical tool to mitigate the risks of non-healing.

Materials and methods

Research design and participants

A retrospective analysis was conducted on elderly patients who underwent internal fixation for intertrochanteric femoral fractures at Wuxi Xishan People's Hospital between March 2021 and December 2024. Patients were classified into two groups based on their healing status three months after surgery: a poor healing group (n=83) and a healing group (n=806). Fractures were classified as poorly healed if X-ray images showed visible fracture lines, breakage of fixation devices, misalignment of fractures, or loosening or detachment of the plate from the bone shaft, all indicative of inadequate bone healing.

Approval for this study was granted by the Institutional Review Board of Wuxi Xishan People's Hospital. Basic patient information was obtained from the hospital's electronic case records. Since the study involved de-identified patient data, informed consent was waived, with this exemption approved by the hospital's Ethics Review Committee. Data collection and analysis followed ethical guidelines set by the hospital's ethics committee.

Selection criteria

Inclusion criteria were as follows: (1) Initial diagnosis of intertrochanteric femoral fractures confirmed through imaging; (2) Underwent internal fixation surgery for these fractures at our hospital; (3) Aged 65 years or older; (4) Availability of complete clinical data.

Exclusion criteria included: (1) Severe organ dysfunction (heart, lung, liver, or kidney); (2) Lower limb paralysis or sensory and motor impairments; (3) Loss to follow-up after surgery or incomplete follow-up; (4) Mental illness or inability to communicate normally or complete assessments.

Data collection

Baseline data were collected from the hospital's case management system, including gender, age, body mass index (BMI), fracture type, and underlying conditions such as diabetes mellitus, hypertension, and osteoporosis. Additional socioeconomic data, including ethnicity, educational level, and monthly household income, were also gathered.

Blood samples (5 ml) were collected before and after surgery. Hemoglobin and albumin levels were measured using an automated blood analyzer (Sysmex XN-1000, Japan). C-reactive protein (CRP) and interleukin-6 (IL-6) levels were assessed using an IMMAGE Immunoassay System (Beckman Coulter, USA). Vitamin D levels were measured with a Waters ACQUITY UPLC System linked to a Xevo TQ-S tandem mass spectrometer (Waters Corporation, USA).

Grading criteria

Fracture alignment was assessed using the Garden alignment index, based on angles observed in both anteroposterior and lateral X-rays [18]. Fracture stability was classified using the Arbeitsgemeinschaft für Osteosynthesefragen (AO)/Orthopaedic Trauma Association (OTA) system [19]. Stable fractures were classified as A1.1 to A2.1, while highly unstable fractures were categorized as A2.2 to A3.3.

Preoperative health status was evaluated using the American Society of Anesthesiologists (ASA) physical status classification [20]. ASA I patients were healthy individuals with no coexisting conditions, while ASA II patients had mild systemic disease without functional limitations. ASA III patients had moderately severe systemic disease with restricted activity, and ASA IV patients had severe disease with poor cardiopulmonary function, indicating a moribund state. No ASA V patients were included in this study.

Psychological and cognitive assessments

Several standardized tools were used to assess mental health and cognitive function. The Conners' Parent Symptom Questionnaire (PSQ) measured anxiety and behavioral problems, with higher scores indicating more severe issues. The Stroop Color-Word Interference Test assessed attentional inhibitory control, with lower scores reflecting better performance. The Wisconsin Card Sorting Test (WCST) evaluated executive function and adaptability to changing rules. The Alternate Uses Task measured cognitive flexibility and creativity by asking participants to suggest alternative uses for common objects. The Pittsburgh Sleep Quality Index (PSQI) assessed sleep quality, with higher scores indicating poorer sleep. These assessments were conducted preoperatively to explore associations with surgical healing outcome.

Statistical analysis

Statistical analysis was performed using SPSS software (version 24.0). Categorical variables were reported as percentages and frequencies, and comparisons were made using the χ^2 test. Continuous variables were assessed for normality using the Shapiro-Wilk test; those conforming to a normal distribution were expressed as means ± standard deviations (X ± sd), and group comparisons were performed using independent samples t-tests. Logistic regression was used to identify factors influencing nonunion following internal fixation for intertrochanteric femoral fractures. Receiver operating characteristic (ROC) curves were constructed, and the area under the curve (AUC) was calculated to evaluate the predictive accuracy of the risk model. An AUC greater than 0.9 indicates high accuracy, between 0.71 and 0.90 suggests moderate accuracy, and between 0.5 and 0.7 signifies poor accuracy. Additionally, Decision Curve Analysis (DCA), calibration curves, and a nomogram were developed to assess the clinical utility and predictive performance of the model. Statistical significance was defined as a *P*-value <0.05. The goodness-of-fit for the risk model was evaluated using the Hosmer-Lemeshow test, where a *P*-value >0.05 indicates adequate model fit.

Results

Comparison of demographic and basic data

A total of 889 elderly patients with intertrochanteric fractures who underwent internal fixation surgery were analyzed to identify risk factors associated with poor healing (**Table 1**). No significant differences were observed between the two groups in terms of gender distribution, age, BMI, ethnicity, hypertension, hyperlipidemia, educational level, or monthly household income per person (all P>0.05). However, certain factors were significantly associated with poor healing outcomes. Specifically, a higher prevalence of a smoking history (P=0.014) and diabetes mellitus (P=0.046) were observed in the poor healing group. Additionally, osteoporosis was more common in the poor healing group compared to the healing group (P=0.003).

Comparison of fracture characteristics

No significant differences were found between the healing and poor healing groups regarding

Table 1. Comparison of baseline data of patients

Data	Healing group (n=806)	Poor healing group (n=83)	t/x²	P
Gender [n (%)]			0.088	0.767
Male	365 (45.29%)	39 (46.99%)		
Female	441 (54.71%)	44 (53.01%)		
Age (years)	68 ± 6	69 ± 6	1.028	0.304
Ethnicity (Han/Other) [n (%)]	742 (92.06%)	77 (92.77%)	0.053	0.819
BMI (kg/m²)	20.29 ± 6.43	19.61 ± 3.54	1.512	0.133
Smoking History [n (%)]	381 (47.27%)	51 (61.45%)	6.053	0.014
Diabetes Mellitus [n (%)]	383 (47.52%)	49 (59.04%)	3.996	0.046
Hypertension [n (%)]	445 (55.21%)	50 (60.24%)	0.772	0.380
Hyperlipidemia [n (%)]	438 (54.34%)	49 (59.04%)	0.669	0.413
Osteoporosis [n (%)]	329 (40.82%)	48 (57.83%)	8.917	0.003
Educational level [n (%)]			0.012	0.912
High school or below	539 (66.87%)	56 (67.47%)		
Junior college or above	267 (33.13%)	27 (32.53%)		
Monthly household income/person [n (%)]			0.033	0.855
<5000	448 (55.58%)	47 (56.63%)		
≥5000	358 (44.42%)	36 (43.37%)		

BMI: Body Mass Index.

Table 2. Comparison of fracture characteristics of patients

Data	Healing group (n=806)	Poor healing group (n=83)	t/x²	P
Fracture Type [n (%)]			0.303	0.582
Stable	414 (51.36%)	40 (48.19%)		
Unstable	392 (48.64%)	43 (51.81%)		
Garden Alignment Index [n (%)]			1.352	0.245
Ideal	423 (52.48%)	38 (45.78%)		
Non-ideal	383 (47.52%)	45 (54.22%)		
Posterior or Medial Wall Bone Defect [n (%)]	296 (36.72%)	44 (53.01%)	8.452	0.004
Cause of Fracture [n (%)]			1.175	0.556
Traffic Accident	262 (32.51%)	29 (34.94%))		
Fall from Height	240 (29.78%)	20 (24.10%)		
Fall	304 (37.72%)	34 (40.96%)		
AO/OTA [n (%)]			0.382	0.536
A1.1-A2.1	418 (51.86%)	46 (55.42%)		
A2.2-A3.3	388 (48.14%)	37 (44.58%)		
ASA score [n (%)]			0.005	0.943
I/II	314 (38.96%)	32 (38.55%)		
III/IV	492 (61.04%)	51 (61.45%)		
Time to Weight Bearing (d)			5.182	0.023
≤15	409 (50.74%)	53 (63.86%)		
>15	397 (49.26%)	30 (36.14%)		

AO/OTA: Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; ASA: American Society of Anesthesiologists.

fracture type (P=0.582), Garden Alignment Index (P=0.245), cause of fracture (P=0.556), AO/OTA classification (P=0.536), or ASA score (P=0.943) (**Table 2**). However, significant differ-

Table 3. Comparison of blood test indicators [n (%)]

Index	Healing group (n=806)	Poor healing group (n=83)	t/x^2	P
Preoperative Hemoglobin (g/L)			0.051	0.822
<110	446 (55.33%)	47 (56.63%)		
≥110	360 (44.67%	36 (43.37%)		
Preoperative Albumin (g/L)			6.385	0.012
≤30	285 (35.36%)	41 (49.4%)		
>30	521 (64.64%)	42 (50.6%)		
Preoperative CRP (mg/L)	3.76 ± 1.51	4.23 ± 2.14	1.927	0.057
Preoperative IL-6 (pg/mL)	12.45 ± 3.52	13.32 ± 4.25	1.807	0.074
Preoperative Vitamin D Level (ng/mL)	23.21 ± 8.55	21.87 ± 7.32	1.378	0.168
Postoperative Hemoglobin (g/L)			3.524	0.060
<110	566 (70.22%)	50 (60.24%)		
≥110	240 (29.78%)	33 (39.76%)		
Postoperative Albumin (g/L)			6.149	0.013
≤30	278 (34.49%)	40 (48.19%)		
>30	528 (65.51%)	43 (51.81%)		
Postoperative CRP (mg/L)	2.73 ± 1.14	3.05 ± 1.53	1.856	0.067
Postoperative IL-6 (pg/mL)	10.55 ± 2.86	11.31 ± 3.91	1.718	0.089
Postoperative Vitamin D Level (ng/mL)	22.15 ± 8.23	20.76 ± 7.18	1.479	0.140

CRP: C-reactive Protein; IL-6: Interleukin-6.

ences were noted for posterior or medial wall bone defects and time to weight bearing. A higher proportion of patients in the poor healing group had posterior or medial wall bone defects compared to the healing group (P=0.004). Additionally, the poor healing group showed a significantly greater proportion of patients who began weight bearing within 15 days post-surgery (P=0.023).

Comparison of blood test indicators

The poor healing group exhibited a higher percentage of patients with preoperative albumin levels ≤30 g/L (P=0.012, χ^2=6.385) and postoperative albumin levels ≤30 g/L (P=0.013, χ^2=6.149) compared to the healing group (**Table 3**). No significant differences were found in preoperative hemoglobin levels (P=0.822), postoperative hemoglobin levels (P=0.060), preoperative CRP (P=0.057), preoperative IL-6 (P=0.074), preoperative Vitamin D levels (P=0.168), postoperative CRP (P=0.067), postoperative IL-6 (P=0.089), or postoperative Vitamin D levels (P=0.140) between the two groups.

Comparison of surgical-related factors

The healing group had a higher percentage of patients treated with proximal femoral nail antirotation (PFNA) compared to the poor healing group, while the poor healing group had a higher proportion of patients treated with DHS (P=0.012) (**Table 4**). No significant differences were observed between the groups in terms of time from fracture to surgery (P=0.398), surgical time (P=0.132), or intraoperative blood loss (P=0.389).

Comparison of preoperative psychological and cognitive tests

The preoperative psychological and cognitive evaluations revealed some trends approaching statistical significance between the healing and poor healing groups (**Table 5**). Specifically, Stroop Test results showed a trend toward significance, with the poor healing group scoring slightly higher than the healing group (t=1.961, P=0.053). No significant differences were found for other measures: PSQ scores, WCST results, and Alternative Use Task performance showed no significant differences between the two groups.

Correlation analysis

The correlation analysis of various indicators identified several significant factors for nonunion after internal fixation in elderly patients

Table 4. Analysis of surgical related factors

Factor	Healing group (n=806)	Poor healing group (n=83)	t/x^2	P
Time from Fracture to Surgery (d)	2.30 ± 0.55	2.34 ± 0.42	0.849	0.398
Internal fixation method			6.317	0.012
PFNA	456 (56.58%)	35 (42.17%)		
DHS	350 (43.42%)	48 (57.83%)		
Surgical Time (h)	49.89 ± 5.60	50.65 ± 4.18	1.517	0.132
Intraoperative Blood Loss (ml)	125.61 ± 23.18	128.46 ± 29.07	0.866	0.389

PFNA: Proximal femoral nail antirotation; DHS: Dynamic hip screw.

Table 5. Comparison of preoperative psychological and cognitive evaluation of patients

Test	Healing group (n=806)	Poor healing group (n=83)	t	P
PSQ Score	13.08 ± 3.15	13.65 ± 3.24	1.570	0.117
Stroop Test Result	49.52 ± 6.31	51.17 ± 7.42	1.961	0.053
WCST results	22.13 ± 2.55	21.54 ± 3.14	1.661	0.100
Alternative Use Task Performance	78.32 ± 10.32	76.45 ± 11.24	1.558	0.120
PSQI Score	6.83 ± 2.21	7.27 ± 2.44	1.687	0.092

PSQ: Parent Symptom Questionnaire; WCST: Wisconsin Card Sorting Test; PSQI: Pittsburgh Sleep Quality Index.

Figure 1. Correlation analysis of various indicators with nonunion after internal fixation in elderly patients with intertrochanteric femoral fractures. PFNA: Proximal femoral nail antirotation; DHS: Dynamic hip screw.

with intertrochanteric femoral fracture (**Figure 1**). Smoking history (rho=0.083, P=0.014) and diabetes mellitus (rho=0.067, P=0.046) were positively correlated with nonunion. Osteopo-

Table 6. Univariate logistic regression analysis of risk factors

	Coefficient	Std Error	Wald	P	OR	CI Lower	CI Upper
Smoking History	0.575	0.236	2.435	0.015	1.778	1.125	2.849
Diabetes Mellitus	0.465	0.234	1.986	0.047	1.592	1.010	2.536
Osteoporosis	0.687	0.234	2.943	0.003	1.988	1.262	3.162
Posterior or Medial Wall Bone Defect	0.665	0.232	2.868	0.004	1.944	1.235	3.071
Preoperative Albumin (g/L) (≤30/>30)	0.539	0.239	2.256	0.024	1.715	1.081	2.768
Postoperative Albumin (g/L) (≤30/>30)	0.579	0.232	2.501	0.012	1.785	1.132	2.813
Time to Weight Bearing (d) (≤15/>15)	0.569	0.232	2.455	0.014	1.767	1.119	2.785
Internal fixation method	-0.580	0.233	2.487	0.013	0.560	0.352	0.882

Table 7. Multivariate logistic regression analysis of risk factors

	Coefficient	Std Error	Wald	P	OR	OR CI Lower	OR CI Upper
Smoking History	0.559	0.244	2.292	0.022	1.750	1.084	2.823
Diabetes Mellitus	0.432	0.243	1.779	0.075	1.541	0.957	2.480
Osteoporosis	0.720	0.241	2.992	0.003	2.055	1.282	3.294
Posterior or Medial Wall Bone Defect	0.675	0.239	2.818	0.005	1.964	1.228	3.140
Preoperative Albumin (g/L) (≤30/>30)	0.418	0.248	1.690	0.091	1.520	0.935	2.469
Postoperative Albumin (g/L) (≤30/>30)	0.515	0.240	2.150	0.032	1.674	1.047	2.678
Time to Weight Bearing (d) (≤15/>15)	0.568	0.241	2.361	0.018	1.765	1.101	2.829
Internal fixation method	-0.664	0.242	-2.748	0.006	0.515	0.321	0.827

rosis (rho=0.100, P=0.003) and posterior or medial wall bone defects (rho=0.098, P=0.004) also demonstrated positive correlations with nonunion. Nutritional status, indicated by albumin levels, showed that low preoperative (≤30 g/L) and postoperative albumin levels were correlated with nonunion (rho=0.076, P=0.023; rho=0.085, P=0.011, respectively). Additionally, early weight bearing (≤15 days) correlated positively with nonunion (rho=0.083, P=0.013). Conversely, the choice of internal fixation method showed a negative correlation with nonunion (rho=-0.084, P=0.012). These results highlight several clinical and surgical factors significantly associated with nonunion risk in the studied population.

Univariate logistic regression analysis

The univariate logistic regression analysis identified several significant risk factors for non-healing in elderly patients with intertrochanteric fractures following internal fixation surgery (**Table 6**). Smoking history was associated with an increased odds of non-healing, with an odds ratio (OR) of 1.778 (P=0.015). Similarly, diabetes mellitus was significantly associated with non-healing, with an OR of 1.592 (P=0.047). Osteoporosis was a strong predictor, with an OR of 1.988 (P=0.003). The presence of posterior or medial wall bone defects significantly increased the risk of non-healing, with an OR of 1.944 (P=0.004). Patients with preoperative albumin levels ≤30 g/L had higher odds of non-healing (P=0.024), as did those with postoperative albumin levels ≤30 g/L (P=0.012). Early weight-bearing (≤15 days) was also associated with increased odds of non-healing (P=0.014). In contrast, the use of PFNA was associated with reduced odds of non-healing (P=0.013), suggesting it has a protective role against nonunion.

Multivariate logistic regression analysis

The multivariate logistic regression analysis identified several independent risk factors significantly associated with non-healing in elderly patients with intertrochanteric fracture post-internal fixation surgery (**Table 7**). Smoking history remained a significant risk factor, with an OR of 1.750 (P=0.022). Osteoporosis emerged as a strong predictor, with an OR of 2.055 (P=0.003). The presence of posterior or medial wall bone defects was also significantly associated with non-healing risk, with an OR of 1.964

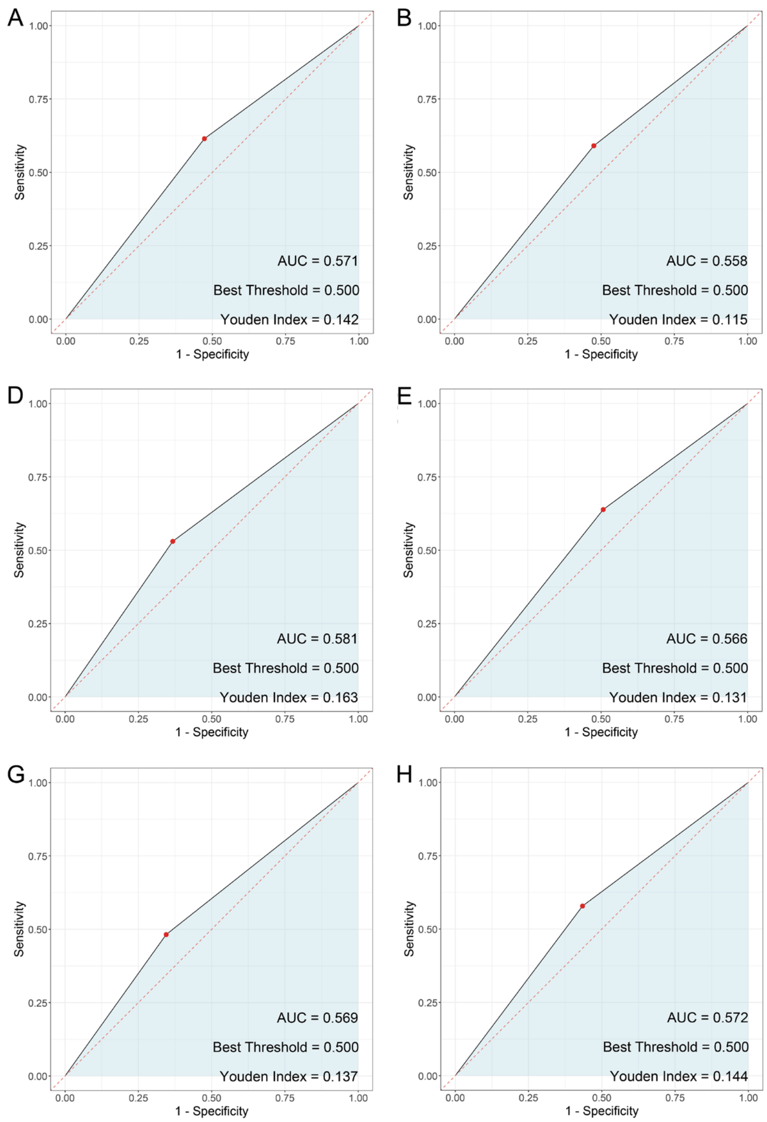

Figure 2. Predictive value of each index for non-union in elderly patients with intertrochanteric fracture after internal fixation. A. Smoking History; B. Diabetes Mellitus; C. Osteoporosis; D. Posterior or Medial Wall Bone Defect; E. Time to Weight Bearing (≤15 d/>15 d); F. Postoperative Albumin (≤30 g/L/>30 g/L); G. Postoperative Hemoglobin (≤30 g/L/>30 g/L); H. Internal fixation method.

(P=0.005). While preoperative albumin levels showed a trend towards significance, postoperative albumin levels ≤30 g/L were significantly associated with non-healing (P=0.032). Early weight bearing (≤15 days) was associated with an increased risk of non-healing (P=0.018). Conversely, the use of a PFNA significantly reduced the likelihood of non-healing, with an OR of 0.515 (P=0.006). Diabetes mellitus (P=0.075) and preoperative albumin levels (P=0.091) did not reach statistical significance in this multivariate analysis, indicating that their effects may be confounded by other variables in the model. These findings emphasize the importance of managing targeted risk factors to optimize patient outcome.

ROC analysis

The analysis of predictive values for non-union in elderly patients with intertrochanteric fractures following internal fixation surgery highlights variable predictive capabilities among different factors (**Figure 2**). Osteoporosis demonstrated the highest sensitivity (0.578) and a specificity of 0.592, with an AUC of 0.585, indicating moderate discrimination between healing outcomes. Posterior or medial wall bone defects exhibited a specificity of 0.633 and sensitivity of 0.530, with an AUC of 0.581. Smoking history, diabetes mellitus, and preoperative albumin levels displayed similar predictive performance, with AUCs of 0.571, 0.558,

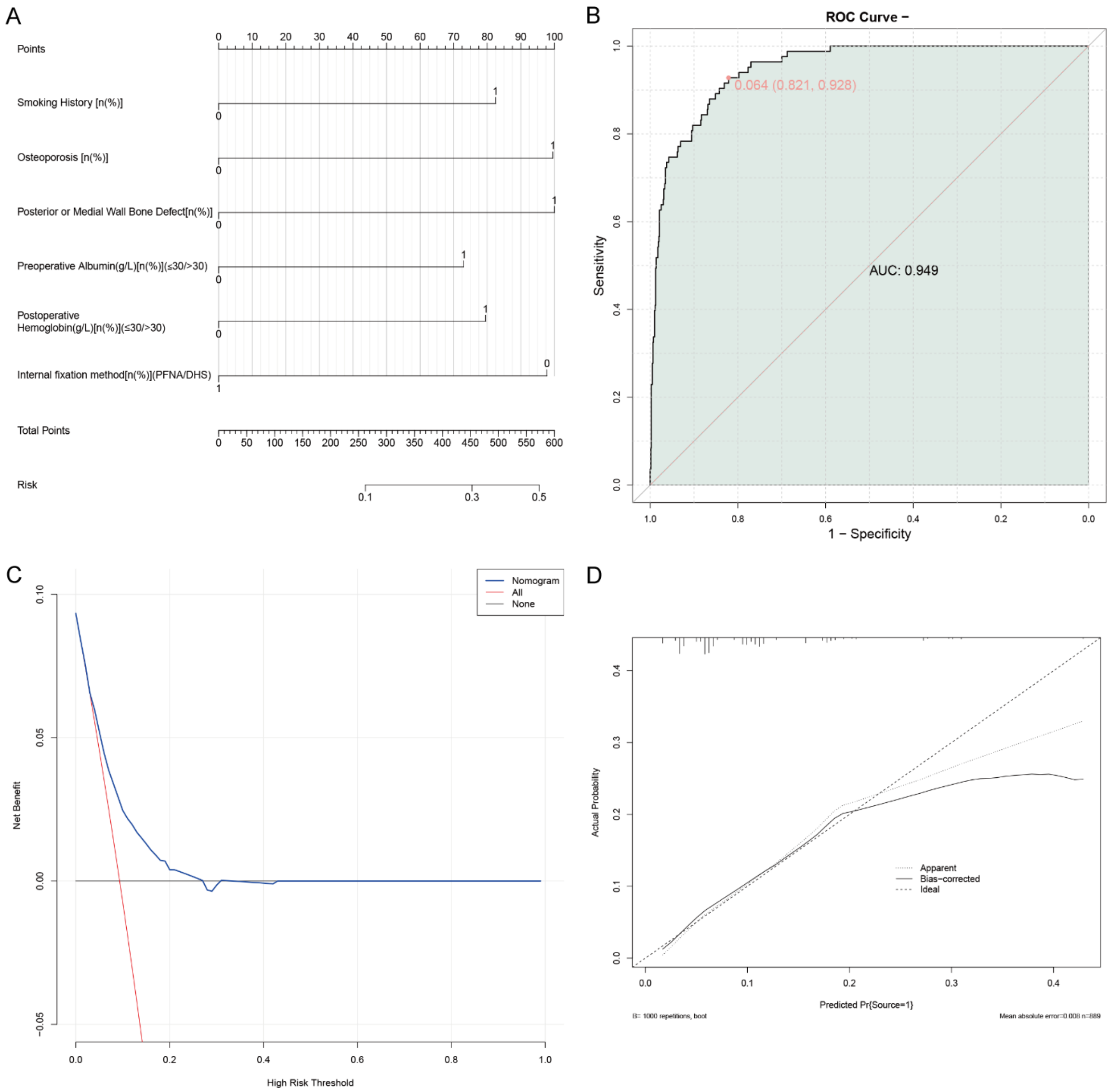

Figure 3. The joint prediction model for non-union in elderly patients following internal fixation for intertrochanteric femoral fractures. A. Nomogram; B. Joint ROC Curve; C. DCA; D. Calibration Curves. ROC: receiver operator characteristic; AUC: area under the curve; DCA: Decision Curve Analysis.

and 0.566, respectively, and Youden indices indicating limited predictive separation. Postoperative albumin levels and time to weight-bearing also had moderate specificities (0.646 and 0.655, respectively), but lower sensitivities, yielding AUCs of 0.570 and 0.569. The internal fixation method revealed balanced sensitivity and specificity, with values of 0.578 and 0.566, respectively, and an AUC of 0.572. Overall, these indicators provide moderate predictive information, suggesting that a multifactorial approach is necessary for accurately predicting non-union risk. The F1 scores, particularly for osteoporosis (0.209) and bone defects (0.208), suggest a need for further refinement in predictive modeling to enhance clinical utility.

Joint prediction model

This study combined various risk factors affecting non-healing in elderly patients with intertrochanteric femoral fracture after internal fixation to construct a comprehensive predictive model for post-surgical non-union (**Figure 3**). The nomogram, based on multivariate regression analysis, accurately predicted individualized risk scores, with strong performance confirmed through internal validation. The model achieved an AUC of 0.949, indicating exceptional predictive value. The Decision Curve Analysis (DCA) demonstrated that our model provided a higher net benefit across a wide range of clinically relevant probability thresholds, suggesting that it can effectively identify high-risk patients. This allows clinicians to make informed decisions about targeted preventive intervention. Calibration curves showed excellent agreement between predicted probabilities and observed outcomes, confirming the model's reliability. Overall, these results affirm the robustness and clinical utility of our predictive model for post-surgical non-union.

Discussion

This study investigated risk factors for non-healing in elderly patients with intertrochanteric femoral fractures treated with internal fixation and developed a predictive model to identify patients at increased risk. Our results indicate that a history of smoking, osteoporosis, and posterior or medial wall bone defects are significantly associated with poor healing after surgery. These findings enhance our understanding of the factors that may compromise healing and underscore the importance of comprehensive management strategies for these patients.

The significant association between smoking and non-healing aligns with existing literature, which shows that smoking impairs bone healing [21, 22]. Cigarette toxinsincluding nicotine, disrupt osteoblast activity and reduce blood flow to the fracture site, hindering bone repair [22]. Smoking also impedes angiogenesis and reduces oxygen levels at the healing site, both of which are crucial for successful fracture repair [23]. Chronic smoking weakens the immune response, potentially delaying the early inflammatory phase that is essential for initiating healing [24]. Collectively, these effects emphasize the importance of smoking cessation as part of orthopedic care for improving healing outcomes.

Osteoporosis emerged as another significant predictor in our analysis. Characterized by reduced bone density and weakened bone structure, osteoporosis is a known contributor to fracture non-union [25]. The pathophysiology of osteoporosis involves an imbalance in bone remodeling, with increased osteoclast activity and decreased osteoblast function [26]. This imbalance leads to porous bone architecture and diminished mechanical stability, both of which are essential for successful fracture healing [27]. Additionally, the reduced osteogenic potential in osteoporotic bone can result in delayed callus formation and inferior callus quality, further complicating the healing process [28]. Pharmacologic management of osteoporosis, such as bisphosphonates to inhibit osteoclast-mediated bone resorption or newer anabolic treatments, may be beneficial in promoting fracture healing.

Our analysis also identified posterior or medial wall bone defects as significant factors contributing to poor healing outcome. The integrity of these bone walls is crucial for maintaining the stability and alignment of fracture fragments during the healing process [29]. Defects in these areas can compromise mechanical support and lead to increased micromovement at the fracture site, which impedes bone regeneration [30]. Biomechanically, stability during the initial inflammatory stage of bone healing is critical, as it sets the stage for subsequent repair and remodeling [31]. Addressing these defects surgically, using techniques such as bone grafting or reinforced fixation methods, may improve outcome by providing enhanced mechanical stability.

Moreover, our findings indicate that both preoperative and postoperative serum albumin levels are important indicators of nutritional status and correlate with healing outcome. Hypoalbuminemia, a marker of poor nutritional status, is critical for collagen synthesis, wound healing, and overall tissue regeneration [32]. Adequate nutrition supports cellular processes essential for healing, including osteogenic cell proliferation and effective immune function [33]. Therefore, optimizing nutrition through dietary interventions or supplementation, should be emphasized preoperatively and maintained throughout recovery to facilitate optimal healing.

Interestingly, early postoperative weight-bearing was identified as a risk factor for non-union. While early mobilization can reduce complications such as deep vein thrombosis and enhance physical conditioning, excessive loading on an unstable fracture can hinder bone healing [34]. This highlights the need for a balanced approach to postoperative management, where a tailored, patient-specific weight-bearing protocol is essential to ensure that movement does not compromise the integrity of the healing bone [35].

The type of internal fixation used during surgery also significantly affected healing. Our data showed that PFNA reduced the risk of non-union compared to DHS. The PFNA design provides better stability by controlling rotation and distributing force more effectively along the bone [36]. This enhanced stability likely explains the lower non-union rates observed with PFNA, suggesting that surgeons should carefully consider the fixation method and its ability to maintain bone stability when planning an operation.

Our predictive model, with a high AUC of 0.949, demonstrates that these risk factors collectively offer robust predictive value. The model's high predictive accuracy reinforces the concept that fracture healing is multifactorial, with clinical, biochemical, and surgical factors all contributing to the risk of non-union. Implementing this model in clinical practice may help identify high-risk patients earlier, allowing for timely interventions based on each patient's specific risks and potentially improving outcome.

While this study provides valuable insights, its limitations must be acknowledged. The retrospective nature of the analysis may have overlooked factors not captured in the data. Future research should involve larger, prospective studies tracking patients over time to validate these findings. Such studies could also investigate additional factors, such as genetic markers or specific surgical techniques, to further refine the model.

In conclusion, our research illustrated that several modifiable and non-modifiable risk factors significantly influence healing outcomes in elderly patients undergoing internal fixation for intertrochanteric femoral fracture. Key strategies to reduce the risk of non-healing include smoking cessation, osteoporosis management, optimal surgical technique selection, and ensuring adequate nutrition. These interventions are crucial for improving both functional outcomes and quality of life in these vulnerable patients. Further advancements in predictive models will enable more personalized care, ultimately enhancing surgical success.

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Disclosure of conflict of interest

None.

Address correspondence to: Jijun Zhao, Department of Orthopedics, Wuxi People's Hospital, No. 299 Qingyang Road, Wuxi 214023, Jiangsu, China. E-mail: zhaojijun2024@126.com

References

[1] Zhang J, Fan X, Zheng Y, Wu J and Yuan X. Intravenous application of tranexamic acid in intramedullary nailing for the treatment of geriatric intertrochanteric fractures: a systematic review and meta-analysis. BMC Musculoskelet Disord 2023; 24: 614.

[2] Yang F, Li X, Zhao L and Yang Q. Dual-screw versus single-screw cephalomedullary nails for intertrochanteric femoral fractures: a systematic review and meta-analysis. J Orthop Surg Res 2023; 18: 607.

[3] Yalın M, Golgelioglu F and Key S. Intertrochanteric femoral fractures: a comparison of clinical and radiographic results with the proximal femoral intramedullary nail (PROFIN), the anti-rotation proximal femoral nail (A-PFN), and the InterTAN Nail. Medicina (Kaunas) 2023; 59: 559.

[4] Xie W, Shi L, Zhang C, Cui X, Chen X, Xie T, Zhang S, Chen H and Rui Y. Anteromedial cortical support reduction of intertrochanteric fractures-a review. Injury 2024; 55: 111926.

[5] Wang H, Chen M, Wu Y and Ge J. 3D printing in intertrochanteric fractures of the femur. Minerva Pediatr (Torino) 2023; 75: 627-629.

[6] Tang Y, Wang D, Wang L, Xiong W, Fang Q, Lin W and Wang G. The PFNA in treatment of intertrochanteric fractures with or without lateral wall fracture in elderly patients: a retrospective cohort study. Eur J Med Res 2023; 28: 380.

[7] T J and Kwek EBK. Are intertrochanteric fractures evolving? Trends in the elderly population over a 10-year period. Clin Orthop Surg 2022; 14: 13-20.

[8] Sniderman J, Vivekanantha P, Shah A, Safir O, Wolfstadt J and Kuzyk P. Hemiarthroplasty for unstable intertrochanteric hip fractures: a matched cohort study. J Arthroplasty 2023; 38: 1522-1527.

[9] Sivakumar A, Rickman M and Thewlis D. Gait biomechanics after proximal femoral nailing of intertrochanteric fractures. J Orthop Res 2023; 41: 862-874.

[10] Sekimura T, Son SJ and Lee C. Reverse obliquity intertrochanteric femur fractures: technical tips to avoid failure. J Orthop Trauma 2023; 37: S19-S25.

[11] Schroeder JD, Turner SP and Buck E. Hip fractures: diagnosis and management. Am Fam Physician 2022; 106: 675-683.

[12] Rincón-Hoyos JA, Gómez-Ramírez JF, Cuesta-Montoya JS, Lara-Garavito AM, Muñoz-Medina SE and Castro-Dangond AJ. Treatment of intertrochanteric fractures using cephalomedullary nail: one or two cephalic screws? Injury 2023; 54 Suppl 6: 110625.

[13] Ricci WM. Stability of intertrochanteric femur fractures. J Orthop Trauma 2023; 37: S1-S4.

[14] Parikh K, Kandemir U and Agarwal A. Intertrochanteric hip fractures: pearls and pitfalls in managing difficult fractures. Instr Course Lect 2023; 72: 375-387.

[15] Nherera L, Trueman P, Horner A, Watson T and Johnstone AJ. In reply to the letter to the editor regarding "Comparison of a twin interlocking derotation and compression screw cephalomedullary nail (InterTAN) with a single screw derotation cephalomedullary nail (proximal femoral nail antirotation): a systematic review and meta-analysis for intertrochanteric fractures". J Orthop Surg Res 2022; 17: 354.

[16] Morrison J and Morrison M. Management of hip fractures. Crit Care Nurs Clin North Am 2024; 36: 575-584.

[17] Mayor J, Birgel V, Clausen JD, Aktas G, Sehmisch S, Einfeldt AK, Giannoudis V, Abdelaal AHK and Liodakis E. Lessons learned from biomechanical studies on cephalomedullary nails for the management of intertrochanteric fractures. A scoping review. Injury 2024; 55: 111180.

[18] Garden RS. Stability and union in subcapital fractures of the femur. J Bone Joint Surg Br 1964; 46: 630-647.

[19] Gu J, He S and Wang L. Analysis of one-year postoperative mortality and risk factors of elderly patients with intertrochanteric fractures after PFNA. Niger J Clin Pract 2022; 25: 1557-1562.

[20] Fjeld A, Fülling T, Bula P and Bonnaire F. Functional outcomes and perceived quality of life following fixation of femoral neck fractures in adults from 18 to 69 years using dynamic hip screw (DHS) and an additional anti-rotation screw- a retrospective analysis of 53 patients after a mean follow-up time of 4 years. Eur J Trauma Emerg Surg 2022; 48: 1893-1903.

[21] Matsubara T, Soma K, Yamada I, Fujita H, Yoshitani J, Oka H, Okada H and Tanaka S. Offset nail fixation for intertrochanteric fractures improves reduction and lag screw position. PLoS One 2022; 17: e0276903.

[22] Maffulli N and Aicale R. Proximal femoral fractures in the elderly: a few things to know, and some to forget. Medicina (Kaunas) 2022; 58: 1314.

[23] Lu Y, Huang Q, Xu Y, Ren C, Sun L, Dong W, Li M, Xue H, Li Z, Zhang K, Ma T and Wang Q. Predictors of long-term mortality after intertrochanteric fractures surgery: a 3-year retrospective study. BMC Musculoskelet Disord 2022; 23: 472.

[24] Liu D, Yu X, Chen L and Wang Z. Ipsilateral femoral neck, intertrochanteric and acetabular fractures with posterior dislocation of the hip: a case report and literature review. Medicine (Baltimore) 2023; 102: e36275.

[25] Liao CS, He FZ, Li XY and Han PF. Proximal femoral nail antirotation versus InterTan nail for the treatment of intertrochanteric fractures: a systematic review and meta-analysis. PLoS One 2024; 19: e0304654.

[26] Li H, Wang D, Zhang W, Xu G, Xu C, Zhang H, Zhang L, Li J and Tang P. Does computer-assisted orthopaedics system (ADAPT system) improve outcomes of intertrochanteric hip fractures? Injury 2023; 54: 1047-1054.

[27] Lähdesmäki M, Ylitalo AA, Karjalainen L, Uimonen M, Mattila VM and Repo JP. Intramedullary nailing of intertrochanteric femoral fractures in a level i trauma center in finland: what complications can be expected? Clin Orthop Relat Res 2024; 482: 278-288.

[28] Katsuyama Y, Okuda Y, Kanamura H, Sasaki K, Saito T and Nakamura S. Surgical versus conservative treatment of greater trochanteric fractures with occult intertrochanteric fractures: retrospective cohort study. Injury 2023; 54: 111055.

[29] Izawa Y, Futamura K, Murakami H, Shirakawa T, Nishida M, Baba T and Tsuchida Y. Risk factors for over-telescoping in reverse oblique intertrochanteric fractures. Eur J Orthop Surg Traumatol 2023; 33: 1101-1107.

[30] Huff S, Henningsen J, Schneider A, Hijji F, Froehle A and Krishnamurthy A. Differences between intertrochanteric and femoral neck fractures in resuscitative status and mortality rates. Orthop Traumatol Surg Res 2022; 108: 103231.

[31] Huang J and Wei Q. Comparison of helical blade versus lag screw in intertrochanteric fractures of the elderly treated with proximal femoral nail: a meta-analysis of randomized-controlled trials. Jt Dis Relat Surg 2022; 33: 695-704.

[32] Hongku N, Woratanarat P, Nitiwarangkul L, Rattanasiri S and Thakkinstian A. Fracture fixation versus hemiarthroplasty for unstable intertrochanteric fractures in elderly patients: a systematic review and network meta-analysis of randomized controlled trials. Orthop Traumatol Surg Res 2022; 108: 102838.
[33] Hantouly AT, Salameh M, Toubasi AA, Salman LA, Alzobi O, Ahmed AF and Ahmed G. The role of cerclage wiring in the management of subtrochanteric and reverse oblique intertrochanteric fractures: a meta-analysis of comparative studies. Eur J Orthop Surg Traumatol 2023; 33: 739-749.
[34] Green J, Watson JT, Shaheen P and Kuldjanov D. Geriatric intertrochanteric fractures: what is the optimal follow-up period? J Orthop Trauma 2023; 37: 557-561.
[35] Goodnough LH, Wadhwa H, Tigchelaar SS, DeBaun MR, Chen MJ, Graves ML and Gardner MJ. Indications for cement augmentation in fixation of geriatric intertrochanteric femur fractures: a systematic review of evidence. Arch Orthop Trauma Surg 2022; 142: 2533-2544.
[36] Duan W, Liang H, Fan X, Zhou D, Wang Y and Zhang H. Research progress on the treatment of geriatric intertrochanteric femur fractures with proximal femur bionic nails (PFBNs). Orthop Surg 2024; 16: 2303-2310.