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ORIGINAL ARTICLE

A prediction model for osteonecrosis of femoral head after internal fixation with multiple cannulated compression screws for adult femoral neck fractures

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Hip fractures usually occur due to traumatic factors, and may be further aggravated due to osteoporosis, leading to pathological fractures. Therefore, hip fractures have high mortality and disability rates, tremendously diminishing the patients' quality of life and increasing their social and medical burdens.[1-3] Femoral neck fractures are the most common form of hip fractures[4,5] and mostly treated by internal fixation with cannulated compression screws in the clinical practice.

As the aging of population accelerates worldwide, national public health systems face enormous

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ABSTRACT

Objectives: This study aims to investigate the high-risk factors for osteonecrosis of the femoral head (ONFH) after internal fixation with multiple cannulated compression screws for adult femoral neck fractures and to construct a prediction model.

Patients and methods: Between from January 2012 and December 2020, a total of 268 patients (138 males, 130 females; mean age: 53±10 years; range, 23 to 70 years) with ONFH who had complete follow-up data were included. Closed reduction in combination with open reduction were performed. All patients received internal fixation with multiple cannulated compression screws and were assigned to ONFH and non-ONFH groups. Logistic regression model was utilized to identify independent risk factors for postoperative ONFH, followed by constructing a nomogram prediction model. The predictive ability of the model was evaluated by receiver operating characteristic curve, Hosmer-Lemeshow test, and calibration curve.

Results: Multivariate analysis revealed that older age (odds ratio [OR]: 2.307, 95% confidence interval [CI]: 1.295-4.108], Charlson Comorbidity Index (CCI) ≥2 (OR: 2.214, 95% CI: 1.035-4.739), fracture displacement (OR: 2.426, 95% CI: 1.122-5.247), unsatisfactory reduction (OR: 2.629, 95% CI: 1.275-5.423), postoperative removal of internal fixation implant (OR: 2.200, 95% CI: 1.051-4.604) were independent risk factors for postoperative ONFH ($p<0.05$). The nomogram prediction model constructed based on these clinical characteristics showed high predictive value (AUC=0.807) and consistency ($p>0.05$).

Conclusion: Age, comorbidity index, fracture type, reduction quality and postoperative removal of internal fixation implant are of utmost importance for postoperative ONFH in patients with femoral neck fractures. The established nomogram prediction model can accurately predict the occurrence of postoperative ONFH.

Keywords: Femoral head, fracture, internal fixation, osteonecrosis, prediction model.

challenges in undertaking the burden of diseases associated with femoral neck fractures.[6,7] Osteonecrosis of the femoral head (ONFH) is regarded as one of the severe complications after surgery for femoral neck fractures. Owing to special anatomical structures and blood supply characteristics of the femoral neck and femoral head, ONFH shows an incidence rate of about 10 to 30% among all patients receiving femoral neck fracture surgery.[8] Previous studies have suggested that clinical factors such as reduction quality and fracture type have a strong relevance to the occurrence of postoperative ONFH.[9] Nonetheless, there have been rare reports concerning clinical prediction models that integrate multiple predictors.

In the present study, we aimed to investigate the high-risk factors for ONFH after internal fixation with multiple cannulated compression screws for adult femoral neck fractures and to construct a corresponding nomogram prediction model.

PATIENTS AND METHODS

This single-center, case-control study was conducted at Yangxian People's Hospital, Department of Orthopedics between January 2012 and December 2020. The clinical data of patients with femoral neck fractures who underwent internal fixation with multiple cannulated compression screws were included. Inclusion criteria were as follows: *(i)* patients aged ≥18 years old, *(ii)* those who met the diagnostic criteria for femoral neck fractures in the Guidelines for Diagnosis and Treatment of Adult Femoral Neck Fractures formulated by the Orthopaedic Traumatology Group of the Orthopaedic Branch of the Chinese Medical Association, and *(iii)* those who signed the informed consent form. Exclusion criteria were as follows: *(i)* patients with pathological fractures, *(ii)* those with severe heart, lung, liver or kidney insufficiency, *(iii)* those with malignancy or severe hematological diseases, *(iv)* those with bilateral femoral neck fractures, *(v)* those with excessive alcohol consumption for a long time or long-term use of glucocorticoids, *(vi)* those who had complications such as nonunion and implant failure, and *(vii)* those with ONFH diagnosed by computed tomography scan. Finally, a total of 290 patients were found to be eligible for the study, of whom 268 (138 males, 130 females; mean age: 53±10 years; range, 23 to 70 years) were followed, with a follow-up completion rate of 92.4%. In terms of the Garden's classification, there were 13 patients of type 1, 114 patients of type 2, 101 patients of type 3 and 40 patients of type 4.

Treatment protocol

All patients were operated on the orthopedic traction bed. First, the patients were treated with closed reduction under general anesthesia or epidural anesthesia, and the effect was confirmed by fluoroscopy using a C-arm X-ray machine. If the fractured bone was well aligned, positioning guide needles were inserted into 3 to 5 cm below the greater trochanter of the femur, and 3 to 4 cannulated compression screws were placed along the guide needles. If closed reduction failed, open reduction and internal fixation were conducted. Specifically, a posterolateral incision (about 12 cm) was made along the affected hip joint, followed by layer-by-layer cutting and separation to fully expose the posterior joint capsule. Next, the joint capsule was cut open and the reduction was performed under direct vision. After achieving satisfactory fracture reduction, screws were placed using the method described above. Finally, the incision was rinsed and sutured layer by layer.

After surgery, all patients received routine functional exercise and regular outpatient review or telephone follow-up. The patient's recovery conditions and complications were evaluated by X-ray re-examination, and the follow-up lasted for about 3.5 (range, 1 to 9) years.

Outcome measures

1. *Clinical measures:* Patient's age, sex, comorbidity and fracture type were observed and compared. Comorbidity was evaluated using the Charlson Comorbidity Index (CCI).[10]
2. *Reduction quality:* Garden's alignment index was applied for evaluation:[11] Grade 1 (excellent): 160° on anteroposterior view and 180° on lateral view, Grade 2 (good): 155° to 180° on anteroposterior view and 155° to 180° on lateral view, Grade 3 (fair): <155° on anteroposterior view or >180° on lateral view, and Grade 4 (poor): <155° on anteroposterior view and >180° on lateral view. By and large, Grade 1-2 represented satisfactory reduction, while Grade 3-4 indicated unsatisfactory reduction.
3. *ONFH:* ONFH was diagnosed according to the corresponding criteria in the Standards for Clinical Diagnosis and Treatment of Femoral Head Necrosis formulated by the Joint Surgery Group of the Orthopaedic Branch of the Chinese Medical Association. X-ray findings of ONFH were described as follows: necrotic focus was surrounded by sclerotic band, showing segmental collapse and crescent sign,

and femoral head collapse was present, but joint space was maintained.[12]

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 19.0 (IBM Corp., Armonk, NY, USA) and R version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria) software. Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. Categorical variables were analyzed using the chi-square test (χ^2). Logistic regression model was employed for multivariate analysis, and the correlations between clinical features and postoperative ONFH were assessed using the odds ratio (OR) and 95% confidence interval (CI). The rms package of R software was applied to construct a nomogram prediction model, and the predictive ability of the model was evaluated by receiver operating characteristic (ROC) curve, followed by calculating the area under the curve (AUC). The Hosmer-Lemeshow test[13] and calibration curve were used to validate the predictive consistency of the model. A p value of <0.05 was considered statistically significant.

RESULTS

Clinical factors influencing occurrence of postoperative ONFH

Among 268 patients with femoral neck fractures, 41 patients developed ONFH after surgery.

TABLE I
Clinical factors influencing occurrence of postoperative ONFH

Clinical factor	ONFH group (n=41)		Non-ONFH group (n=227)		χ^2/t	p
	n	%	n	%		
Age (year)						
<40	5	12.2	51	22.5		
40-60	16	39.0	132	58.1	16.621	<0.001
>60	20	48.8	44	19.4		
Sex						
Male	18	43.9	120	52.9	1.116	0.291
Female	23	56.1	107	47.1		
Charlson Comorbidity Index						
0-1	24	58.5	174	76.7	5.906	0.015
≥2	17	41.5	53	23.3		
Fracture type						
No displacement	11	26.8	116	51.1	8.206	0.004
Displacement	30	73.2	111	48.9		
Reduction quality						
Satisfactory	18	43.9	152	67.0	7.960	0.005
Unsatisfactory	23	56.1	75	33.0		
Weight-bearing time (month)						
<3	10	24.4	41	18.1		
3-6	23	56.1	101	44.5	4.497	0.034
>6	8	19.5	85	37.4		
Postoperative removal of internal fixation implant						
No	19	46.3	145	63.9	0.037	0.848
Yes	22	53.7	82	36.1		
Reduction method						
Open	16	39.02	142	62.56	0.037	0.848
Closed	25	60.98	85	37.44		
Number of screws						
3	22	53.66	89	39.21	2.989	0.084
4	19	46.34	138	60.79		

ONFH: osteonecrosis of the femoral head.

TABLE II
Results of multivariate analysis for predicting postoperative ONFH

Clinical factor	β-value	Standard error	Wald	OR	95% CI	*p*
Age	0.836	0.294	8.057	2.307	1.295-4.108	0.005
Charlson Comorbidity Index	0.795	0.388	4.194	2.214	1.035-4.739	0.041
Fracture type	0.886	0.394	5.071	2.426	1.122-5.247	0.024
Reduction quality	0.967	0.369	6.848	2.629	1.275-5.423	0.009
Postoperative removal of internal fixation implant	0.788	0.377	4.375	2.200	1.051-4.604	0.036

ONFH: Osteonecrosis of the femoral head; OR: Odds ratio; CI: Confidence interval.

Compared to those in non-ONFH group, patients in the ONFH group were significantly older (>60 years old: 48.8% *vs.* 19.4%) and had a relatively higher proportion of CCI ≥2 (41.5% *vs.* 23.3%), fracture displacement (73.2% *vs.* 48.9%), unsatisfactory reduction (56.1% *vs.* 33.0%) and postoperative removal of internal fixation implant (53.7% *vs.* 36.1%) ($p<0.05$). Sex and weight-bearing time showed no significant differences between the two groups ($p>0.05$) (Table I).

Multivariate analysis results of risk factors for postoperative ONFH

The aforementioned five clinical variables with significant correlations were incorporated into the logistic regression model and assigned as follows: age (<40 years old =1, 40 to 60 years old =2, >60 years old =3), CCI ("0-1" =1, "≥2" =2), fracture type (no displacement =1, displacement =2), reduction quality (satisfactory =1, unsatisfactory =2), and postoperative removal of internal fixation implant (No=1, Yes=2). Multivariate analysis revealed that advanced age (OR: 2.307, 95% CI: 1.295-4.108), CCI ≥2 (OR: 2.214, 95% CI: 1.035-4.739), fracture displacement (OR: 2.426, 95% CI: 1.122-5.247), unsatisfactory reduction (OR: 2.629, 95% CI: 1.275-5.423) and postoperative removal of internal fixation implant (OR: 2.200, 95% CI: 1.051-4.604) were independent risk factors for postoperative ONFH ($p<0.05$) (Table II).

Construction of prediction model for postoperative ONFH

In the light of multivariate analysis results, the aforementioned five independent risk factors were selected as predictors to construct a nomogram model for predicting the occurrence of postoperative ONFH in 268 patients with femoral neck fractures (Figure 1). Based on this model, all the patients were categorized into three risk groups: low-risk group (0-15 points, n=167) with an ONFH incidence rate of 4.2%, medium-risk group (16-26 points, n=81) with an

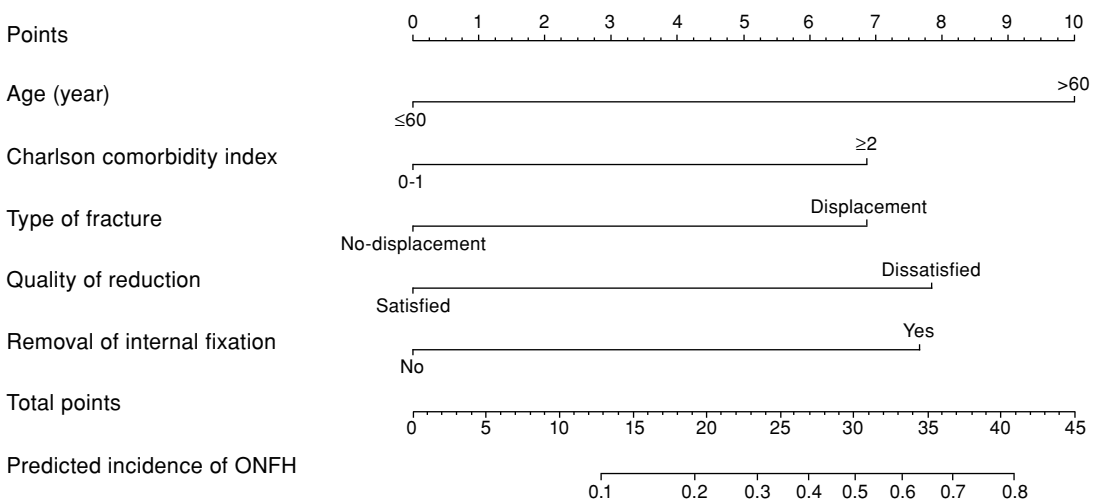

FIGURE 1. Nomogram model for predicting postoperative ONFH.
ONFH: Osteonecrosis of the femoral head.

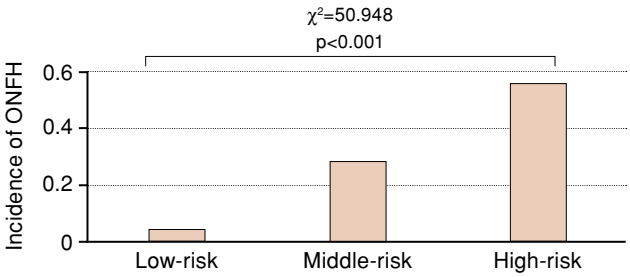

FIGURE 2. Nomogram prediction model for risk stratification of postoperative ONFH.
ONFH: Osteonecrosis of the femoral head.

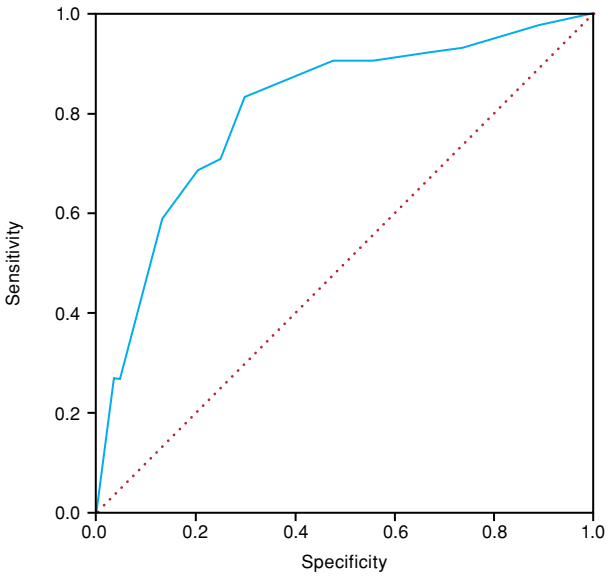

FIGURE 3. ROC curve of nomogram model for predicting postoperative ONFH.
ROC: Receiver operating characteristic; ONFH: Osteonecrosis of the femoral head.

ONFH incidence rate of 28.4%, and high-risk group (30-40 points, n=20) with an ONFH incidence rate of 55.0% (Figure 2).

Predictive value of nomogram prediction model

The nomogram prediction model had an AUC of 0.807 (95% CI: 0.731-0.882, p<0.05) for predicting the occurrence of postoperative ONFH (Figure 3). The Hosmer-Lemeshow test showed that the model had good consistency for predicting postoperative ONFH (p>0.05). Additionally, calibration curve exhibited that the predicted incidence rate of postoperative ONFH indicated by the model was favorably consistent with the actual incidence rate of ONFH after surgery (Figure 4).

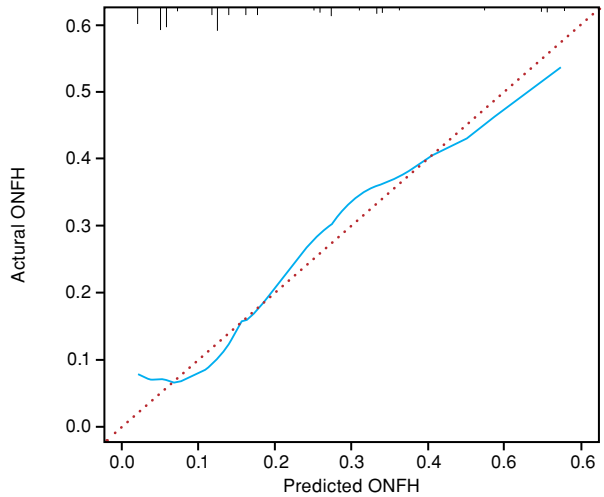

FIGURE 4. Calibration curve of nomogram model for predicting postoperative ONFH.
ONFH: Osteonecrosis of the femoral head.

DISCUSSION

Currently, patients with femoral neck fractures are predominately treated by internal fixation with multiple cannulated compression screws, which has the advantages of minimal trauma, less bleeding, potent fixation and simple operation.[14] Nonetheless, owing to special anatomical structures, the incidence rate of ONFH after internal fixation with multiple cannulated compression screws remains high,[9,15,16] posing serious threats to patient's quality of life. Today, total hip replacement may be a better choice for patients at high risk for ONFH. Thus, more efforts have been made to accurately evaluate the probability of ONFH after internal fixation with cannulated compression screws for femoral neck fractures.

In the present study, there were close associations of fracture type, reduction quality and postoperative removal of internal fixation implant with the occurrence of postoperative ONFH, which was consistent with the results of Pei et al.[9] Firstly, fracture displacement resulting from femoral neck fractures can directly block the blood supply to the femoral head, thereby leading to ischemic necrosis. Furthermore, severer fracture displacement makes the reduction surgery more difficult, notably increasing the risk of ONFH.[17] A poor reduction quality indicates that the contact area of the fracture ends decreases, which may diminish the blood supply to the femoral head and result in ONFH.[18] Secondly, removing the internal fixation implant

after surgery may cause damage to the blood supply near the screw hole, irritate local blood supply to induce spasm, and cause intra-articular hematoma, consequently leading to ONFH.[9] Additionally, we found that age and comorbidities were also the main factors influencing the occurrence of postoperative ONFH. Older patients may have more complications and cannot easily recover, increasing the incidence rate of postoperative ONFH.[19,20] Based on these results, making efforts to improve the reduction quality in patients with femoral neck fractures, particularly in elderly with fracture end displacement, contributes to effectively reducing the risk of ONFH. In addition, the indications for postoperative removal of the fixation implant after internal fixation with cannulated compression screws should be meticulously evaluated by clinicians. Furthermore, we found that unsatisfactory reduction was also an independent influencing factor for ONFH in patients with femoral neck fractures after internal fixation by cannulated compression screws. The quality of reduction is closely related not only with the stability of fracture, but also with the degree of fracture healing and the postoperative occurrence of ONFH. Similarly, Suh et al.[21] reported that the quality of fracture reduction was one of the main factors leading to the poor prognosis of patients with femoral neck fractures.

Nonetheless, this study has limitations. First, the reduction method was not a risk factor for ONFH, but further research is still needed to confirm this finding. Second, femoral neck fractures can be classified according to the location of the fracture line (subcapital, transcervical, or basicervical). Compression hip screws and derotational screws are recommended for the fixation of basicervical and comminuted neck fractures. Therefore, cannulated screws are unsuitable for fixing all types of femoral neck fracture.

In conclusion, age, comorbidities, fracture type, reduction quality and postoperative removal of internal fixation implant are independent risk factors associated with ONFH after internal fixation with multiple cannulated compression screws for femoral neck fractures. Effective interventions targeting these clinical features are able to lower the risk of ONFH occurrence in clinical practice. Furthermore, total hip replacement may be a favorable selection for high-risk individuals who are likely to be susceptible to ONFH.

Ethics Committee Approval: The study protocol was approved by the Yangxian People's Hospital Ethics Committee (date: 04.01.2012, no: KY-2023-322). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Designed this study and prepared this manuscript: Z.J., L.C., D.W.; Collected and analyzed clinical data: Y.Y., J.F.; Writing: Z.Y., B.H. All authors approved the final version of this manuscript.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

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