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Original Article

Risk factors affecting the incidence of postoperative periprosthetic femoral fracture in primary hip arthroplasty patients: a retrospective study

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Abstract: The purpose of this study was to identify the characteristics and risk factors for postoperative periprosthetic femoral fracture (PFF). This was a retrospective cohort study of 108 patients with and 432 control patients without postoperative PFF. Demographic characteristics, surgery-related information (primary hip disease diagnosed, fixation, femoral stem, method of operation, and bone resorption of the proximal femur), and postoperative patient outcomes (hip function, treatment history, and patients' lifestyle behaviors) were recorded and compared between the groups. PFF characteristics, such as the classification, time, and cause, were also documented, and a Cox regression model was built to identify the independent risk factors for postoperative PFF in these patients. Six independent risk factors for postoperative PFF were identified, namely, advanced age (hazard ratio (HR) = 1.026, 95% confidence interval (CI) = 1.007-1.045), femoral neck fracture as the primary disease (HR = 4.536, 95% CI = 2.955-6.961), osteoporosis (HR = 2.043, 95% CI = 1.234-3.383), hemiarthroplasty (or HA, HR = 2.173, 95% CI = 1.327-3.558), bone resorption of the proximal femur (HR = 1.627, 95% CI = 1.090-2.430), and a standard- or long-stem femoral prosthesis (HR = 2.996, 95% CI = 1.480-6.067). The predictive values for a low risk (estimated incidence ≤ 50%), moderate risk (estimated incidence 51%-89%), and high risk (estimated incidence ≥ 90%) of PFF were ≤ 3.0 points, 3.0-10.0 points, and ≥ 10.0 points, respectively. Most patients with postoperative PFF had Vancouver type B fractures. Six independent risk factors for postoperative PFF were identified: advanced age, hip fracture as the primary disease, osteoporosis, HA, bone resorption of the proximal femur, and a long femoral stem.

Keywords: Periprosthetic femoral fracture, risk factor, hip arthroplasty

Introduction

Total hip arthroplasty (THA) is an effective treatment for end-stage hip diseases [1, 2]. However, some complications of THA can compromise the prognosis in terms of joint function, patient satisfaction, and implant longevity. These complications mainly include periprosthetic fracture, dislocation, aseptic loosening, and infection [3-6]. In recent years, postoperative periprosthetic fracture, especially postoperative periprosthetic femoral fracture (PFF), has gradually become one of the leading causes of hip revision, second only to prosthesis loosening and recurrent dislocation [7-9].

Periprosthetic fractures are challenging to treat and are associated with a high treatment failure rate. Therefore, understanding and avoiding risk factors for periprosthetic fracture is key to reducing the incidence of this complication. PFF is an uncommon but potentially devastating complication following THA [10, 11]. Once a fracture occurs, it is a disastrous setback for the patient [12], with a considerable burden both psychologically and economically. The incidence of postoperative PFF varies by region and race [13, 14]. The incidence of mortality following revision surgery ranges from 9% at 90 days to 21% at one year and 60% at five years in the highest-risk group. These fractures pose significant challenges to orthopaedic surgeons.

In recent years, although understanding of periprosthetic fracture after hip arthroplasty has deepened, the characteristics and influencing factors for PFF are still not clear, and there is a lack of systematic evaluations of PFF. Additionally, we found that little attention is given to patients' postoperative lifestyle habits and treatments. Therefore, our goal was to determine the risk factors for PFF and identify individualized measures for evaluation and prevention. Based on the above information, we believe there is a need to prevent postoperative periprosthetic fracture in patients undergoing primary hip arthroplasty. Thus, the aims of this study were as follows: (1) to identify risk factors for postoperative PFF; (2) to identify the types, causes, and occurrence times of postoperative PFF; and (3) to establish a predictive scoring system to evaluate the risk of postoperative PFF in these patients.

Methods

Study design

This was a retrospective cohort study. Patients who underwent primary hip arthroplasty were identified and followed retrospectively for the occurrence of postoperative PFF. Cox regression analysis was used to determine the independent risk factors for postoperative PFF.

Clinical characteristics of PFF

Patients who underwent primary hip arthroplasty at our institute between January 2007 and December 2020 were investigated in this retrospective study. According to whether postoperative periprosthetic fracture (PFF) occurred, the patients were divided into two groups: a fracture group and a nonfracture group. Each postoperative PFF was identified using follow-up data over a period of at least 12 months and confirmed by radiological examination (X-ray, computed tomography, or magnetic resonance imaging). To reduce differences due to the surgical techniques and instruments used in each period, the control group (non-PFF) was selected as follows: two consecutive patients who received THA before and after each PFF patient, for a total of 4 patients. The inclusion criterion was treatment with primary hip arthroplasty. The exclusion criteria were as follows: intraoperative or early PFF, defined as fracture occurring within 3 months after the operation; hip arthroplasty with a modular femoral prosthesis; revision surgery; and incomplete medical records or radiological images. The study was approved by the institutional review board of our hospital and was conducted in accordance with the Declaration of Helsinki. As this was a retrospective study and all patient information was deidentified before analysis, informed consent was not needed.

We collected all the clinical and radiologic data of patients, including demographic information and radiologic parameters. Demographic characteristics, including sex, age, body mass index (BMI), surgical side, smoking history, alcohol consumption, underlying diseases (e.g., osteoporosis, hypertension, and diabetes), steroid use history, and neurological disease, were collected from the medical records. Dual-energy X-ray absorptiometry (DEXA) (Hologic, Inc., Waltham, MA, USA) scans were used to determine the quality of bone around the hip. The bone mass was divided into three groups: normal bone density, bone mass reduction, and osteoporosis. Other essential surgery-related information (primary hip disease diagnosis, fixation and femoral stem, method of operation, bone resorption of the proximal femur) and postoperative patient outcomes (hip function, treatment history, and patients' lifestyle behaviors) were also investigated using postoperative follow-up data recorded in the electronic medical record system. Bone resorption was defined as decreased cancellous bone density, cortical bone thinning, transparent zone, and cystic change, and the Gruen zone was used to identify these features [15, 16]. The primary disease was divided into femoral neck fracture and other (e.g., osteonecrosis, osteoarthritis, and hip dysplasia). The types of femoral fixation included cemented and uncemented fixation. The types of surgery included THA and hemiarthroplasty (HA). The type of femoral stem prosthesis included short-stem and standard- or long-stem prostheses. The Harris hip score was applied to assess hip function after hip arthroplasty. Note that for patients who underwent bilateral hip arthroplasty, the Harris hip score was evaluated independently for each side. We also investigated the postoperative treatments administered to patients, including the administration of anti-osteoporosis treatments and oral analgesics. In addition, the lifestyle behaviors of the patients were routinely included in the survey. The assessed data included whether the patient used a walking aid in their daily life. All the above indicators were recorded from immediately after the operation to the last follow-up. To test the intraobserver reproducibility, the surgeon performed all the radiographic measurements in 20 randomly selected patients. The measurements were repeated after 2 weeks. The intraclass correlation coefficient was used to assess intraobserver reliability. The results showed good reliability (intraclass correlation coefficient > 0.9 in all measurements).

The radiologic data of these PFF patients were used to determine the fracture characteristics, including the fracture classification, cause, and time of occurrence after surgery. In patients who underwent bilateral surgery (either simultaneously or sequentially), the two records were considered two independent individuals.

Outcomes of interest

Postoperative PFFs were defined as femoral fractures diagnosed by radiologic images or medical records. The occurrence of postoperative PFFs was considered the primary endpoint event in this study. The corresponding event time variable (follow-up time) was calculated as the time from hip replacement to the last follow-up. The general data of patients with periprosthetic fractures and patients undergoing hip arthroplasty in the same time period were counted. Each PFF was classified according to the Vancouver classification [17-19], and the corresponding characteristics were estimated, including the time of occurrence and cause. Subsequently, multivariate analysis was performed to determine independent risk factors for postoperative PFF in these patients.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, NY). Continuous variables are expressed as the mean ± standard deviation, and categorical variables are expressed as frequencies. The Mann-Whitney U test was performed for comparisons between continuous variables. The chi-square test was performed for comparisons between categorical variables. Cox regression models were used to explore the independent risk factors for postoperative PFF. The examined factors were as follows: age, sex, BMI, surgical side, smoking history, alcohol consumption, steroid use, comorbidities (hypertension, neurological disease, osteoporosis, and diabetes), primary disease, type of fixation, method of operation, bone resorption of the proximal femur, femoral stem type, Harris hip score, analgesic use, anti-osteoporosis treatment, and walking aid use. A stepwise regression method was used to determine the final independent variables in the equation. After identifying the initial risk factors, receiver operating characteristic (ROC) curve analysis was applied to identify the best diagnostic cut-off point of continuous variables and convert them into dichotomous variables (age). The test variable value corresponding to the maximum value of the Youden index was selected as the critical value. Then, continuous variables were converted into categorical variables. Another Cox regression model was created to establish the diagnostic model, including the converted categorical variables. The hazard ratio (HR), 95% confidence interval (95% CI), and β-coefficient were calculated to indicate the strength of the correlation for each risk factor. According to the β-coefficient, a weighted scoring system was constructed to help predict the occurrence of postoperative PFF in patients. A total of 20 scores for the scoring system were set. Notably, the weight of each factor may have been fine-tuned according to clinical significance and calculation convenience. After the ROC curve of the scoring system was created, the area under the curve (AUC) was calculated to evaluate the predictive accuracy of the scoring system, and some cut-off points were identified to estimate the risk of PFF. These cut-off points were selected from the coordinate points of the ROC curve. A *P* value less than 0.05 was considered a significant difference.

Results

Patient characteristics

In this retrospective study, a total of 540 patients/hips (266 left hips and 274 right hips) were included, with a mean follow-up of 64.78 months (range: 0.2 to 163 months). According to the periprosthetic fracture status after hip arthroplasty at the final follow-up, patients were divided into two groups, i.e., the PFF and non-PFF groups. There were 108 patients in the postoperative PFF group and 432 patients in the non-PFF group. There were 338 males and

Table 1. Demographic information

Patient characteristic	PFF group (n = 108)	Non-PFF group (n = 432)	Total (n = 540)	Test statistics	P
Sex					
Male	56 (51.9%)	282 (65.3%)	338 (62.6%)	6.652#	0.01
Female	52 (48.1%)	150 (34.7%)	202 (37.4%)		
Age (years)	67.91±13.82	52.47±12.09	55.58±13.87	-89.973*	< 0.001
BMI (kg/m^2)	24.21±2.81	25.33±3.67	25.10±3.54	-18.084*	< 0.001
Surgical side					
Left	54 (50.0%)	212 (49.1%)	266 (49.3%)	0.030#	0.863
Right	54 (50.0%)	220 (50.9%)	274 (50.7%)		
Hypertension					
No	62 (57.4%)	343 (79.4%)	405 (75.0%)	22.284#	< 0.001
Yes	46 (42.6%)	89 (20.6%)	135 (25.0%)		
Smoking					
No	96 (88.9%)	384 (88.9%)	480 (88.9%)	0.000#	1
Yes	12 (11.1%)	48 (11.1%)	60 (11.1%)		
Alcohol consumption					
No	95 (88.0%)	382 (88.4%)	447 (88.3%)	0.018#	0.893
Yes	13 (12.0%)	50 (11.6%)	63 (11.7%)		
Steroid use					
No	103 (95.4%)	400 (92.6%)	503 (90.06%)	1.045#	0.307
Yes	5 (4.6%)	32 (7.4%)	37 (9.94%)		
Diabetes					
No	90 (83.3%)	380 (88.0%)	470 (87.0%)	1.641#	0.200
Yes	18 (16.7%)	52 (12.0%)	72 (13.0%)		
Osteoporosis					
No	48 (44.4%)	378 (87.5%)	426 (78.9%)	96.171#	< 0.001
Yes	60 (55.6%)	54 (12.5%)	114 (21.1%)		
Neurological disease					
No	72 (66.7%)	394 (91.2%)	466 (86.3%)	43.987#	< 0.001
Yes	36 (33.3%)	38 (8.8%)	74 (13.7%)		

PFF = Periprosthetic Femoral Fracture; BMI = Body Mass Index. *Mann-Whitney U test; #Chi-square test.

202 females. The average age and BMI were 55.58±13.87 years and 25.10±3.54 kg/m^2, respectively. Patient data regarding hypertension, smoking history, alcohol consumption, steroid use, diabetes, osteoporosis, and neurological disease status are shown in **Table 1**. The proportion of females in the PFF group was higher than that of males in the non-PFF group (P = 0.01). There were significant differences in age, BMI, hypertension, osteoporosis, and neurological disease between the two groups (P < 0.001) and no significant differences in the other characteristics between the two groups. Comparisons of general information between the two groups is shown in **Table 1**.

Characteristics of patients with and without postoperative PFF

Data regarding the primary disease, type of fixation, method of operation, bone resorption of the proximal femur, and femoral stem type are shown in **Table 2**. Primary hip disease indicating primary hip arthroplasty was investigated in this study. Patients whose primary disease was femoral neck fracture accounted for 59.3% (64/108) of the PFF group. We identified two groups based on the primary disease, i.e., femoral neck fracture in one group; and other diseases, including osteonecrosis, hip dysplasia, osteoarthritis, and rheumatoid arthritis, in the

Table 2. Primary disease, type of fixation and femoral stem, method of operation, and bone resorption of the proximal femur

Patient characteristic	PFF group (n = 108)	Non-PFF group (n = 432)	Total (n = 540)	Test statistics	P
Primary disease					
Other	44 (40.7%)	385 (89.1%)	429 (79.4%)	123.836#	< 0.001
Femoral neck fracture	64 (59.3%)	47 (10.9%)	111 (20.6%)		
Type of fixation					
Cemented	31 (28.7%)	14 (3.2%)	45 (8.3%)	73.333#	< 0.001
Uncemented	77 (71.3%)	418 (96.8%)	495 (91.7%)		
Method of operation					
THA	74 (68.5%)	426 (98.6%)	500 (92.6%)	114.075#	< 0.001
HA	34 (31.5%)	6 (1.4%)	40 (7.4%)		
Bone resorption of the proximal femur					
No	57 (52.8%)	366 (84.7%)	423 (78.3%)	51.948#	< 0.001
Yes	51 (47.2%)	66 (15.3%)	117 (21.7%)		
Femoral stem type					
Short stem	10 (9.3%)	225 (52.1%)	235 (43.5%)	64.463#	< 0.001
Other stem (standard or long)	98 (90.7%)	207 (47.9%)	305 (56.5%)		

PFF = Periprosthetic Femoral Fracture; HA = Hemiarthroplasty; THA = Total Hip Arthroplasty; #Chi-square test; Note: Other primary diseases included osteonecrosis, hip dysplasia, osteoarthritis, and rheumatoid arthritis.

Table 3. Treatment history, lifestyle behaviors, and hip function

Patient characteristic	PFF group (n = 108)	Non-PFF group (n = 432)	Total (n = 540)	Test statistics	P
Analgesic use					
No	98 (90.7%)	391 (90.5%)	489 (90.6%)	0.005#	0.941
Yes	10 (9.3%)	41 (9.5%)	51 (9.4%)		
Anti-osteoporosis treatment					
No	98 (90.7%)	402 (93.1%)	500 (92.6%)	0.675#	0.411
Yes	10 (9.3%)	30 (6.9%)	40 (7.4%)		
Walking aid use					
No	95 (88.0%)	365 (84.5%)	460 (85.2%)	0.825#	0.364
Yes	13 (12.0%)	67 (15.5%)	80 (14.8%)		
Harris hip score (points)	92.89±6.101	95.64±3.395	95.09±4.221	-45.589*	< 0.001
Excellent	95 (88.0%)	413 (95.6%)	508 (94.1%)	31.276#	< 0.001
Good	4 (3.7%)	18 (4.2%)	22 (4.1%)		
Fair	8 (7.4%)	1 (0.2%)	9 (1.7%)		
Poor	1 (0.9%)	0 (0.0%)	1 (0.2%)		

PFF = Periprosthetic Femoral Fracture; #Chi-square test; *Mann-Whitney U test; Note: A Harris hip score of 90-100 was considered to indicate excellent hip function; 80-89, good; 70-79, fair; and less than 70, poor.

other group. We also analysed patients' treatment history, lifestyle behaviours, and hip function in the different groups (**Table 3**). Femoral neck fracture as the primary disease (X^2 = 123.836, P < 0.001), cemented fixation (X^2 = 73.333, P < 0.001), HA (X^2 = 114.075, P < 0.001), bone resorption of the proximal femur (X^2 = 51.948, P < 0.001), and a standard or long stem (X^2 = 64.463, P < 0.001) were significantly more common in the PFF group than in the non-PFF group. Additionally, the Harris hip score was lower in the PFF group (92.89±6.101 vs. 95.64±3.395, P < 0.001) (**Table 3**). There were no significant differences between the two groups regarding analgesic use, anti-osteoporosis treatment, or walking aid use (**Table 3**).

Table 4. PFF classification, time, and cause

Patient characteristic	Count	Proportion
Total	108	100%
Fracture classification (Vancouver)		
A	7	6.48%
AG	5	4.63%
AL	2	1.85%
B	91	84.26%
B1	44	40.74%
B2	42	38.89%
B3	5	4.63%
C	10	9.26%
Fracture cause		
High-energy trauma	20	18.52%
Low-energy trauma	83	76.85%
Occult fracture	5	4.63%
Time to fracture (months)	30.35±23.15	-

PFF = Periprosthetic Femoral Fracture; Low-energy trauma includes slipping, tripping, or falling from a standing height; High-energy trauma includes traffic accidents and falls from a tall height.

PFF characteristics

The characteristics of each PFF, such as the classification, time of occurrence, and cause, were also investigated. According to the Vancouver classification, 7 patients (6.48%) had Vancouver type A fractures, 91 patients (84.26%) had Vancouver type B fractures, and 10 patients (9.26%) had Vancouver type C fractures. In addition, the three leading causes of fracture were as follows: high-energy injury accounted for 18.52% (20/108), low-energy injury accounted for 76.85% (83/108), and occult fracture accounted for 4.63% (5/108). The average time of fracture was 30.35 months after surgery. The details of these PFF characteristics are shown in **Table 4**.

Risk factors for postoperative PFF

This study identified six independent risk factors for postoperative PFF in patients after hip arthroplasty. Advanced age was the first risk factor: every 1-year increase in age increased the HR of PFF by 2.6% (HR = 1.026, 95% CI = 1.007-1.045). Femoral neck fracture as the primary disease was the second independent risk factor. The probability of PFF in patients with femoral neck fracture compared with patients with other primary hip diseases was increased by approximately 3.54-fold (HR = 4.536, 95% CI = 2.955-6.961). The third independent risk factor for PFF was osteoporosis. PFF was more likely in patients with osteoporosis than in patients with normal bone quality (HR = 2.043, 95% CI = 1.234-3.383). In addition, compared to patients who underwent THA, patients who underwent HA were more likely to experience PFF after surgery (HR = 2.173, 95% CI = 1.327-3.558). The fifth risk factor for PFF was bone resorption of the proximal femur. Compared to patients with no bone resorption of the proximal femur, patients with bone resorption had an approximately 0.627-fold increased risk of PFF (HR = 1.627, 95% CI = 1.090-3.430). The type of femoral stem was the last risk factor for PFF. The PFF risk was nearly two-fold higher with a standard or long stem than with a short stem (HR = 2.996, 95% CI = 1.480-6.067). These independent risk factors, HRs, and 95% CIs are shown in **Table 5**.

Scoring system for predicting PFF in patients after hip arthroplasty

We established a new scoring system for surgeons to evaluate patients after hip arthroplasty and determine the risk of periprosthetic fracture. After Cox regression analysis, a total of 6 factors were included in this scoring system. Regression coefficient B represents the weighted score corresponding to each factor. The total score of all factors was taken as the final score, and the highest score was 20 points. The AUC of this scoring system was 0.918 (95% CI = 0.889-0.948). The predictive scores for a low risk (estimated incidence ≤ 50%), moderate risk (estimated incidence 51%-89%), and high risk (estimated incidence ≥ 90%) of PFF were ≤ 3.0 points, 3.0-10.0 points, and ≥ 10.0 points, respectively. When the critical point was set to 10 points, the sensitivity and specificity of this scoring system were 0.769 and 0.877, respectively. The details of the scoring system for predicting hip fracture in patients with hip disease are shown in **Table 6**.

Discussion

Hip arthroplasty is the most effective method for treating end-stage hip diseases. It can relieve pain and effectively restore the function of the hip joint. As the proportion of patients

Table 5. Independent risk factors for PFF

Risk factor	Hazard ratio	95% Confidence interval	P
Age (years)	1.026	1.007-1.045	0.008
Primary hip disease			
Other (ref.)	-	-	-
Femoral fracture	4.536	2.955-6.961	< 0.001
Osteoporosis			
No (ref.)	-	-	
Yes	2.043	1.234-3.383	0.006
Surgery type			
THA (ref.)	-	-	-
HA	2.173	1.327-3.558	0.002
Bone resorption of the proximal femur			
No (ref.)	-	-	-
Yes	1.627	1.090-2.430	0.017
Femoral stem type			
Short stem (ref.)	-	-	-
Other stem (standard or long)	2.996	1.480-6.067	0.002

PFF = Periprosthetic Femoral Fracture; HA = Hemiarthroplasty; THA = Total Hip Arthroplasty; ref., reference; Note: Cox proportional hazards regression analysis was used to estimate hazard ratios, confidence intervals, and *P* values. All possiblel risk factors, including demographic characteristics, primary diseases, type of surgery, fixation and femoral stem, method of operation, bone resorption of the proximal femur, lifestyle behaviors, treatment history and hip function (i.e., all variables reported in **Tables 1**-**3**), were initially included in the regression models. The stepwise regression method was used to determine the final independent variables in the equation. Variables with P > 0.05 were removed from the equation.

undergoing hip arthroplasty increases each year, the number of patients with postoperative complications also increases annually. However, many postoperative complications can affect the efficacy of hip arthroplasty, such as periprosthetic fractures, and present great challenges for patients and doctors. Periprosthetic fractures are difficult to treat and are associated with a high treatment failure rate. Therefore, determining the risk factors for periprosthetic fractures is key to reducing the incidence. Adequate preoperative evaluation, skilled and rigorous intraoperative performance, and appropriate equipment selection can decrease the occurrence of periprosthetic fractures to a great extent. However, it is challenging to prevent the occurrence of postoperative periprosthetic fracture in patients treated with hip arthroplasty due to various complex influencing factors. Determining the independent risk factors related to PFF and taking corresponding preventive measures in advance can largely prevent their occurrence. In this retrospective cohort study, we collected and analysed the clinical data of patients with PFF after hip arthroplasty to determine the independent risk factors. Our results show that many patients with postoperative periprosthetic fractures shared the same primary disease, and this represented a significant difference between the PFF group and the control group (non-PFF group). A total of six independent risk factors (advanced age, hip fracture as the primary disease, osteoporosis, HA, bone resorption of the proximal femur, and long femoral stem) for postoperative PFF were identified in this study. A scoring system was built based on these risk factors to help predict the probability of postoperative PFF in patients.

PFF characteristics

PFF characteristics, including classification, cause, and time of occurrence, were also investigated in our study. The findings regarding the classifications and causes of PFF were largely consistent with those of previous studies. Accurate PFF classification is helpful for formulating a treatment plan. According to previous reports, there are more than ten methods for classifying periprosthetic fractures. Nevertheless, these classification methods are essentially the same, as they take into account both the fracture location and the relationship of the fracture with the prosthesis. The Vancouver classification is the most widely used method for PFF classification and is accepted by doctors. This classification refers to the location of the fracture and comprehensively considers the stability of the prosthesis as well as the bone mass of the proximal femur, which is advantageous.

Most of the fractures in our study were Vancouver type B fractures (84.3%), and type A (6.5%) and type C (9.2%) fractures were rare. Periprosthetic fractures are mainly caused by traumas, which can be divided into low-energy and high-energy injuries. Low-energy injuries

Table 6. Scoring system for predicting hip fracture in patients with hip disease

Risk factor	β-Coefficient	Predictive score (total = 20 points)
Age (years)		
≤ 63 (ref.)		0
≥ 64	0.929	3.5
Primary hip disease		
Other (ref.)		0
Femoral fracture	1.522	5.7
Osteoporosis		
No (ref.)		0
Yes	0.661	2.5
Surgery type		
THA (ref.)		0
HA	0.798	3
Bone resorption of the proximal femur		
No (ref.)		0
Yes	0.531	2
Femoral stem type		
Short stem (ref.)		0
Other stem (standard or long)	0.868	3.3

HA = Hemiarthroplasty; THA = Total Hip Arthroplasty; ref., reference; Note: The area under the curve of this scoring system was 0.918 (95% confidence interval = 0.889-0.948). The total score was the sum of each item's score. The predictive scores for a low risk (estimated incidence ≤ 50%), moderate risk (estimated incidence 51%-89%), and high risk (estimated incidence ≥ 90%) of PFF were ≤ 3.0 points, 3.0-10.0 points and ≥ 10.0 points, respectively.

(e.g., slipping or falling) accounted for 76.9% of fractures. High-energy injuries (e.g., traffic accidents) accounted for only 18.5%, but high-energy injuries often cause comminuted fractures. Cross et al. [20] reported that most postoperative PFFs were caused by low-energy injuries. Minor traumas, including falls and spontaneous fractures, are the leading causes of these injuries. Additionally, some of these fractures are occult fractures, with no distinguished history of trauma. We consider that these fractures may be caused by severe osteoporosis, femoral bone mass loss, cortical bone thinning, increased brittleness, and slight hip movement. These fractures may be challenging to identify in the early stage, and weight-bearing activity may cause further splitting of the fracture as well as severe pain. Lindahl et al. [21] studied the statistical data of 1049 patients with periprosthetic fractures and found that 75% of patients had fallen from a standing position or from a chair. Spontaneous periprosthetic fractures are also common in revision surgery. Beals et al. [22] analysed the data of 93 patients with periprosthetic fractures and found that 66% had fallen indoors and 18% had fallen outdoors. Our results show that the average time of fracture was 30.35±23.15 months after the operation. A study conducted by Yi Deng et al. [8] showed a fracture time of 6.03 years after primary THA and 4.08 years after revision THA, which deviates from our results.

Six independent risk factors for PFF in patients who underwent hip arthroplasty

Advanced age: Our study found that advanced age is an independent risk factor for postoperative PFF. The physiological status, lifestyle habits, and medical diseases of elderly patients may have an impact on the occurrence of periprosthetic fractures. Additionally, an increase in age is bound to be associated with a decrease in bone mass, an increase in medical diseases, and an increase in fall risk. The demographic information examined in this study included age, sex, BMI, hypertension, neurological diseases, osteoporosis, and other factors. While these factors showed statistically significant differences between the two groups ($P < 0.05$), only age and osteoporosis were independent risk factors for periprosthetic fracture in the final multivariate Cox regression analysis. Advanced age is closely related to the occurrence of postoperative PFF; every 1-year increase in age increased the HR of hip fracture by 2.6% (HR = 1.026, 95% CI = 1.007-1.045). The increase in PFF incidence is mainly related to the poor physical function of elderly individuals, the lack of mechanical support provided by the bone cortex, the increase in bone fragility, and other factors. In a retrospective cohort study [23], J N Lamb et al. reported that increasing age (HR, 1.02 per year) was associated with PFF after primary THA. Previous studies [24, 25] have also indicated that advanced age increases the risk of periprosthetic fracture. Age is recognized as a risk factor for periprosthetic fracture.

Primary disease, especially femoral neck fracture: In addition to age, we also found that the primary disease affected the occurrence of PFF. Our results show that the probability of PFF in patients with hip fracture (mainly femoral neck fracture) was significantly higher than that in patients hospitalized for primary diseases such as femoral head necrosis, osteoarthritis, and hip replacement dysplasia (HR = 4.536, 95% CI = 2.955-6.961). Patients whose primary disease was hip fracture had a 3.5-fold increased risk of periprosthetic fracture. Femoral neck fractures can occur with minor traumas, which usually indicates poor bone quality. Fractures also often occur in elderly individuals. Therefore, poor bone quality and advanced age may be the main reasons for hip fracture, and detailed recovery guidance for hip fracture patients should be given in a timely manner to prevent the occurrence of refracture after the operation.

Osteoporosis: The third risk factor is osteoporosis. In this study, BMD was measured by dual-energy X-ray absorptiometry. Due to the interference of the metal hip prosthesis, the bone mineral density of the contralateral femoral head or lumbar spine was measured. Patients were diagnosed with osteoporosis according to the standards of the World Health Organization (WHO) (T < -2.5). Osteoporosis reduces bone strength and increases bone fragility. Under these conditions, a slight external force can cause a periprosthetic fracture; thus, osteoporosis is recognized as a risk factor for PFF [26]. In our study, compared with patients with a normal bone mineral density, the risk of postoperative PFF was 2-fold higher in patients with significant osteoporosis (HR = 2.043, 95% CI = 1.234-3.383). The initial stability of prostheses, especially uncemented prostheses, depends on the press-fit between the prosthesis and bone socket. The minimum breaking strength of the proximal femur must exceed the pressure between the femoral stem and the medullary canal, which is required for stable compression of the prosthesis. This means that osteoporosis affects the stability between the proximal femoral bone marrow cavity and the prosthesis and is one of the reasons for aseptic loosening. Osteoporosis results in decreased bone strength, which might cause failure of the press-fit of the prosthesis. Beals et al. [22] reported that 38% of PFF patients had a history of vertebral body or long shaft epiphyseal fractures. Some PFF patients had not been diagnosed with osteoporosis but had osteopenia. Hennings et al. [27] reported that the use of anti-osteoporosis drugs such as alendronate can effectively reduce periprosthetic bone loss after hip arthroplasty and further prevent the occurrence of periprosthetic fractures.

Method of operation, especially HA: The method of operation was also a risk factor for PFF in the present study. Compared with patients who underwent THA, patients who underwent HA had a 2-fold higher risk of postoperative PFF (HR = 2.173, 95% CI = 1.327-3.558). THA and HA are the most common surgical methods in orthopaedics. The former is suitable for most patients, while the latter is mainly used for older patients and patients with more comorbidities. Compared with HA, THA is associated with faster recovery of hip function and significantly less pain. HA may cause pain and dysfunction due to progressive wear of the acetabulum. Acetabular cartilage wear is a complication of HA that leads to hip pain. However, avoiding hip pain by restricting activity increases the probability of disuse osteoporosis. Poor hip function and bone quality are the leading causes of fracture. A meta-analysis [28] conducted by Peng W et al. showed that THA was better than HA for hip fracture at the one-year follow-up. However, some studies [29, 30] have shown higher revision rates among THA patients than HA patients. Because the age of THA patients is generally lower than that of HA patients, there is more activity after the surgery, which increases the probability of trauma. After HA, more attention should be given to the treatment of medical complications, such as with the appropriate use of analgesics and anti-osteoporosis treatments.

*Bone resorption of the proximal femu*r: The fifth risk factor for postoperative PFF was bone resorption of the proximal femur (HR = 1.627, 95% CI = 1.090-2.430). There are many mechanisms of bone resorption (bone loss) after hip arthroplasty, such as natural loss, bone remodelling or stress shielding, mechanical factors, and granular disease caused by polyethylene dissolution. Proximal bone resorption can influence the stability of the femoral stem to a certain degree. The implantation of a femoral prosthesis changes the mechanical conduction of the proximal femur and results in mechanical adaptation of the bone for load transfer to the implant. Stress shielding can reduce the weight-bearing capacity of the femoral prosthesis and lead to significant periprosthetic bone loss, aseptic loosening, an increased chance of low-energy fracture, early implant failure and complex revision. Beals et al. found that fractures caused by uncemented prostheses are related to stress shielding [22]. The weight of the body on the femoral head prosthesis and the supporting force of the calcar femoral can cause the stem of the femoral prosthesis to swing outwards and the implant to loosen, and swinging of the prosthesis in the medullary cavity can result in thinning of the medial and lateral cortex of the femur and potentially lead to PFF. Hsieh et al. analysed 887 cases of THA with uncemented fixation [31]. We found that 23 cases of PFF were caused by osteolysis of the greater trochanter region, for an incidence rate of 2.6%. Bone resorption is still a challenging problem in revision hip surgery. Regular imaging examinations are necessary, and timely treatment can help prevent the occurrence of fractures.

Standard or long femoral stem: In our study, the use of a standard- or long-stem femoral prosthesis was also a risk factor for postoperative PFF. The risk of postoperative PFF with a standard- or long-stem femoral prosthesis in primary replacement was nearly 3-fold higher than that with a short-stem prosthesis (HR = 2.996, 95% CI = 1.480-6.067). Many studies have reported that short stems have potential advantages over long stems; for example, more bone and soft tissue can be conserved by using a short stem. However, the fixation methods of the two types of femoral prostheses are different. Short-stem prostheses are placed with proximal press-fitting (metaphyseal press-fitting), and long-stem prostheses are placed with distal fixation. These different fixation methods lead to differences in the direction of mechanical conduction. The greater metaphyseal engagement and contact of short stems conforms to the normal mechanical conduction of the human body, which stresses the proximal femur and preserves more proximal bone mass over time than the mechanics resulting from longer stems. This means that the stress-shielding effect of short-stem prostheses is much lower than that of long-stem prostheses. Briem D et al. and Kress AM et al. indicated that the long-term results of collum femoris-preserving stems show a high rate of stability and a low rate of aseptic loosening [32, 33]. Therefore, if the patient has sufficient bone mass in the proximal femur at the primary replacement, a short-stem prosthesis may be better. In our study, patients with cement prostheses seemed more prone to PFF than those with uncemented prostheses. Previous literature has shown that uncemented fixation is associated with a higher risk of PFF. This is contrary to our research. Some literature also shows that PFF can easily occur within half a year after surgery when using an uncemented stem, which may be related to the stress concentration of the local bone cortex caused by reaming. The fracture site is mainly within 4 cm from the intertrochanteric area to the tip of the femoral stem. The fracture of the cement-type prosthesis occurred approximately 5 years after the operation, and most of the fractures occurred at the tip of the handle or beyond the prosthesis. We think this may be related to the failure to include early PFF in the study.

On Cox regression analysis, revision was not an independent risk factor for PFF, which may be related to less activity and greater care to avoid falling after revision. Physical activity and specific comorbidities associated with an increased risk of trauma due to falling may be factors similar to and perhaps more decisive than bone mass. Contrary to previous findings, our observation that sex had no specific influence on the risk of periprosthetic fracture might support this theory.

Predictive scoring system for postoperative PFF

The ultimate goal of identifying risk factors for postoperative PFF is to stratify patients at a higher risk and prevent the occurrence of fracture. Six independent risk factors (age ≥ 64 years, hip fracture as the primary disease, osteoporosis, hemiarthroplasty (HA), bone resorption of the proximal femur, and long femoral stem) of PFF were identified in patients according to the Cox regression model. The occurrence of postoperative PFF was determined by these risk factors together rather than individually, and the contribution of each risk factor to the occurrence of hip fracture varied. Therefore, we built a weighted scoring system to comprehensively consider these risk factors and evaluate patients' overall risk. Surgeons can make clinical decisions according to the score of individual patients. If the patient's score is ≥ 10, the risk of periprosthetic fracture is considered to be high, and appropriate preventive measures are necessary to reduce the incidence of periprosthetic fracture.

Limitations

(1) This was a single-centre retrospective study. The sample size was not very large, and the results may not represent the overall population. (2) Without the participation of a third party, there may be some bias involved in the data collection and postoperative follow-up. (3) The incidence of postoperative periprosthetic fracture was not evaluated in this study. (4) The occurrence of postoperative PFF is affected by many factors, and one study cannot cover all potential factors. Therefore, some relevant factors might have been missed or undetected in the current study. (5) The predictive scoring system has not been verified or examined over a long follow-up period.

Conclusion

By conducting this retrospective study, we sought to determine some characteristics of postoperative PFF, such as the fracture classification (mainly Vancouver type B, accounting for nearly 80% of cases), fracture cause (mostly low-energy injury, such as slipping, tripping, or falling from a standing height), and time to fracture (30.35±23.15 months after operation). In addition, in our study, six independent risk factors for postoperative PFF were identified, namely, age ≥ 64 years, hip fracture as the primary disease, osteoporosis, HA, bone resorption of the proximal femur, and a long femoral stem were associated with a high risk of postoperative PFF. Furthermore, a predictive scoring system with a total score of 20 points was established for clinical surgeons to rapidly evaluate patients' postoperative PFF risk. A score less than 3 points indicates a low risk of PFF, while a score greater than 10 points indicates a high risk of PFF. Screening for high-risk patients undergoing THA, providing detailed discharge instructions, and implementing corresponding preventive measures in a timely manner may be strategies to help reduce the incidence of postoperative PFF.

Disclosure of conflict of interest

None.

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