

Original Article

A Study of Periprosthetic Femoral Stem Fractures in Hip Arthroplasty for Femoral Neck Fracture

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This study investigated the risk factors for bone fragility and perioperative periprosthetic femoral stem fractures in patients undergoing hip arthroplasty for femoral neck fractures. The records of 215 patients (42 male, 173 female; mean age, 84.4 years) were analyzed to assess correlations among periprosthetic fracture rates and sex, age, body mass index (BMI), Dorr classification, femoral stem fixation type (cemented/cementless), and bone mineral density (BMD) of the contralateral proximal femur. The overall prevalence of perioperative periprosthetic fractures was 4.7%. All patients with periprosthetic fractures were female, and all but one were ≥ 80 years of age. Fracture rates were higher in patients with lower BMI, although this difference was not significant. The fracture rates were 0%, 4.7%, and 7.9% for Dorr types A, B, and C, respectively, and 0% and 5.3% for patients who received cemented and cementless stems, respectively. The findings indicated that female patients, those of advanced age, those with lower BMI, and those with Dorr type C had lower BMDs. Although BMD was significantly lower in patients who received cemented stems compared to those who received cementless stems, no fractures were observed in the former group, suggesting that the use of cemented stems is safe for this high-risk population.

Key words: bone mineral density, cemented stem, Dorr classification, femoral neck fracture, periprosthetic femoral stem fracture

Femoral neck fractures are common in older adults with osteoporosis and are expected to increase in Japan, which has an aging population [1]. These fractures often lead to functional disability and have poor prognoses [2, 3]. Osteosynthesis is recommended for nondisplaced femoral neck fractures due to the high incidence of nonunion with conservative treatment [4, 5]. Conversely, prosthetic replacements, such as bipolar hip arthroplasty (BHA) or total hip arthroplasty (THA), are recommended for displaced femoral neck fractures because of the high incidence of osteonecrosis associated with osteosynthesis [6, 7]. While the treatment of displaced femoral neck fractures with prosthe-

ses generally yields good outcomes [6, 7], perioperative complications, such as periprosthetic femoral stem fractures, are known to occur. The one year mortality rate after periprosthetic femoral stem fractures is 11.2% [8]. The incidence of such fractures during the perioperative period is estimated to be between 1% and 5% [9-11]. Typically, cementless stems exhibit a higher fracture rate than cemented stems, with reported incidence rates of 3-5% for cementless and 0.1-1% for cemented stems [9-11]. The intraoperative fracture rate for cementless stems has been reported to be 14 times higher than that for cemented stems [12].

Consequently, conventional guidelines in Western countries recommend cemented stems for prosthetic

Received October 28, 2024; accepted April 3, 2025.

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Conflict of Interest Disclosures: No potential conflict of interest relevant to this article was reported.

replacement in femoral neck fractures [13, 14]. In contrast, in Japan, the second edition of the 2011 Japanese Orthopaedic Association (JOA) Clinical Practice Guidelines on the Management of Hip Fractures indicated that either cemented or cementless stems could be selected, depending on the case [15]. However, in the latest (third) edition, revised in 2021, the guidelines recommend cemented stems for cases with bone fragility to prevent periprosthetic femoral stem fractures [16]. Nonetheless, no clear indicators of bone fragility have been identified. In addition, while the use of cemented stems is expected to increase exponentially, in Japan their general use for femoral neck fractures remains technically challenging. For example, because there is only one hip surgeon who have extensive experience with cemented stems in our department, we find it challenging to use cemented stems for all proximal femoral fractures.

Additionally, femoral neck fractures are indicated for surgery on a quasi-emergent basis, making preoperative bone mineral density (BMD) testing practically impossible. There is thus a need for preoperative indicators beyond BMD to assess bone fragility.

Typically, the risks of osteoporotic and periprosthetic femoral stem fractures are higher in women and older individuals, as well as in those with low body mass index (BMI) [17-20]. The Dorr classification is commonly used to evaluate bone quality in the proximal femur through radiographic images [21]. Dorr *et al.* studied the biochemical, radiographic, and histological characteristics of different proximal femoral geometries, and classified them into types A, B, and C [21]. Type A features a thick cortex, narrow diaphysis, funnel shape, and dense bone. Type B indicates bone loss from the medial and, particularly, the posterior cortices, with the most proximal portion of the posterior cortex being thinned or absent. Type C proximal femurs show virtual loss of the medial and posterior cortices and possess a wide intramedullary canal, resulting in what is often described as a “stovepipe” appearance. The anterior and posterior cortices in type C may also be dramatically thinned. Type C is an additional risk factor for periprosthetic femoral stem fractures [21].

To our knowledge, few studies have investigated the risk factor of bone fragility necessitating cemented stems in patients undergoing hip arthroplasty for femoral stem fracture. To address these challenges, we here investigated whether bone fragility and periprosthetic

femoral stem fracture rates could be predicted based on easily quantifiable preoperative parameters such as sex, age, BMI, and the Dorr classification.

Materials and Methods

Ethical approval. This retrospective comparative study was conducted in accordance with the principles of the Declaration of Helsinki and approved by the Ethics Committee of Okayama Red Cross Hospital (approval number: 2023-18; approval date: May 30, 2023), which waived the requirement for informed consent due to the retrospective nature of this study.

Study design. This retrospective cohort study included 215 patients who underwent BHA or THA out of 275 femoral neck fractures treated at our department between August 2018 and June 2022 (Fig. 1). THA rather than BHA was indicated for highly active patients with low anesthesia risks. The exclusion criteria were as follows: 1) age < 65 years; 2) underwent conservative treatment; and 3) underwent osteosynthesis. Since this study focused on femoral neck fractures associated with osteoporosis, the target age range was set at ≥ 65 years. All patients had undergone BMD testing 1 week after surgery for the femoral neck fracture.

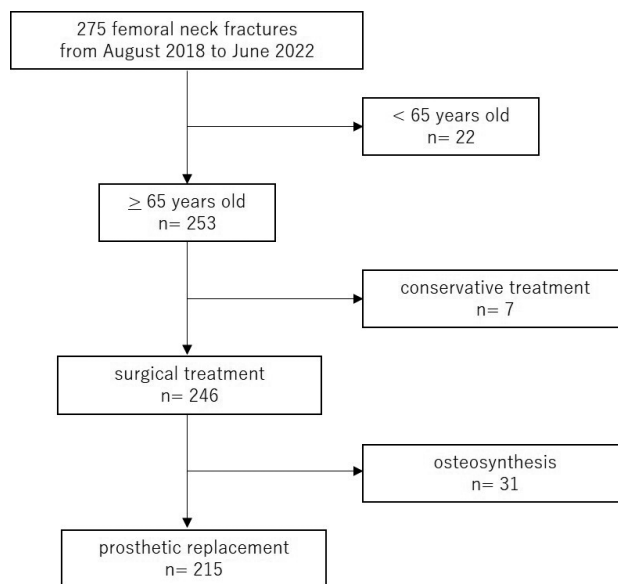


Fig. 1 Flow diagram depicting the retrospective patient selection. Of the 275 femoral neck fractures treated at our department between August 2018 and June 2022, 215 were included after application of the exclusion criteria.

Parameters. We investigated correlations between the rates of perioperative periprosthetic femoral stem fractures and each of sex, age, BMI, Dorr classification, surgical procedure (BHA or THA), surgeon experience, femoral stem type, and BMD of the contralateral proximal femur 1 week postoperatively.

Cohorts were formed based on age: <80, 80-89, and ≥ 90 years. The cutoff value for BMI was set at 18.5 kg/m^2 , which is regarded as the threshold for the underweight range. The Dorr classification was based on preoperative radiographic images of the hip. Surgeons were grouped based on their experience level as either <5 years or ≥ 5 years.

The BMD of the proximal femur was measured using dual-energy X-ray absorptiometry. The 2015 edition of the Japanese Guidelines for the Prevention and Treatment of Osteoporosis defines osteoporosis as a BMD <70% of the young adult mean (YAM). As per these guidelines, a young adult is regarded as 20-29 years old [22]. Thus, 70% was set as the cutoff value, and a comparative analysis was conducted between $\text{YAM} \leq 70\%$ and $>70\%$.

Patients who had already undergone contralateral proximal femur implantation were excluded from this comparative analysis. Consequently, BMD of the contralateral proximal femur was measured in 185 patients.

The choice of femoral stem was left to the discretion of the attending orthopedic surgeon, based on factors such as age and bone quality; however, no clear criteria were established in our department. Perioperative periprosthetic femoral stem fractures were defined as fractures diagnosed intraoperatively or caused by minor external forces within 1 month of surgery.

Statistical analysis. Age and YAM percentage values were expressed as means $\pm$ standard deviations unless otherwise indicated. Fisher's exact test was used to analyze the statistical significance of the correlations among the described parameters and the prevalence of perioperative periprosthetic femoral stem fractures. Differences in BMD according to the described parameters were analyzed using the Mann-Whitney *U* test and analysis of variance. The level of statistical significance was set at $p < 0.05$. All statistical analyses were performed using IBM SPSS statistics for Windows (version 23.0; IBM Corp., Armonk, NY, USA).

Results

The 215 patients included 42 males and 173 females, with a mean age of 84.4 ± 6.6 years. Perioperative periprosthetic femoral stem fractures occurred in 4.7% ($n = 10$) of patients, with 6 fractures diagnosed intraoperatively and 4 postoperatively. Intraoperative fractures were wired in 5 cases; in 1 case, the originally planned cementless stem was changed to a cemented stem due to an intraoperative fracture. One patient received no treatment for the fracture because of mild displacement.

All postoperative fractures were mildly displaced, and conservative treatment was selected after consultation with the patients and their families. One patient subsequently underwent modular head replacement to lengthen the leg due to stem subsidence without loosening.

The BMD of the contralateral proximal femur measured in 185 patients yielded an overall mean YAM percentage of $69.7 \pm 13.5\%$.

Table 1 depicts the prevalence of perioperative periprosthetic femoral stem fracture as determined by BMD, sex, age, BMI, Dorr classification, surgical procedure, years of surgeon experience, and femoral stem fixation type. None of these parameters yielded a statistically significant difference in fracture rates (all $p > 0.05$).

Specifically, in regard to the BMD by YAM the fracture rates were 1.1% ($n = 1$) and 6.5% ($n = 6$) in patients with $\text{YAM} > 70\%$ and $\leq 70\%$, respectively ($p > 0.05$). The fracture rates according to sex were 0% in males and 5.8% ($n = 10$) in females ($p > 0.05$). The fracture rates increased by successive age cohorts, from 2.1% ($n = 1$) to 5.2% ($n = 6$) and 5.8% ($n = 3$) in the <80, 80-89, and ≥ 90 -year-old cohorts, respectively, albeit without significant difference among them ($p > 0.05$). The fracture rates by BMI group were 9.2% ($n = 6$) for BMI < 18.5 kg/m^2 and 2.7% ($n = 4$) for BMI $\geq 18.5 \text{ kg/m}^2$ ($p > 0.05$). The fracture rates were higher for Dorr classification types B and C, at 4.7% ($n = 7$) and 7.9% ($n = 3$), than for type A, in which there were no fractures ($p > 0.05$). The fracture rates according to surgical procedure were 4.5% ($n = 9$) for BHA and 5.9% ($n = 1$) for THA, again with no significant difference ($p > 0.05$). When examined by surgeon experience, the fracture rates were 4.2% ($n = 8$) and 7.7% ($n = 2$) for inexperienced (<5 years) and experienced (≥ 5 years) surgeons, respectively ($p > 0.05$).

Fracture rates by fixation type were 0% for cemented stems and 5.3% ($n=10$) for cementless stems ($p>0.05$). Finally, 89% (25/28) of cemented stems and 88% (164/187) of cementless stems were implanted by surgeons with <5 years of experience; these rates were roughly equal and not significantly different ($p>0.05$).

The intraoperative and postoperative fracture rates, along with selected treatments according to the type of cementless stem, are presented in Table 2. In addition, the fracture rates according to stem products are listed in Table 3.

In addition to the above analyses of fracture rates,

we conducted an analysis of BMD differences by sex, age, BMI, Dorr classification, and stem fixation type, as shown in Table 4. We found that BMD was significantly lower in female patients, older patients, those with lower BMI, and those with Dorr classification type C ($p<0.05$). Lastly, BMD was significantly lower in patients who received cemented stems compared to those with cementless stems ($p<0.05$).

Discussion

The prevalence of perioperative periprosthetic fem-

Table 1 Prevalence of perioperative periprosthetic femoral stem fractures, as determined by BMD, sex, age, BMI, Dorr classification, surgical procedure, years of surgeon experience and femoral stem fixation type

Parameter	Cohort	Fracture rate, n (%)	P -value
BMD (YAM%)	>70% ($n=93$)	1 (1.1%)	0.064
	≤70% ($n=92$)	6 (6.5%)	
Sex	Male ($n=42$)	0 (0%)	0.216
	Female ($n=173$)	10 (5.8%)	
Age (years)	<80 ($n=48$)	1 (2.1%)	0.089
	80–89 ($n=115$)	6 (5.2%)	
	≥90 ($n=52$)	3 (5.8%)	
BMI (kg/m ²)	<18.5 ($n=65$)	6 (9.2%)	0.070
	≥18.5 ($n=150$)	4 (2.7%)	
Dorr classification	Type A ($n=27$)	0 (0%)	0.266
	Type B ($n=150$)	7 (4.7%)	
	Type C ($n=38$)	3 (7.9%)	
Surgical procedure	BHA ($n=198$)	9 (4.5%)	0.802
	THA ($n=17$)	1 (5.9%)	
Years of surgeon experience	<5 years ($n=189$)	8 (4.2%)	0.432
	≥5 years ($n=26$)	2 (7.7%)	
Stem fixation type	Cemented ($n=28$)	0 (0%)	0.366
	Cementless ($n=187$)	10 (5.3%)	

BMD, bone mineral density; BMI, body mass index; BHA, bipolar hip arthroplasty; THA, total hip arthroplasty; YAM, young adult mean. The level of statistical significance is set at $p<0.05$.

Table 2 Prevalence and treatment of intraoperative and postoperative periprosthetic femoral stem fractures by type of cementless stem

Type	Intraoperative fracture	Postoperative fracture	Treatment
Fit and fill ($n=69$)	1 (1.4%)	1 (1.4%)	Wiring, 1; conservative, 1
Flat taper ($n=108$)	5 (4.6%)	3 (2.8%)	Wiring, 3; conservative, 4; conversion to cemented stem, 1

Table 3 Prevalence of perioperative periprosthetic femoral stem fractures as determined by stem type

Product name	Corporation	Type	Fracture rate, <i>n</i> (%)
Perfix C [®] (<i>n</i> = 23)	Kyocera	Composite beam	0 (0%)
EXETER [®] (<i>n</i> = 5)	Stryker	Taper slip	0 (0%)
910PFXAGHA collared [®] (<i>n</i> = 69)	Kyocera	Fit and fill	2 (2.9%)
Ovation Tribute Hip Stem [®] (<i>n</i> = 42)	Japan Medical Dynamic Marketing	Flat taper	2 (9.5%)
Taperloc Complete Microplasty [®] (<i>n</i> = 23)	Zimmer Biomet	Flat taper	1 (6.3%)
Avansera [®] (<i>n</i> = 25)	Mizuho	Flat taper	2 (8.0%)
Profemur TL [®] (<i>n</i> = 18)	Microport Orthopaedics	Flat taper	1 (5.6%)
Tri-Lock BPS [®] (<i>n</i> = 17)	Depuy Synthes	Flat taper	0 (0%)

Table 4 Prevalence of BMD, as determined by sex, age, BMI, Dorr classification, and stem fixation type

Parameter	Cohort	BMD (mean YAM, %)	<i>P</i> -value
Sex	Male (<i>n</i> = 37)	76.8% ± 11.6	<0.001
	Female (<i>n</i> = 148)	68.0% ± 13.4	
Age (years)	< 80 (<i>n</i> = 45)	72.7% ± 13.6	0.020
	80–89 (<i>n</i> = 98)	70.5% ± 13.4	
	≥ 90 (<i>n</i> = 42)	64.9% ± 12.8	
BMI (kg/m ²)	< 18.5 (<i>n</i> = 46)	60.9% ± 12.2	<0.001
	≥ 18.5 (<i>n</i> = 139)	71.2% ± 13.0	
Dorr classification	Type A (<i>n</i> = 26)	80.2% ± 12.7	<0.001
	Type B (<i>n</i> = 133)	71.1% ± 11.1	
	Type C (<i>n</i> = 26)	52.5% ± 9.7	
Stem fixation type	Cemented (<i>n</i> = 22)	63.8% ± 15.6	0.026
	Cementless (<i>n</i> = 163)	70.6% ± 13.1	

BMD, bone mineral density; BMI, body mass index; YAM, young adult mean. The level of statistical significance is set at *p* < 0.05.

oral stem fractures in this study was 4.7%, slightly higher than in other studies [9–11]. This may be attributed to the fact that cementless stems were used in most of the cases (87%) in this study. Globally, among hip arthroplasties for patients aged >75 years, cemented stems are associated with lower perioperative fracture and revision rates compared to cementless stems. Nevertheless, cementless stems are frequently utilized, a phenomenon known as the “uncemented paradox” [23]. This trend arises from concerns regarding the complexity of cementation and bone cement implantation syndrome.

Conversely, the mortality rate after proximal femur

fractures increases with longer preoperative waiting times, and thus surgical intervention for these fractures should be performed as early as possible [24]. This need for timely intervention, combined with the high prevalence of this type of fracture, frequently results in treatment by general orthopedic surgeons who are not accustomed to the cementing technique. In the present study, for example, 88% (189/215) of surgeries were performed by surgeons with <5 years of experience. Thus, to assist the triage of patients with proximal femur fractures, so that patients with bone fragility, who will require cemented stems, can be assisted by a hip surgeon with sufficient experience with cemented

stems, we sought to identify parameters predictive of bone fragility other than BMD.

BMD increases from childhood to adolescence, with bone mass peaking by adulthood. In adulthood, bone resorption by osteoclasts surpasses bone formation by osteoblasts due to aging and menopause, leading to a decline in BMD [25]. Consequently, the prevalence of osteoporosis rises with age and is significantly higher in women than in men. In a Japanese survey of the general population aged >40 years, 3.4% of men and 12.4% of women were found to have osteoporosis of the lumbar spine, while 19.2% of men and 26.5% of women had osteoporosis of the femoral neck, indicating a clear gender disparity [17]. Furthermore, the incidence of proximal femoral fractures mirrors the trends of osteoporosis, increasing with age. In the present study, BMD was significantly lower in women and older patients; however, no statistically significant differences were observed in fracture rates. Notably, all patients with periprosthetic fractures were female, and all but one were aged ≥ 80 years, indicating that these parameters are risk factors for periprosthetic fractures.

In addition, mechanical loading affects bone metabolism. BMD increases in response to mechanical loading [26] and decreases in conditions such as quadriplegia or weightlessness [27]. Therefore, osteoporosis is more prevalent in individuals with lower BMI. For every 1 kg/m² decrease in BMI, proximal femur BMD decreases by 0.0082 g/cm², irrespective of age, sex, or race [28]. Lower BMI correlates with higher fracture rates of the proximal femur [29]. In the present study, BMD was significantly lower in patients with BMI < 18.5 kg/m², although there were no significant differences in fracture rates according to BMI. The only case of periprosthetic fracture was a patient who was <80 years of age and had an extremely low BMI of 11.6 kg/m².

Regarding the Dorr classification, type A provides good fixation with or without cement, type B presents no problems with fixation, and type C is not suitable for fixation. Type C is associated with lower BMD [30] and higher incidence of periprosthetic fractures [31]. In the present study, although BMD was significantly lower in patients with type C, no significant differences in fracture rates were observed among the Dorr classification groups. The periprosthetic fracture rate was higher in type C, with no cases in type A, although this difference was also not significant.

Cemented stems were employed when bone quality

was deemed poor. Although BMD was significantly lower in cases with cemented stems compared to those with cementless stems, no fractures were observed in any of the patients with cemented stems. In addition, similar to the case with cementless stems, 89% of surgeries using cemented stems were performed by surgeons with <5 years of experience. Based on these observations, we conclude that even inexperienced surgeons can use this technique safely if they are assisted by surgeons familiar with cemented stems.

This study has a few limitations. First, due to the small population size and relatively low prevalence of periprosthetic fractures, no statistically significant differences were observed. In addition, the use of cemented or cementless stems was left to the discretion of the attending orthopedic surgeon, without fixed criteria, leading to potential selection bias. The use of cemented stems in only 12% (26/215) of cases exemplifies this issue.

In conclusion, we found that female patients, those of advanced age, those with lower BMI, and those with Dorr type C had lower BMDs in our analysis cohort. The overall fracture rate in this study was somewhat high at 4.7%. Although BMD was significantly lower in patients who received cemented stems compared to those with cementless stems, no fractures were observed in the cemented stem group, suggesting that cemented stems are safe for this high-risk population.

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