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Does the Periprosthetic Fracture Pattern Depend on the Stem Fixation Method in Total Hip Arthroplasty?

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Background: Management of periprosthetic femoral fractures (PFFs) is reportedly challenging. Different patterns of PFFs would occur based on whether stem fixation was primarily cemented or cementless and whether these patterns would be associated with clinical outcomes, such as subsidence, fracture union, and complications, after stem revision.

Methods: A retrospective comparative study was performed, involving 52 PFF patients treated with tapered fluted modular stems (TFMSs). In the 52 patients with Vancouver B2 or B3, including 21 cemented stems and 31 cementless stems, fracture patterns and bone stock were analyzed. Clinical outcomes after revision surgery using the TFMSs were compared between the two groups.

Results: Transverse or short oblique type PFFs occurred around the cemented stem with loosening at the bone-cement interface. The Paprosky type III femoral deficiency and Vancouver type B3 fracture were observed more frequently in the cemented stem group. Otherwise, spiral fractures occurred more frequently in the cementless group ($p < 0.001$). Excessive subsidence of > 5 mm was observed more frequently in the cemented stem group ($p < 0.001$). The re-revision rates were higher in the cemented group than in the cementless group ($p = 0.047$).

Conclusions: In our study, it was found that the patterns of transverse or oblique PFFs were more frequently produced with cemented stems, while long spiral fractures were more frequent with cementless stems. Stem subsidence and reoperation related to complications were more common in patients with PFFs around cemented stems than those with PFFs around cementless stems.

Keywords: *Taper fluted modular stem, Periprosthetic femoral fracture, Revision total hip arthoroplasty*

The incidence of postoperative periprosthetic femoral fractures (PFFs) is estimated to be between 0.07% and 18% and is likely to increase with the increasing incidence of multiple revision surgeries.[1,2] PFFs are major complications associated with hip arthroplasty and pose a tough challenge for reconstructive orthopedic surgeons. The most commonly occurring fractures around femoral stems are of the Vancouver type B.[3] Generally, using a locking plate with or without cerclage wiring and the addition of a cortical strut allograft can be performed to manage type B fractures if the stem is stable (Vancouver type B1). However, if the stem *in situ* is loose, then revision with standard or long stems (type B2) or bypassing the fracture region with allogenic bone grafting or composite bone graft techniques in the bone defect (type B3) is commonly recommended.[4-9)]

Distally fixed tapered fluted modular stems (TFMSs) have proven to be a reliable treatment for B2 or B3 PFFs.[10] While unique fracture patterns around the well-fixed cemented stems have been reported, there has been no re-

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port of fracture patterns around cemented stems whether the bone-cement interface had been loosened.[11] Additionally, it has been reported that a specific pattern of periprosthetic fracture was observed in the case of well-fixed cementless stems coated by grit blasting.[12] Therefore, in this study, we aimed to compare the fracture patterns and treatment results around the rectangular cementless and polished cemented stems that required stem revision.

METHODS

This study was approved by the Institutional Review Board of Jeonbuk National University Hospital (No. CUH 2019-02-042). Due to the nature of the retrospective study and medical record review, IRB approval was obtained without patient informed consent. PFFs were classified using the Vancouver periprosthetic fracture classification system. PFFs due to high-energy injuries, polytrauma, or intraoperative fractures were excluded. Consistent with the aim of the study, we included only Vancouver B2 or B3 PFFs that required stem revision in the study population. Loosening was confirmed by intraoperative assessment of the fracture site to determine stem stability. A ball-tip pusher was used to test stem stability through the fractured window. It was double-checked using a stem removal set after dislocation when stem loosening was suspected.

Seventy-seven patients met the inclusion criteria, but 22 were excluded because they were not available for follow-up for more than 12 months. Finally, 52 hips (16 women and 36 men) were included in the study cohort (Table 1). The mean follow-up duration was 24.7 months (range, 12–67 months). The mean patient age was 69.8 years (range, 53–82 years). Twenty-one patients had a taper slip-type polished cemented stem in the index operation. Seven femoral stems were Heritage (Zimmer, Warsaw, IN, USA) and 14 were Exeter (Stryker, Newbury, UK). All 31 had a grit-blasted rectangular cementless stem as the primary stem. Fifteen femoral stems were SL-PLUS (Smith & Nephew, Baar, Switzerland). Sixteen femoral stems were C2 (Lima-Lto, Udine, Italy). Routine preoperative investigations included radiography and three-dimensional computed tomography to evaluate periprosthetic fractures and stem stability.

We analyzed whether there was any difference in fracture characteristics according to the cementless or cemented stem used in the primary hip arthroplasty. A transverse fracture pattern was defined as a break at a right angle to the long axis of the femur. An oblique fracture was defined as a break in the oblique direction. A long oblique or spiral fracture was defined as a break that traversed both planes or when the fracture line was at least twice the length of the diameter of the diaphysis. Femoral deficiency around the primary stem was retrospectively investigated on radiographs obtained before the occurrence of PFF using the Paprosky classification.[13]

Pre-injury radiographs were collected to identify

Table 1. Demographic Characteristics of the Patients with PFFs

Variable	Cemented stem (Taper-slip, n = 21)	Cementless stem (Grit-blasted, n = 31)	*p*-value
Sex			0.064
Male	11 (52.4)	25 (80.6)	
Female	10 (47.6)	6 (19.4)	
Age at the occurrence of PFFs (yr)	71.5 (67–80)	68 (53–82)	0.126
Age at primary hip arthroplasty (yr)	65 (52–77)	58 (35–72)	< 0.001
Survival time of stem to the occurrence of PFFs (yr)	4 (1–20)	9 (1–26)	0.349
Primary cause of index hip arthroplasty			< 0.001
Osteoarthritis	2	3	
Osteonecrosis of the femoral head	4	23	
Femoral neck fracture	16	9	
Follow-up (mo)	26 (12–58)	23.5 (12–67)	0.837

Values are presented as number (%) or median (range).
PFF: periprosthetic femoral fracture.

loosening of the stem or examine the bone/cement interface. All cemented primary stems generally had a taper-slip type with a polished surface. All cementless primary stems were tapered rectangular stems with grit-blasted coating (type 3C using the classification system of cementless stems).[14] All patients underwent revision surgery using the same previous surgical approach; 39 underwent surgery using a posterior approach, and 13 underwent surgery using a direct lateral approach in a modified Hardinge fashion in the lateral decubitus position by a single surgeon (SJY). Extended trochanteric osteotomies were performed for the complete extraction of the remnant cement mantle in 2 hips.

During the operation, the most distal part of the fracture was identified, and then a cerclage wire was applied at the most proximal part of the intact distal femur to prevent further distal propagation of the fracture. It also served as a useful radiological marker for measuring prosthesis migration during postoperative follow-up. After removal of the loose femoral stem, an appropriate distal component of the modular femoral stem was inserted to reduce the displaced femoral fracture and achieve stability of the femoral side. Thirty-one revision femoral stems were the lima modular revision stem (Lima-Lto, Udine, Italy). The osteotomized greater trochanter or osteoporotic fractured proximal femur was reconstructed with 2 or 3 wires. An autogenous bone graft from the iliac crest was performed on the fracture site. Postoperatively, weight-bearing was protected for the first 6–8 weeks. Full weight-bearing was usually achieved at 3 months.

The duration of radiological union of the fractures and failures after revision surgery were evaluated. Radiological union was defined as the presence of trabecular crossing in at least 2 views, and clinical failure was defined as the necessity for re-revision surgery within 1 year after revision surgery. If there was apparent component loosening or stem subsidence of 15 mm or more, it was considered radiologic failure.[15] Radiological evaluation included full-sized radiographs of the femur. Stem subsidence was assessed by measuring the distance from the reference points (with the knot in the wire or junction of the modular stem serving as the reference point) to the tip of the stem. Radiographic magnification was adjusted using femoral head templates. Clinical evaluation was performed using modified Harris hip score (mHHS)[16] and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores.[17]

Statistical analyses were performed using IBM SPSS ver. 21.0 (IBM Corp., Armonk, NY, USA). Categorical variables were compared using the chi-square test or with linear-by-linear associations, and continuous variables were analyzed using the Mann-Whitney *U*-test. Results are presented as mean ± standard deviation or median with range. Statistical significance was set at $p < 0.05$.

RESULTS

The median patient age at the index arthroplasty in the cemented stem group was older than that in the cementless stem group (Table 1). The median age at the time of periprosthetic fractures was 71.5 years (range, 67–80 years) in the cemented stem group and 68 years (range, 53–82 years) in the cementless stem group. These differences were not statistically significant ($p = 0.207$). There was no significant difference between the two groups in terms of the time to fracture from the primary arthroplasty. The median time from the index operation to the periprosthetic fracture was 4 years (range, 1–20 years) in the cemented group and 9 years (range, 1–26 years) in the cementless stem group ($p = 0.133$).

The primary reason for the index arthroplasty was femoral neck fractures in the cemented stem group, while osteonecrosis of the femoral head was the major reason for the index arthroplasty in the cementless stem group ($p < 0.001$). According to the Dorr classification, the shapes of the proximal femurs at primary arthroplasty were not significantly different between the two groups ($p = 0.482$). Other demographic variables are shown in Table 1. Periprosthetic fracture-related variables were compared between the two groups. The Paprosky classifications of the femoral deficiencies were significantly different between the two groups; type IIIb deficiencies were more commonly observed in the cemented stem group than type II deficiencies were, and type IIIa deficiencies were predominant in the cementless stem group (Table 2). Based on the Vancouver classification, the cemented stem group presented with the B3 type more often than the B2 type, which was predominant in the cementless group ($p < 0.001$). These stems were pathologically loose on pre-injury radiographs.

In terms of fracture patterns, transverse or short oblique fractures were observed more frequently in the cemented stem group than in the cementless group (Fig. 1). The spiral fracture with or without butterfly segments was the major pattern in the cementless group ($p < 0.001$) (Fig. 2). In the cemented stem group, most fractures occurred near the distal end of the stem and cement plug (Table 2).

The mean postoperative mHHS at the 1-year follow-up was 80.2 points (range, 54–81 points) in the cemented group and 82.5 points (range, 62–87 points) in the cementless group. The mean WOMAC scores were

Table 2. Fracture-Related Variables in Primary Cemented or Cementless Stem Groups

Variable	Cemented stem (Taper-slip, n = 21)	Cementless stem (Grit-blasted, n = 31)	*p*-value
Fracture pattern			< 0.001
Transverse	10	0	
Oblique	5	0	
Spiral (butterfly)	0	29	
Comminuted	6	2	
Paprosky classification of femoral deficiency (%)			0.046
II	2	10	
IIIa	8	14	
IIIb	11	7	
Vancouver classification (%)			< 0.001
B2	6	26	
B3	15	5	
BMD (T score), median (range)	–3.4 (–0.5 to –4.8)	–2.5 (0.1 to –4.7)	0.267

BMD: bone mineral density.

Fig. 1. Preoperative radiograph obtained after a periprosthetic fracture (transverse type) around a cemented stem (Vancouver type B2) at 6 years after the index surgery in a 75-year-old female patient.

Fig. 2. Preoperative radiograph obtained after a periprosthetic fracture (long spiral type) around a cementless stem (Vancouver type B2) at 11 years after the index surgery in a 70-year-old male patient.

79 and 82 in the cemented and cementless group, respectively. Thus, the HHS and WOMAC scores (the indicators of postoperative clinical outcomes) showed better results in the cementless group, but the difference was not statistically significant ($p = 0.75$).

All patients achieved satisfactory union uneventfully. While the mean time required for the radiological bone union was longer in the cemented stem group (mean, 4.6 months; range, 3.8–6.7 months) than in the cementless group (mean, 3.7 months; range, 2.8–5.2 months), this difference was not significant ($p = 0.09$).

Excessive subsidence of > 5 mm was observed more

Table 3. Incidence and Causes of Further Surgery after Revision Surgery in Patients with Primary Cemented and Cementless Stems

Outcomes and complications of revision using a modular tapered stem	Cemented stem (Taper-slip, n = 21)	Cementless stem (Grit-blasted, n = 31)	*p*-value
Stem subsidence 5–10 mm	9 (43)	2 (7)	
Stem subsidence ≥ 10 mm	3 (14)	1 (3)	
Subtotal	12 (57)	3 (10)	< 0.001
Greater trochanter upward migration	2 (9)	0	
Infection	1 (5)	1 (3)	1.000
Re-revision due to any reason	5 (23)	1 (3)	0.047

Values are presented as number (%).

frequently in the cemented stem group than in the cementless stem group ($p < 0.001$). The rate of re-revision surgery for any reason was higher in the cemented group than in the cementless group ($p = 0.047$). Two greater trochanter nonunion and migration cases were managed with autogenous bone grafts with wiring or a greater trochanter grip plate (Table 3). An extended trochanteric osteotomy was additionally performed to remove the cement mantle, and nonunion occurred in this area. In the follow-up period, all original PFF sites obtained union.

DISCUSSION

Transverse Nature of Fracture Patterns around the Cemented Stem

The pattern of PFFs associated with cemented fixation may affect the clinical outcomes of patients undergoing femoral component revision surgery; however, this has not yet been documented. In this study, PFF patterns around loose femoral components were different based on whether cemented or cementless fixation was used. The most common fracture pattern was transverse or oblique fractures around the cemented stems and spiral fractures around the cementless stems. In terms of fracture characteristics, loosening in the cement-host bone interface might allow abnormal stress concentration around the distal tip of the femoral component or cement plug level, which could frequently result in transverse or oblique patterns of PFFs around the end of the stem. In 6 patients, PFFs showed comminuted fracture patterns around the stem. A possible explanation is that oblique fracture patterns might start from the end of the stem and then propagate to the osteolytic area, changing into a burst fracture pattern with high proximal comminution (Fig. 1). However, in a cementless stem, spiral fracture patterns occurred around partially loosened stem beds, which might have caused dissociation of the remnant on-growth interlock from the surface of the grit-blasted coated stems in this study (Fig. 2). Additionally, we postulated that the periprosthetic fracture patterns in the primary cemented stems, such as oblique or transverse fractures, might also contribute to the delayed union because of the smaller surface area available for bone healing in these types of fractures compared to that in spiral fracture types, which can adversely affect early stability and bone union. Overall, the time required for union during fracture healing after revision surgery for primary cemented stems was longer.

TFMS Stem Subsidence in the Cemented Stem Group

This study observed a greater prevalence of reoperation after stem revision with TFMSs in PFFs around primary cemented stems than in those around primary cementless stems. Possible causes are discussed in this section, concerning which characteristics of PFFs might be associated with fixation methods of stems in the femoral canal. TFMSs have become popular for managing PFFs because of their advantages for controlling leg length and anteversion. With this stem, gradual subsidence is a relatively common complication that generally occurs within 3 months. In this study, significant subsidence of the stem occurred more frequently in the cemented primary stem group than in the cementless group after revision surgery using TFMSs. In some cases, it was impossible to completely remove the cement from the part where complete debonding did not occur at the bone/cement interface. Therefore, subsidence might be associated with incomplete cement mantle removal or endosteal ischemia due to cementation during primary stem fixation. Mumme et al.[18] reported that there is still some difficulty in achieving complete removal of a residual well-fixed cement mantle, showing a mean value of 1.6 ± 0.4 mm with conventional methods.[19) These remnants of the cement mantle in the intramedullary canal may interrupt on-growth on the stem surface. Additionally, cement extraction is a procedure that endangers the bone stock, particularly in cases of constant contact and indentation between cement and the bone. A cortical window or transfemoral approach may be helpful, but these methods induce weakness of the bone, resulting in reduced healing at the osteotomy site, limited diaphysis contact of the cementless revision stem, and an increased risk of infection due to the extended time required for the surgical approach.

Incomplete Removal of Bone Cement

Preservation of the periosteal and endosteal blood supply is an important factor for bone healing after fracture.[20,21)] Revision surgery for periprosthetic fractures includes open reduction, reaming, and insertion of a new stem into the medullary canal and additional periosteal cerclage. These procedures can jeopardize the periosteal area and interfere with endosteal blood circulation, which may in turn result in ischemia of endo-/exosteal circulation. In particular, primary cemented stems can lead to unfavorable situations for a bone union. Endosteal circulation may be damaged by thermal injury during cementation during the index operation and by using power-driven instruments, including drills and burrs, for cement removal during cement extraction.[22-26)]

Deficient Bone Stocks around the Cemented Stem

Furthermore, in the primary cemented group, Paprosky femoral deficiency type IIIb proximal femoral deficiencies and Vancouver type B3 fractures were observed more frequently. Proximal femoral remodeling was more common in loosely cemented femoral stems than in cementless stems. Those factors could not only induce intraoperative fractures during the insertion of revision stems, but they could also affect the reconstitution of proximal femurs after revision surgery. A comminuted fracture around cemented stems could affect delayed fracture healing after stem revision and result in a greater trochanter migration or nonunion.

Limitation of the Study

Our study has several limitations. First, it is a retrospective study conducted at a single level I trauma center. Second, the study had a small sample size and was potentially underpowered. Third, patterns of periprosthetic fractures or loosening could be associated with the types of coated surfaces of the cementless stems; however, we did not consider types of surface coating in this study. The type of stem in terms of the fixation method in the cementless stem group was also not considered. Recently, concerning the specific characteristic of PFFs, it has been reported that long spiral fractures were frequently observed in rectangular, grit-blasted primary stems.[12)] We did not control for the use of tapered rectangular stems used in primary arthroplasty as a potential confounder.

Further investigation is needed to elucidate the effects of cement fixation and loosening around the stem on fracture patterns and clinical outcomes using a case-controlled multicenter study. Therefore, further studies should be needed to identify the factors affecting PPFs regarding the multivariate analysis. Grammatopoulos et al.[11)] reported observing a periprosthetic fracture pattern around the cemented stem. Among the patients included in their study, the period from index arthroplasty to periprosthetic fracture was less than 3 years in 7 cases (33.3%). Also, 8 cases (38%) were Vancouver A or B1, not B2 or higher fractures requiring stem revision. The observation period is different from our study.

Moreover, PFFs around the cemented stem with loosened bone/cement interface can be viewed as a long spiral pattern because it can proceed in a bursting pattern starting from a fractured form of a transverse or short oblique pattern. However, this study classified it as a transverse or short oblique fracture with bursting instead of spiral. In this case, PFFs that require stem revision were mostly Vancouver B2 or B3.

Nevertheless, this study indicates that cemented or cementless stems may create different periprosthetic fracture patterns associated with loosening characteristics. The cemented stem may produce transverse or oblique patterns of PFFs compared to long spiral fractures in cementless stems. The PFFs around the cemented stem may be more challenging to treat with tapered fluted stems than those occurring around a cementless stem in terms of nonunion, subsidence, and the requirement for rerevision surgery. Stem subsidence and reoperation were more common complications in PFFs around cemented stems than around cementless stems treated by TFMSs. To improve clinical outcomes, surgeons should consider (1) complete removal of cement materials when using extended trochanteric osteotomy, (2) autogenous bone grafts at the fracture site, and (3) allo-strut augmentation to reconstitute low femoral bone stock for PFFs around loose cemented femoral components.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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