Risk Factors for Intraoperative Proximal Femoral Fracture During Primary Cementless THA

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abstract

Intraoperative proximal femoral fracture, one of the most common complications of total hip arthroplasty (THA), occurs more often in cementless procedures and can affect rehabilitation, hospitalization time, and cost of treatment. The goal of this study was to identify risk factors for intraoperative proximal femoral fracture in THA to identify high-risk groups preoperatively and minimize the incidence of this complication. This nested case-control study included 904 primary cementless THA procedures (769 patients) performed between January 2009 and July 2015. Of this group, 24 fractures occurred, accounting for 2.65% of cases. Predisposing factors for intraoperative proximal femoral fracture from the medical records included patient sex, diagnosis of osteoarthritis, operated on hip (left or right), type of implant, alcohol consumption, operative approach, age, and body mass index. The Noble classification, Dorr classification, and Metaphyseal-Diaphyseal Index score measured by picture archiving and communication systems were used to evaluate the anatomy and morphologic features of the proximal femur. A multivariate analysis was performed to evaluate potential risk factors for fracture during THA, including anterolateral (modified Hardinge) approach, use of the Corail (DePuy, Warsaw, Indiana) stem, Metaphyseal-Diaphyseal Index score, age, and sex. A Corail stem, the anterolateral approach, advanced age, and a low Metaphyseal-Diaphyseal Index score were associated with increased risk of fracture. All fractures were treated with cerclage wire techniques, and none has required revision to date. [*Orthopedics*. 2017; 40(2):e281-e287.]

As a successful "operation of the century," total hip arthroplasty (THA) can relieve pain and help patients to recover hip function.[1] With an aging population and increasing numbers of THA implants in service, the incidence of intraoperative proximal femoral fracture has increased. However, even though THA has been used successfully for several decades, intraoperative proximal femoral fracture is a common complication of primary THA, especially with cementless femoral components.[2] According to the literature, the incidence of intraoperative fracture is 3% to 18% for primary THA. These fractures occur primarily during the process of femoral canal broaching or implant insertion while the surgeon is attempting to obtain a tight press-fit.[3] This complication can affect rehabilitation, hospitalization time, and cost of treatment. Inadequate fixation can lead to fracture displacement or nonunion, poor bone ingrowth, and aseptic loosening of the femoral stem, ultimately requiring reoperation.[4]

The choice of cementless primary THA or THA with cement remains controversial. Intraoperative periprosthetic fracture occurs more often in cementless procedures because the operative technique requires more aggressive reaming of the medullary canal and tight fixation

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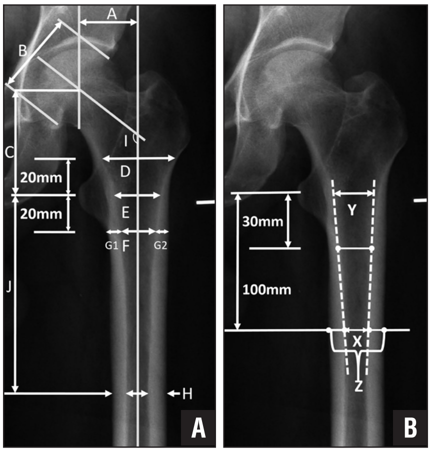

Figure 1: Radiologic measurements of the proximal femur according to Noble et al.[7] A, femoral head offset; B, femoral head diameter; C, femoral head position; D, canal width 20 mm above the mid-lesser trochanter line; E, canal width at the mid-lesser trochanter line; F, canal width 20 mm below the mid-lesser trochanter line; G1 and G2, the 2 cortical thicknesses at the same level as F; H, isthmus diameter; I, neck-shaft angle; J, isthmus position below the mid-lesser trochanter line. The canal flare index defined by Noble et al[7] is D/H; the Metaphyseal-Diaphyseal Index defined by Chana et al[9] is D÷F/(G1+G2) (A). Radiologic measurements of the proximal femur: canal-to-calcar ratio (X/Y) and cortical index [(Z-X)/Z] (B).

of the stem to avoid micromotion between the femoral component and cortical bone.[5] Surgeons now pay greater attention to the effect of intraoperative proximal femoral fracture on operative outcomes. Although investigation of risk factors could help to identify groups at high risk for this complication and possibly reduce the incidence rate, there are few relevant research reports on cementless primary THA. This study investigated risk factors for intraoperative proximal femoral fracture to identify high-risk groups and reduce the incidence of fracture.

Materials and Methods

This nested case-control study included a series of 904 procedures (769 patients) performed between January 2009 and July 2015. Surgery was performed by 6 senior surgeons. Of these surgeons, 3 used an anterolateral (modified Hardinge) approach and the other 3 used a posterolateral approach. The study included 366 male patients (439 procedures) and 403 female patients (465 procedures). Of 139 patients undergoing bilateral THA, all had the same implant type on both sides and none had intraoperative proximal femoral fracture on both sides. Because some patients underwent bilateral THA, the total number of procedures was used for analysis and calculations. Average age at the time of primary THA was 57.38±12.60 years (range, 17-97 years). Average body mass index at the time of surgery was 24.91±3.60 kg/m^2 (range, 15.81-38.57 kg/m^2). All patients had 1 of 2 femoral components for THA: Synergy (Smith & Nephew, Memphis, Tennessee) or Corail (DePuy, Warsaw, Indiana). The Synergy implant is intended for proximal fixation and is porous, with hydroxyapatite coating, with a tapered and straight design. The Corail stem is of mixed fixation type, with hydroxyapatite coating, double tapering, and a straight design. In the current study, 42 procedures were performed with the Corail stem with an anterolateral (modified Hardinge) approach, and the other 57 were performed with a posterolateral approach.

The current study used patient records and radiographs to analyze the annual incidence of fracture and risk factors for intraoperative proximal femoral fracture in THA. For all patients, a C-arm radiograph machine was used to determine whether there were intraoperative fractures that were not detected during surgery. Reinspection with a bedside radiograph machine was performed before patients left their beds. A total of 24 patients had intraoperative fractures. Intraoperative proximal femoral fracture was defined as a nondisplaced incomplete linear fracture above the lesser trochanter.[6] Of the 24 fractures, 9 occurred in male patients and 15 occurred in female patients, none of whom had bilateral THA. All proximal femoral fractures occurred during impaction of the final femoral component rather than during reaming or broaching of the canal or during trial reduction. No postoperative periprosthetic femoral fractures occurred.

Risk factors for intraoperative proximal femoral fracture were estimated by univariate analysis (chi-square test, analysis of variance, and Student's *t* test), followed by multivariate analysis. For all patients, the authors obtained information on patient sex, diagnosis of osteoarthritis, operated on hip (left or right), type of implant, alcohol consumption, operative approach, age, and body mass index from the medical records. Picture archiving and communication systems were used in every case, and the Noble classification, Dorr classification, and Metaphyseal-Diaphyseal Index score were used to evaluate the anatomy and morphologic features of the proximal femur (**Figure 1**).[7-9]

Noble et al[7] used the canal flare index to describe the shape of the proximal femur: canal flare index scores of less than 3.0 are described as stovepipe-shaped canals, scores of 3.0 to 4.7 are described as normal canals, and scores of 4.8 to 6.5 are described as champagne flute-shaped canals (**Figure 1**).

Dorr et al[8] classified the proximal femur into 3 distinct patterns, based on shape and bone structure. Type A bone has thick medial and lateral cortices on anteroposterior radiographs and a large posterior cortex on lateral radiographs. Patients with a thick diaphyseal cortex have a funnel-shaped proximal femur. Type B bone exhibits bone loss from the medial cortex and especially the posterior cortex. The intramedullary canal of type B femurs is wider than that of type A femurs. Type C bone has virtually lost the medial and posterior cortices; in addition, the anterior and posterior cortices are thinned and appear fuzzy on lateral radiographs. The diameter of the intramedullary canal is usually wide on lateral radiographs.

Compared with the canal-to-bone ratio, the Metaphyseal-Diaphyseal Index offers more information. The Metaphyseal-Diaphyseal Index can describe both bone quality and morphologic features to predict suboptimal femoral morphologic features and a high chance of periprosthetic fracture in osteoporotic femurs of poor bone quality, where a cementless prosthesis would be contraindicated (**Figure 1**).[9]

Radiologic measurements were reanalyzed by the same observer (H.C.) to determine intraobserver agreement and by another observer (Y.L.) to determine interobserver agreement.

For univariate analyses, $P<.05$ was considered significant. Multivariate analysis was performed with an entry method stepwise bivariate logistic regression according to univariate analysis results. Significance was established at $P<.05$. All univariate and multivariate analyses were performed with SPSS, version 19.0 (IBM, Armonk, New York).

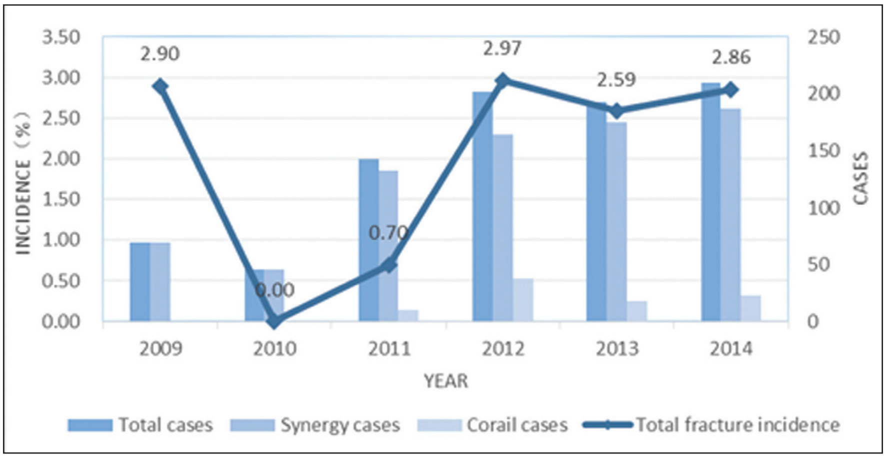

Figure 2: Annual incidence of fractures and surgical cases (Synergy; Smith & Nephew, Memphis, Tennessee; Corail; DePuy, Warsaw, Indiana).

Results

Of the 904 primary cementless THA procedures, 24 (2.65%) intraoperative proximal femoral fractures occurred (**Figure 2**). Because this study covered only the period through July 2015, the incidence of fractures and surgical cases for all of 2015 was not recorded.

Of the 904 primary cementless THA procedures included in this study, 805 were performed with Synergy stems and another 99 were performed with Corail stems. Of the subgroup of patients who underwent treatment with Synergy stems, 16 fractures (1.99%) occurred. In the Corail subgroup, 8 fractures occurred (8.08%). All of the risk factors that were considered for univariate analysis are shown in **Table 1**.

No significant statistical differences in proximal femur type were found between the nonfracture group and the fracture group, according to the Noble and Dorr classifications.[7,8] In addition to femoral head offset, radiologic measurements showed no statistical significance (**Tables 2-3**). In the fracture group, the Metaphyseal-Diaphyseal Index score was much lower than that of the nonfracture group (P=.016).

Intraobserver variation of canal flare index and Metaphyseal-Diaphyseal Index score, assessed by calculating the intraclass correlation coefficient, was 0.982 and 0.959, respectively; interobserver variation, assessed by calculating the interclass correlation coefficient, was 0.958 and 0.833, respectively. The kappa statistic was used to assess intra- and interobserver variation of the Dorr classification, and the findings were 0.901 and 0.784, respectively. No statistically significant differences in agreement or reliability of intra- and interobserver measurements were found.

Univariate analysis showed that statistically significant risk factors in the fracture group included anterolateral (modified Hardinge) approach (P=.003), Corail stem (P=.003), and Metaphyseal-Diaphyseal Index score (P=.016). The other factors were not significant. Covariates of multivariate logistic regression analysis included these 3 factors, with adjustment for age and sex (**Table 4**), showing that, in addition to these 3 factors, advanced age was a significant and independent risk factor for intraoperative proximal femoral fracture. However, it is possible that univariate analysis included confounding factors that may have affected the accuracy of results.

All fractures were treated with cerclage wire techniques and trained with no weight-bearing functional exercise until 6 weeks after surgery. To date, no patient has required revision.

Discussion

Along with increasing numbers of THA implants in service and an aging population, the rate of intraoperative proximal femoral fracture is also increasing.[3] The odds of fracture are higher for cementless stems than for cemented stems because these fractures always occur during implant insertion while the surgeon is attempting to obtain a press-fit.[10]

Because of variety in sample size, femoral stem manufacturers, insertion techniques, and demographic changes, the reported incidence of intraoperative proximal femoral fracture has varied significantly.[11] The incidence is estimated to be 3% to 18% during primary THA,[3] but Berend and Lombardi[12] reported a higher incidence (2.95%-27.8%). In the current study, the incidence of fracture was 2.65%, and there was a change in the overall fracture rate over time (**Figure 2**). No fractures occurred in 2010, and the highest incidence of fracture (2.97%) occurred in 2012. Synergy stems were the only type of stems used for THA in 2009 and 2010, and the incidence of fracture was higher in 2009 and gradually declined with time. This change may have been re-

Table 1

Univariate Analysis of Risk Factor Data

Risk Factor/Attribute	Nonfracture Group	Fracture Group	Incidence	*P*
Total No.	880	24	2.65%	
Sex, No.				
Female	450	15	3.23%	.272
Male	430	9	2.05%	
Diagnosis, No.				
Developmental dysplasia of the hip	232	11	4.52%	.218
Avascular necrosis	369	6	1.60%	
Femoral head/neck fracture	145	3	2.03%	
Idiopathic	42	2	4.55%	
Rheumatoid arthritis	61	2	3.17%	
Posttraumatic	31	0	0.00%	
Operated on hip, No.				
Right	410	10	2.38%	.633
Left	470	14	2.89%	
Implant stem, No.				
Synergy[a]	789	16	1.99%	.003
Corail[b]	91	8	8.08%	
Alcohol, No.				
Yes	122	2	1.61%	.338
No	758	22	2.82%	
Operative approach, No.				
Anterolateral	316	16	4.82%	.002
Posterolateral	564	8	1.40%	
Body mass index, mean±SD, kg/m^2	24.96±3.75	24.09±3.82		.265
Age, mean±SD, y	57.26±12.568	61.83±13.57		.079
Canal flare index shape, No.				
Stovepipe	34	2	5.56%	.318
Normal	575	14	2.38%	
Champagne flute	271	8	2.87%	
Dorr classification, No.				
Type A	453	12	2.58%	.430
Type B	345	8	2.27%	
Type C	82	4	4.65%	
Metaphyseal-Diaphyseal Index score, mean±SD	32.94±14.22	25.89±8.11		.016

[a]*Smith & Nephew, Memphis, Tennessee.*
[b]*DePuy, Warsaw, Indiana.*

lated to a learning curve with a new type of stem. As surgeon experience with this stem increased over time, the incidence of intraoperative fracture decreased significantly. From 2011 to 2014, the surgeons used both stem types, and during this period, the incidence of fracture increased initially and then reached a plateau at approximately 2.65%. The incidence of fracture increased after use of the Corail stem, which was an independent high-risk factor.

Although implant design was a risk factor for intraoperative proximal femoral fracture, the reason why the Corail stem carried a high risk of fracture is difficult to interpret. The use of 2 types of indications for prosthesis is heavily dependent on the preoperative preference of the surgeon. In this study, Corail stems were used in a small number of patients, and for years, the authors have used a Corail stem that is shorter than the Synergy stem. This may represent a bias toward greater experience with the Synergy stem, and there may be a learning curve associated with the Corail stem. However, the surgeons in the study had extensive experience with THA, and all of the surgeons used both types of femoral components. From 2011 to 2014, the annual rate of fracture with Corail stems remained at a fixed level, unlike the rate in patients receiving Synergy implants. Therefore, it is unlikely that less experience with the Corail component would be the only explanation for the difference in fracture rates.

A greater percentage of female patients received Corail implants (66.67%) compared with Synergy implants (49.57%) (P=.01). Female sex was previously reported as a risk factor for fracture during femoral component implantation.[5] Although sex was not an independent risk factor in the current study, more female patients were included in the Corail group (P=.01, Student's t test), which may have been a reason why Corail femoral components were more easily fractured. However, logistic analysis controlled for all other covariates when implant stems were analyzed to reduce the effects of confounding factors; therefore, differences in sex had little effect on the result.

The authors hypothesized that the different designs in 2 types of prosthesis stems potentially could affect fracture incidence. After the femoral canal is broached, femoral preparation instrumentation fits well in the canal. To achieve an initial press-fit between a cementless femoral prosthesis and bone, stems are approximately 1 mm larger than corresponding broaches and the broached canal. The authors named the difference between the perimeter of the prosthesis and the perimeter of the broached medullary cavity the "perimeter difference," and each prosthesis had a different perimeter difference. When an oversized femoral component is inserted into the medullary cavity, it can easily fracture; with an increase in perimeter difference, inserting a prosthesis may produce greater assembly strain.[13,14]

Preparation of the femoral canal for the Corail implant involves a "broach-only" technique that can compact and preserve bone instead of reaming the canal. The broach design differs from the typical diamond tooth broach pattern used in the Synergy technique, in which reaming the diaphyseal canal, followed by broaching of the metaphysis with a diamond tooth broach, typically crushes and extracts bone.[15] The manufacturer's information indicated that the perimeter difference of the Synergy stem was 1.25 mm, but this information was not supplied for the Corail stem. Because cancellous bone was preserved in the canal for the Corail implant, this technique could lead to expansion of the perimeter difference during insertion. All of the fractures in the current study occurred during implant insertion and may have been related to greater microstrain during insertion. Considering the wear effect of repetitive femoral preparation instrumentation, the perimeter difference could increase even more. However, this conjecture has not been confirmed and will be addressed in future work.

Table 2

Radiologic Measurements of Femoral Canal Shape[a]

Radiologic Measurement	Nonfracture Group	Fracture Group	P
Femoral head offset, mm	36.93	33.54	.030
Femoral head diameter, mm	48.64	50.66	.054
Femoral head position, mm	58.61	56.7	.286
Canal width +20 mm, mm	56.1	52.73	.355
Canal width +0 mm, mm	28.4	28.11	.750
Canal width -20 mm, mm	21.36	22.57	.207
Isthmus position, mm	126.6	128	.715
Isthmus width, mm	13.15	13.14	.984
Neck-shaft angle	133.1°	135.8°	.230

[a]*According to Noble et al.*[7]

Table 3

Radiologic Measurements[a]

Radiologic Measurement	Nonfracture Group	Fracture Group	P
Cortical index			
Anterior-posterior	0.50	0.50	.790
Medial-lateral	0.45	0.47	.258
Canal-to-calcar ratio	0.69	0.66	.374

[a]*According to Dorr et al.*[8]

Table 4

Results for Each Risk Factor in Multivariate Analysis

Risk Factor	Odds Ratio	95% Confidence Interval	$P_{logistic}$
Sex	1.442	0.570-3.649	.439
Age	1.041	1.004-1.079	.027
Anterolateral approach	3.553	1.447-8.728	.006
Corail stem[a]	4.494	1.752-11.527	.002
Metaphyseal-Diaphyseal Index score	0.923	0.875-0.973	.003

[a]*DePuy, Warsaw, Indiana.*

The current study found a significantly increased risk of fracture in THA procedures performed through an anterolateral (modified Hardinge) approach to the hip (4.82%) compared with THA procedures performed through a posterior approach (1.40%). Difficulties in exposure and adequate visualization with the anterolateral approach may have contributed to this complication. Factors related to the increased risk of fracture associated with the anterior approach may include positioning of the leg and the resulting forces directed on the proximal femur by the retractors, capsule, abductors, and external rotators during femoral exposure and preparation. Variations in exposure of the trochanteric bed through the anterior and posterior approaches also may play a role in this observed difference, in addition to the potential effect of femoral bowing on implant position.[16]

The effect of age on intraoperative proximal femoral fracture is controversial. Advanced age is related to poor bone quality, osteoporosis, and falls.[11] In contrast, Nowak et al[5] reported that younger age was a high risk factor because osteoarthritis in younger patients is often secondary to another disorder that could result in anatomic changes within the proximal femur, qualitative changes in bone tissue, and functional changes or limited hip movement. Therefore, risk related to age probably differed in previous studies because of a variety of factors, and this risk can be confounded by osteoporosis and medical comorbidities.

The anatomy and morphologic features of the proximal femur are critical for press-fitting to the femoral stem, and the loss of cortical bone and simultaneous widening of the intramedullary canal of the proximal femur could reduce the strength of the femur and increase the risk of fracture.[17] Although univariate analysis did not show statistical significance, the incidence of fracture was high in stovepipe-shaped proximal femurs and Dorr type C proximal femurs (**Table 1**). In the fracture group, the average Metaphyseal-Diaphyseal Index score, the ratio of the diaphysis to the metaphysis, was much lower than in the nonfracture group, confirming poor bone quality in the fracture group.

The etiology of osteoarthritis has an important impact on femoral fracture. Developmental dysplasia of the hip is a common etiology of THA. In the current study, there were 243 (26.88%) cases of developmental dysplasia of the hip in 904 procedures and 11 cases of developmental dysplasia of the hip in the fracture group. When the cases were divided into groups with and without developmental dysplasia of the hip, the rate of femoral fracture in developmental dysplasia of the hip was 2.65 times higher than in those without developmental dysplasia of the hip (P=.034). Developmental dysplasia of the hip leads to alterations in femoral anatomy, such as increased neck-shaft angle (coxa valga) and antetorsion angle, shortening of the extremity, and stenosis of the medullary canal. These deformities of the proximal femoral metaphysis can lead to difficulty during femoral component fixation and increase the risk of fracture.[18,19] Rheumatoid arthritis also can lead to a high risk of fracture because of poor bone quality, multiple joint involvement with the need for replacement of different joints, and considerable comorbidity.[20]

Much research has shown that female sex is a risk factor for fracture, probably because of the association with osteoporosis and remaining structural bone.[5,10,16] In the current study, there were 15 female patients among the 24 fractures, even though the data showed no statistical significance. Future research with more rigorous statistical modeling and a larger sample size may be necessary to evaluate this risk factor.

Much of the previous literature considered body mass index a potential risk factor for intraoperative proximal femoral fracture, but its influence is controversial. Biomechanical evaluation showed that when body mass index was greater than 33 kg/m^2, femoral specimens had a significantly higher rate of periprosthetic fracture.[21] However, in some other studies, body mass index was not a significant risk factor. Ponzio et al[6] found that the average body mass index in the fracture group was 29.1±6.5, which was not significantly different from that in the nonfracture group (29.1±5.1). Nowak et al[5] also reported that body mass index appeared to be a nonsignificant factor. In the current study, body mass index had no significant effect on the incidence of intraoperative proximal femoral fracture (P=.265). However, average body mass index in the current study was 24.91±3.60 kg/m^2, so the study sample may not have been suitably representative of obesity.

Treatment of periprosthetic femoral fracture in THA depends on fracture location and implant stability.[22] Treatments include nonoperative management, cerclage wires, long-stem prostheses, and allograft cortical struts, among others. Many treatment options have been described, but no single treatment has been found to be the gold standard.[11,22] All fractures in the current study were intraoperative nondisplaced incomplete linear fractures. These fractures were treated with cerclage wire techniques to reduce the risk of crack propagation and achieve satisfactory initial stability of the implant,[23] prolonged avoidance of weight bearing, and subsequent protected weight bearing. No revisions of the femoral component have been required in the fracture cohort to date.

Limitations

In the current study, the Corail stem, anterolateral (modified Hardinge) approach, advanced age, and low Metaphyseal-Diaphyseal Index score were significant independent risk factors for intraoperative proximal femoral fracture. However, this study had several limitations. First, the study was a retrospective analysis, which leads to a nonrandomized cohort of surgical approaches and implant selection. Second, the series involved 6 surgeons, which may be a confounding factor. Third, only 99 patients were treated with the Corail stem, and the sample size was not balanced. Future research must control for this imbalance. Finally, some user-dependent bias occurred in the image survey, although this bias was eliminated by selecting corrected points along the boundary.

Conclusion

Preoperative templating may reduce the incidence of proximal femoral fracture. Surgeons must pay greater attention to patients with the Corail stem, the anterolateral approach, advanced age, and low Metaphyseal-Diaphyseal Index score, especially those with lower body mass index. During insertion of the femoral components, a sudden change in resistance is highly suggestive of this complication. The outcome of this type of fracture treated with cerclage wire techniques should be studied in the future.

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