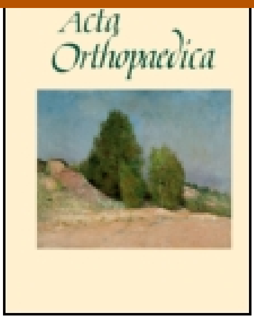

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Risk factors for intraoperative calcar fracture in cementless total hip arthroplasty

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Background and purpose — Intraoperative periprosthetic femoral fracture is a known complication of cementless total hip arthroplasty (THA). We determined the incidence of—and risk factors for—intraoperative calcar fracture, and assessed its influence on the risk of revision.

Patients and methods — This retrospective analysis included 3,207 cementless THAs (in 2,913 patients). 118 intraoperative calcar fractures were observed in these hips (3.7%). A control group of 118 patients/hips without calcar fractures was randomly selected. The mean follow-up was 4.2 (1.8–8.0) years. Demographic data, surgical data, type of implant, and proximal femur morphology were evaluated to determine risk factors for intraoperative calcar fracture.

Results — The revision rates in the calcar fracture group and the control group were 10% (95% CI: 5.9–17) and 3.4% (CI: 1.3–8.4), respectively. The revision rate directly related to intraoperative calcar fracture was 7.6%. The Hardinge approach and lower age were risk factors for calcar fracture. In the fracture group, 55 of 118 patients (47%) had at least one risk factor, while only 23 of118 patients in the control group (20%) had a risk factor (p = 0.001). Radiological analysis showed that in the calcar fracture group, there were more deviated femoral anatomies and proximal femur bone cortices were thinner.

Interpretation — Intraoperative calcar fracture increased the risk of revision. The Hardinge approach and lower age were risk factors for intraoperative calcar fracture. To avoid intraoperative fractures, special attention should be paid when cementless stems are used with deviant-shaped proximal femurs and with thin cortices.

■

The use of cementless femoral stems in total hip arthroplasty (THA) has increased in recent years (Mäkelä et al. 2010, SHAR 2011, THL 2011, AOANJRR 2012). One reason for this shift has been the associated lower revision rate due to aseptic loosening in young patients (Wechter et al. 2013). On the other hand, better survival of THAs with cemented stems than with cementless stems has been found in older patients (Mäkelä et al. 2014). A close geometric fit between cementless femoral stems and supporting proximal femoral bone has been proposed to be essential for long-term implant fixation (Soballe et al. 1992, Dorr et al. 1993, Fessy et al. 1997, Laine et al. 2000, Emerson et al. 2002, Lecerf et al. 2009). Implant designs have been improved and tapered, and porous-coated stems have been introduced (Kim and Kim 1993, McLaughlin and Lee 1997, McNally et al. 2000, Casper et al. 2012, Streit et al. 2013).

Intraoperative calcar fracture is a known complication of cementless THA (Lindahl 2007). Female sex, higher age, smaller stem size, and thin cortical bone have been reported to be risk factors for intraoperative femoral fracture (Napoli et al. 2012, Ponzio et al. 2015).

We investigated the incidence of and risk factors for intraoperative calcar fracture in cementless THAs. Several radiographic classifications have been proposed to assess the shape and cortical thickness of the proximal femur (Noble et al. 1988, Rubin et al. 1992, Dorr et al. 1993, Husmann et al. 1997, Laine et al. 2000, Yeung et al. 2006, SHAR 2011). We used the Noble and Dorr classifications for our radiological analysis of the anatomy of the proximal femur. In addition, we studied whether the femoral component migrated during follow-up, how the fractures were treated, and whether calcar fracture influenced the revision risk.

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Table 1. Patient demographics and surgical data

	Calcar fracture group n (%)	Control group n (%)	p-value
Sex			
Male	50 (42)	64 (54)	
Female	68 (58)	54 (46)	0.07
Mean age at surgery (range)	60 (29–81)	61 (32–79)	0.3
Diagnosis			
Primary osteoarthritis	70 (59)	93 (79)	
Developmental dysplasia of the hip	23 (20)	11 (9)	
Fracture [a]	7 (6)	6 (5)	
Rheumatoid arthritis	8 (7)	3 (2)	
Avascular necrosis	5 (4)	4 (3)	
Other	5 (4)	1 (1)	0.03
Surgical approach			
Posterior	35 (30)	55 (47)	
Hardinge–lateral	83 (70)	63 (53)	0.01
Femoral implant type			
Tapered	13 (11)	10 (8.5)	
Fit and fill	96 (81)	108 (92)	
Other	9 (8)	0	0.01

[a] Acute or sequelae of the hip

Table 2. Risk factors for calcar fracture

Risk factor	Calcar fracture group n (%)	Control group n (%)	p-value
None	63 (53)	95 (81)	
At least one risk factor	55 (47)	23 (20)	< 0.001
Developmental dysplasia of the hip	20 (17)	2 (1)	
Long-term cortisone medication	8 (7)	8 (7)	
Rheumatoid arthritis	7 (6)	7 (6)	
Osteoporosis	5 (4)	1 (1)	
Hip fracture [a]	5 (4)	1 (1)	
Alcohol abuse	1 (1)	4 (3)	
Other	9 (8)	0	

[a] Acute or sequelae of the hip

Patients and methods

Patients

This was a retrospective case-control study. 3,207 THAs (in 2,913 patients, 1,609 males (50%)) underwent cementless THA between January 2004 and December 2009 in 3 participating university hospitals (Table 1). The mean follow-up time was 4.2 (1.8–8.0) years.

There were 118 intraoperative calcar fractures (3.7%). A control group was formed by selecting THAs from the patient pool of 3,090 THAs without calcar fracture by using a random number generator. The control patients were stratified according to hospital.

THAs were done from the lateral decubitus position via the posterolateral or direct lateral (Hardinge) surgical approach. The operations were performed by 39 orthopedic surgeons and by 7 residents under the direct supervision of the senior orthopedic surgeon.

The THAs used 16 different cementless femoral stems (Table 1), which were arbitrarily divided into 3 groups based on design: tapered (e.g. Conserve Profemur TL (Wright Medical Technology, Arlington, TN), M/L Taper (Zimmer, Warsaw, IN), and Corail (DePuy Orthopaedics, Warsaw, IN)); fit and fill (e.g. Bi-Metric (Biomet, Warsaw, IN) and Synergy (Smith and Nephew, Memphis, TN); and other (e.g. Reach (Biomet) and Biomet CDH). THAs were performed according to the manufacturers' instructions.

Treatment of the intraoperative calcar fractures included fixation with cables (n = 114) or partial weight bearing without cables (n = 4). In the control group, full immediate weight bearing was allowed for all patients. Reasons for revision were analyzed from the patient medical records and radiographs.

Risk factors

Patient-dependent risk factors (age, sex, diagnosed osteoporosis, long-term oral cortisone medication for any reason, rheumatoid arthritis, and history of alcohol abuse) were analyzed from the patient medical records (Table 2). Other patient-dependent factors such as developmental dysplasia of the hip, previous childhood hip osteotomies, and acute and previous hip fractures were also evaluated and considered as potential risk factors. Diagnosis of hip dysplasia was based on the patient medical records. Surgeon's experience (consultant orthopedic surgeon or resident) was also analyzed as a risk factor.

Radiological analysis

Radiological analyses were based on preoperative and postoperative radiographs, and also the latest radiograph. The first postoperative radiograph was taken in the supine position during the first 48 h after THA. Subsequent radiographs were taken in the standing position. Picture archiving and communication systems (PACS) were used in every participating hospital, and radiological scaling with a magnifying marker was used for every radiograph.

The canal flare index (CFI) was calculated (Figure). The CFI expresses the shape of the proximal femur. CFIs < 3.0 are described as stovepipe-shaped canals, 3.0–4.7 as normal canals, and 4.8–6.5 as champagne flute-shaped canals (Noble et al. 1988).

Femurs were qualitatively assessed based on 3 distinct patterns of the shape and bone structure of the proximal femur (Dorr et al. 1993). Type-A femurs had thick medial and lateral cortices on anterior-posterior radiographs and a large posterior cortex on lateral radiographs. Thick diaphyseal cortices render the proximal femur funnel-shaped. Type-B femurs showed bone loss from the medial cortex on anterior-posterior radiographs and from the posterior cortex on lateral radiographs. The intramedullary canal of type-B femurs was wider than that in type-A femurs. Type-C femurs had lost nearly all medial and posterior cortices; they were thin and might

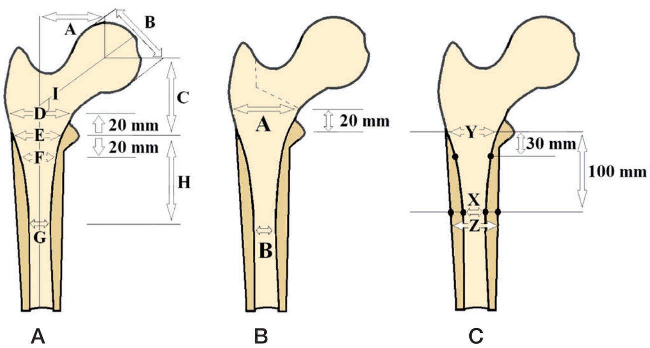

Figure. A. Radiological measurements of the proximal femur according to Noble: A, femoral head offset; B, femoral head diameter; C, femoral head position; D, canal width 20 mm above the mid-lesser trochanter line; E, canal width at the mid-lesser trochanter line; F, canal width 20 mm below the mid-lesser trochanter line; G, isthmus diameter; H, isthmus position below the mid-lesser trochanter line; I, neck-shaft angle.
B. Radiological canal flare index (CFI) measurements of the proximal femur according to Noble: A, canal width +20 mm above the mid-lesser trochanter line; B, isthmus diameter. CFI = A / B.
C. Radiological measurements of the proximal femur: canal-calcar ratio (X / Y) and cortical index ((Z–X) / Z).

display a fuzzy appearance on radiographs. The intramedullary canal diameter was usually wide on lateral radiographs. Anterior-posterior cortical index, mediolateral cortical index, and the canal-to-calcar ratio were measured (Figure) (Dorr et al. 1993).

Migration of the femoral component during follow-up was evaluated by measuring the distance from the tip of the greater trochanter to the femoral component shoulder, based on postoperative radiographs and the most recently obtained radiograph after calibration of the digital radiographic image measurement tool.

Measurements were re-analyzed after 2 months, by the same observer (SM) to determine intraobserver agreement and by the other observer (JK) to determine interobserver agreement. The reliability of the observers was also evaluated with a parallel test.

Statistics

For continuous variables, comparisons between the calcar fracture group and the control group were done using the Mann-Whitney U-test. For categorical variables, Pearson's chi-square test was used. Fischer's exact test was used to analyze differences in operative diagnosis between the groups. The multivariable logistic regression model was used, due to heterogeneity of the variables involved affecting the risk of calcar fracture. The variables selected for analysis are known to be potentially confounding factors for arthroplasty registry database studies. These variables were age, sex, surgical approach, and proximal femur morphology according to Noble and Dorr. The selection of these adjustment variables was based on our own hypotheses and the previous literature. There are many different radiological measurements and classifications of the proximal femur in the literature, but we believe that the Noble and Dorr classifications are the best known and the most often used. Bland-Altman comparison analysis was used to determine the intra- and interobserver agreement, and Pitman's test of difference was done to study intra- and interobserver reliability. Any p-value ≤ 0.05 was considered statistically significant. The data were analyzed using SPSS 19.0.0 and Stata 13 software.

Ethics

The ethics review committee of the University of Turku gave permission for this study (ETMK: 78/1801/2013).

Results

The incidence of intraoperative calcar fracture in the 3,207 patients was 3.7%. In the calcar fracture group, the incidence of hip dysplasia was 20%, as compared to 9.3% in the control group (p = 0.001) (Table 1). There was no statistically significant difference in follow-up time between the calcar fracture group and the control group.

The multivariable logistic regression analysis showed that the Hardinge approach was an independent risk factor for calcar fracture (OR = 2.4, 95% CI: 1.3–4.4) (Table 7). The Hardinge approach was used in 70% of the THAs in the calcar fracture group but in only 47% of the THAs in the control group (p = 0.01) (Table 1). The multivariable logistic regression analysis showed that lower age was an independent risk factor for calcar fracture (OR = 0.94, CI: 0.94–1.00; p = 0.03).

There was a statistically significant difference in the distribution of femoral stem types between groups (p = 0.006) (Table 1). The mean migration of the femoral component during follow-up was 1.2 (0–23) mm in the calcar fracture group and 0.7 (0–28) mm in the control group (p = 0.2).

Risk factors for calcar fracture

In the calcar fracture group, 55 of the 118 patients (47%) had at least 1 risk factor; in the control group, the corresponding number was 23 of 118 (20%; p = 0.001) (Table 2).

Consultant orthopedic surgeons performed 113 of the 118 operations (96%) in the calcar fracture group and 116 of the 118 operations (98%) in the control group. Residents carried out 5 of the 118 THAs (4%) in the calcar fracture group and 2 of the 118 THAs (1.7%) in the control group (p = 0.03).

Influence of calcar fracture on revision surgery

Revision for any reason was performed on 12 of the 118 patients (10%; CI: 5.9–17) in the calcar fracture group and on 4 of the 118 patients (3.4%; CI: 1.3–8.4) in the control group (p = 0.04). In the calcar fracture group, 9 of the 12 revisions were performed as a result of calcar fracture during the index operation. 4 of 9 of these femoral revisions were performed within 2 days after the index surgery. All of these 4 revisions were performed because the intraoperative calcar

Table 3. Radiological measurements of femoral canal shape according to Noble (Noble et al. 1988)

Radiological measurements	Calcar fracture group [a] mean (range)	Control group mean (range)	p-value
Femoral head offset, mm	40 (0–59)	43 (28–59)	0.01
Femoral head diameter, mm	48 (0–67)	50 (39–68)	0.02
Femoral head position, mm	56 (0–83)	61 (42–86)	0.01
Canal width +20 mm, mm	42 (0–60)	44 (30–57)	0.01
Canal width +0 mm, mm	26 (0–36)	28 (17–35)	0.04
Canal width –20 mm, mm	20 (0–31)	21 (14–28)	0.2
Isthmus position, mm	118 (0–194)	119 (79–160)	0.8
Isthmus width, mm	11 (0–19)	12 (6–19)	0.05
Neck-shaft angle, degrees	129 (0–153)	132 (120–151)	0.08

[a] The proximal femurs of 2 patients were so deformed that some measurements could not be performed in a reliable way.

Table 4. Classification of femoral canal shape according to Noble et al. (1988). 118 hips in each group

CFI shape	Calcar fracture group n (%)	Control group n (%)
Stovepipe	17 (14)	10 (9)
Normal	78 (66)	105 (82)
Champagne flute	21 (18)	13 (9)
Impossible to measure	2 (2)	0

p-value 0.02

Table 5. Radiological measurements according to Dorr et al. (1993)

Radiological measurements	Calcar fracture group [a] mean (range)	Control group mean (range)	p-value
Intramedullary femoral canal diameter, mm			
AP	12 (0.0–20)	12 (6–19)	0.2
AP proximal	28 (0.0–39)	30 (21–40)	0.01
ML	16 (0.0–38)	17 (0.0–25)	0.7
ML proximal	32 (0.0–49)	35 (0.0–46)	0.06
Cortical index			
AP	0.57 (0.0–0.73)	0.59 (0.46–0.75)	0.08
ML	0.45 (0.0–0.66)	0.50 (0.0–0.69)	0.06
Canal-to-calcar ratio	0.60 (0.0–1.29)	0.59 (0.36–0.83)	1.0

[a] The proximal femurs of 2 patients were so deformed that some measurements could not be performed in a reliable way.
AP: anteroposterior; ML: mediolateral.

Table 6. Radiological classification according to Dorr et al. (1993). 118 hips in each group

Dorr classification	Calcar fracture group n (%)	Control group n (%)
Type A	55 (47)	72 (61)
Type B	42 (36)	39 (33)
Type C	13 (11)	2 (2)
Impossible to measure	8 (7)	5 (4)

P-value 0.01

fracture was not diagnosed until the postoperative radiography. On the other hand, the revision rate after adequate cable fixation during the index surgery was 4% (5/118). There were 8 femoral stem revisions in a subgroup (n = 114) in which the intraoperative calcar fracture was treated with cables and full or partial weight bearing. 4 calcar fractures were treated with partial weight bearing without cables and 1 one of these had a femoral stem revision (p = 0.02).

Morphological measurements from radiographs

In the calcar fracture group, the patients had narrower proximal femoral canals and more varus femoral necks (Tables 3–6).

The multivariable logistic regression analyses were done by comparing proximal femur types according Noble and Dorr classifications with adjustment for age and sex (Noble et al. 1988, Dorr et al. 1993). In the Noble classification, stovepipe-type and champagne flute-type proximal femurs were compared to normal-type proximal femurs to evaluate the risk of intraoperative calcar fracture of these 2 types of proximal femurs. The stovepipe-type proximal femurs did not have a higher risk of intraoperative calcar fracture than normal-type proximal femurs (OR = 1.9, CI: 0.76–4.9; p = 0.2) (Table 7). The champagne flute type had a higher risk of having intraoperative calcar fracture than the normal type (OR = 2.8, CI: 1.1–6.9) (Table 7). In the Dorr classification, Dorr type B and Dorr type C were compared with Dorr type A. Dorr type B did not have a higher risk of intraoperative calcar fracture than Dorr type A (OR = 1.5, CI: 0.76–2.9) (Table 7). There was a higher risk of calcar fracture if the proximal femur was Dorr type C rather than Dorr type A (OR = 6.5, CI: 1.3–33) (Table 7).

Intra- and interobserver error

The mean difference between intraobserver measurements ranged from −2.3 mm to 1.3 mm (CI: −3.8 to 3.8) and the mean difference in measured neck-shaft angle was −2.3° (CI: −3.8 to −0.8). The mean difference between interobserver measurements ranged from −0.2 mm to 4.0 mm (CI: −1.7 to 5.8) and the mean difference in measured neck-shaft angle was −2.5° (CI: −5.7 to 0.7). Pitman's test revealed that there were no statistically significant differences in agreement or in the reliability of intraobserver and interobserver measurements.

Discussion

Second-generation cementless THAs were introduced in the late 1980s, and their use became widespread in the late 1990s (McNally et al. 2000, Dumpleton and Manley 2005, Kim 2005). Correct size and positioning of the femoral compo-

Table 7. Multivariable logistic regression analysis adjusted for age and sex. In the Noble classification, stovepipe-type and champagne flute-type proximal femurs were compared to normal-type proximal femurs. In the Dorr classification, Dorr type-B and Dorr type-C were compared to Dorr type-A

	Calcar fracture group n (%)	Control group n (%)	OR	95% CI	p-value
Sex					
Male	50 (42)	64 (54)	1		
Female	68 (58)	54 (46)	1.3	(0.69–2.3)	0.5
Mean age at surgery	60	61	0.97	(0.94–1.0)	0.03
(range)	(29–81)	(32–79)			
Surgical approach					
Posterior	35 (30)	55 (47)	1		
Hardinge–lateral	83 (70)	63 (53)	2.4	(1.3–4.4)	0.01
CFI shape					
Normal	78 (66)	105 (82)	1		
Stovepipe	17 (14)	10 (8)	1.9	(0.76–4.9)	0.2
Champagne flute	21 (18)	13 (9)	2.8	(1.1–6.9)	0.03
Impossible to measure	2 (2)	0 (0)			
Dorr classification					
Type A	55 (47)	72 (61)	1		
Type B	42 (36)	39 (33)	1.5	(0.76–2.6)	0.2
Type C	13 (11)	2 (2)	6.5	(1.3–33)	0.02
Impossible to measure	8 (7)	5 (4)			

OR: odds ratio.

nent is essential for restoration of the function of the hip and for osseointegration and survival of the implant (Rubin et al. 1992). A press-fit stem may cause fracturing of the calcar area of the femur during implantation (Berry 2002). Contemporary femoral stems usually have a built-in feature of press-fit, i.e. stems are about 1 mm larger than corresponding broaches. Intraoperative fracture of the calcar area is a well-known complication of cementless THA, but the risk factors for fracture are partly unclear (Berry 1999, Lindahl 2007).

Heterogeneities in study populations, implants, and surgical approaches affect the incidence of intraoperative calcar fracture after cementless THA. We are not aware of any clinical publication with a study group as large as ours, and where the incidence and reasons for the intraoperative calcar fracture were evaluated in detail. There have been some studies with smaller study groups and with more homogeneous populations and femoral components (Ponzio et al. 2015). Reported incidences of intraoperative calcar fracture in these studies have varied between 0.4% and 5.4% (Berry 1999, Berend and Lombardi 2010, Cameron 2004, Ponzio et al. 2015). The incidence of calcar fracture in our study was 3.7%, which is similar to that in previous studies.

Surgery was performed more often in the calcar fracture group, due to congenital hip dysplasia or hip fracture. There were also less primary OAs in the fracture group than in the control group. The difference in operative diagnosis may also explain the difference in femoral stem types used in the 2 groups; thus, there were more femur stems of "other" type in the calcar fracture group. Compared to consultant orthopedic surgeons, residents were associated with an increased risk of calcar fracture during surgery.

Treatment of an intraoperative calcar fracture is usually done with cable or wire fixation at the level of the lesser trochanter (Berend et al. 2004). In the present study, all but 4 intraoperative calcar fractures were treated with cables. The small number of non-cabled patients meant that comparison between the groups was not meaningful.

The multivariable logistic regression analysis showed that the Hardinge approach was an independent risk factor for calcar fracture. During THA perfomed with this approach, the medial gluteal muscle may direct broaches and final implant positions in the medial and anterior directions, introducing stress forces to the medial cortex and predisposing to calcar fracture. Lower age was also found to be an independent risk factor for calcar fracture. The reason for this finding might be that in the calcar fracture group there were more diagnoses other than osteoarthritis, which was the most common operative diagnosis in the control group. In addition, women have been shown to have a higher risk of calcar fracture with cementless stems (Cameron 2004, Ponzio et al. 2015). There were more calcar fractures in women, although the difference was not statistically significant. A previous study showed that one reason for the higher calcar fracture rates in women might be related to the smaller dimensions of the proximal femur (Bonnin et al. 2015). Our study supports this finding, as we found that deviant proximal femurs (champagne flute and stovepipe types) and thin cortices (Dorr type C) may increase the risk of intraoperative calcar fracture.

The geometry of the proximal femur is critical for press-fitting to the femoral stem and subsequent survival of the THA (Rubin et al. 1992). The anatomy and morphology of the proximal femur have been studied repeatedly (Rubin et al. 1992, Dorr et al. 1993, Laine et al. 2000, Casper et al. 2012). There are wide variations in the shape of the proximal femur (Noble et al. 1988). Aging usually narrows the cortices and simultaneously widens the intramedullary canal of the proximal femur (Newell 1997, Casper et al. 2012). These changes in bone morphology reduce the strength of the proximal femur and the risk of fracture increases (Casper et al. 2012). These changes in bone morphology occur earlier in women than in men (Newell 1997, Casper et al. 2012). The loss of cortical bone has been reported to occur especially in the lateral cortices, which are responsible for supporting secondary tensile forces (Casper et al. 2012). Comparison of middle-aged patients with elderly patients has revealed a decrease in the thickness of cortices in the elderly, which leads to increased isthmus width and decreasing CFI (Casper et al. 2012). Our CFIs are comparable to those reported from other studies in which the mean patient age was the same as in our study group (Kavanagh et al. 1989, Søballe et al. 1992, SHAR 2011, Casper et al. 2012).

We observed more champagne flute-shaped and stovepipe-shaped proximal femurs in the calcar fracture group than in the control group. There were also more Dorr type-C proximal femurs in the calcar fracture group. This wider type variation in proximal femurs in the calcar fracture group may be because there were more women in the fracture group; women have smaller proximal femurs and smaller CFIs than men. Dysplasia also changes proximal femur anatomy, and the incidence of hip dysplasia was higher in the calcar fracture group.

Our study had some limitations. First, Noble's CFI is based on isthmus position, and there is user-dependent bias in determination of the canal boundary. This bias was eliminated by selecting corrected points along the boundary. In addition, all measurements were performed by the same investigator. Retrospectively obtained data did not allow us to determine whether X-ray templates or digital templating were used, and whether the size of the implanted stem was different from that of the templated one. Secondly, our study did not reveal whether there was a between-group difference in patient satisfaction with THA.

In conclusion, patients with deviant proximal femurs and wide proximal femur canals with thin cortices were at higher risk of calcar fracture. Patients with indications for surgery other than primary osteoarthritis had a higher risk of intraoperative calcar fracture. The Hardinge approach was associated with a substantially higher risk of intraoperative calcar fracture than the posterior approach. Lower age was also associated with a higher risk of intraoperative calcar fracture, presumably due to increased prevalence of secondary osteoarthritis in the calcar fracture group, as these conditions usually lead to THA in younger patients than primary osteoarthritis does. Our results demonstrate the necessity of considering the various shapes of the proximal femur when selecting cementless femoral stems.

SM participated in planning the study protocol, collecting data, analyzing radiographs, performing statistical analyses, and preparing the manuscript. TM, IK, KM, JK, and VR participated in planning the study protocol, collecting data, and preparing the manuscript. JK also participated by doing the interobserver measurements from the radiographs. HH participated in planning the study protocol, performing statistical analyses, and preparing the manuscript.

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No competing interests declared.

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