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ORIGINAL ARTICLE • HIP - ARTHROPLASTY

Femoral cortical thickness influences the pattern of proximal femoral periprosthetic fractures with a cemented stem

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Abstract

Introduction Periprosthetic fractures of the proximal femur place a significant burden on the patients who endure them, as well as the medical health system that supports them. The purpose of this study was to determine whether femoral cortical thickness, as an absolute measurement, is a predictor of periprosthetic fracture pattern.

Method A cohort of 102 patients who had sustained a periprosthetic hip fracture were retrospectively identified. This included 58 males and 44 females with a mean age of 79.8 years. The femoral periprosthetic fracture pattern was classified based on the Vancouver classification system. Stem fixation was recorded and femoral cortical thickness measured. Patients were grouped into cemented and cementless stems. The relationship between cortical thickness and periprosthetic fracture pattern was assessed using the primary stem fixation method. Receiver operating characteristic (ROC) curve analysis was used to identify a threshold in the cortical thickness that predicted fracture pattern. Multinomial logistic regression analysis was used to adjust for confounding variables to assess the independent influence of cortical thickness on the risk of sustaining a Vancouver type A, B or C.

Results There were 65 (63.7%) patients in the cemented group and 37 (36.3%) in the cementless group. The pattern of periprosthetic fractures around cemented stems was significantly ($p < 0.001$) influenced by the femoral cortical thickness, with a thinner cortical thickness associated with a type A fracture pattern. In contrast, no association between femoral cortical thickness and fracture pattern assessment was demonstrated in the cementless group ($p = 0.82$ Chi square). Comparing the rate of type A fracture patterns between the groups illustrated a significantly decreased risk in the cemented group with a cortical thickness of > 7 mm (odds ratio 0.03, $p < 0.001$). ROC curve analysis of the cemented group demonstrated a threshold value of 6.3 mm, offering a sensitivity of 83.3% and a specificity of 78.9% in predicting an A type fracture. Using this threshold, patients with a cortical thickness of 6.3 mm or less were significantly more likely to sustain a Vancouver type A fracture (OR 18.9, 95% CI 2.0–166.7, $p < 0.001$) when compared to patients with a cortical thickness of > 6.3 mm. In contrast, the ROC curve analysis did not find cortical thickness to be a predictor of fracture pattern in the cementless group. When adjusting for confounding variables, multinomial logistic regression demonstrated a cortical thickness of 6.3 mm or less was a significant predictor of a type A fracture (OR 3.28, 95% CI 1.06–10.16, $p = 0.04$) relative to those sustaining a type B fracture.

Conclusion Cortical thickness was found to influence the periprosthetic fracture pattern around cemented femoral stems, but this was not observed with cementless stems. Type A fracture patterns were significantly more likely to occur with a cortical thickness of 6.3 mm or less around cemented stems.

Keywords Periprosthetic hip · Corical thickness · Fracture

Introduction

Periprosthetic proximal femoral fractures are a significant burden to patients, and they incur a substantial economic impact on health systems when treated at specialist centres [1]. The incidence of periprosthetic proximal femoral fractures is increasing. A high rate of postoperative

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complications and poor clinical outcomes is associated with this injury [1–3]. One explanation for the observed increase may relate to widened indications for hip arthroplasties, as well as a secondary increase in the number of revisions and re-revisions, combined with an aging population and thus more hip replacements [4].

Patients requiring operative treatment for femoral periprosthetic fractures around the hip have a mortality rate at 1 year approaching that of fractures of the neck of the femur [5]. Phillips et al. [1] reported on the financial cost of treating periprosthetic hip fractures, with figures demonstrating that the mean cost of treatment is £23,469 (range £615–£223,000).

There are numerous risk factors associated with periprosthetic fractures of the femur: advanced age, female gender, post-traumatic osteoarthritis, osteoporosis and rheumatoid arthritis, proximal femoral deformities, previous surgery of the affected hip, implant design, errors in surgical technique such as cortical perforation, cortical stress risers, low-energy trauma, osteolysis, loosening and revision hip arthroplasty [6]. Periprosthetic proximal femoral fractures vary greatly in the pattern and architecture of the fracture, the stability of the prosthesis and the integrity of the femoral component fixation. The Vancouver classification of Duncan and Masri [7, 8] addressed fracture pattern, quality of the surrounding bone stock and implant stability. This information is essential to surgeons when planning operative interventions and methods for revision.

Fracture pattern is affected by a number of variables, including stem fixation, implant choice and femoral geometry [9–13]. We hypothesise that femoral cortical thickness affects the pattern of the periprosthetic fracture around the femur. The primary aim of this study was to assess the relationship between femoral cortical thickness, method of stem fixation (cemented or cementless) and the influence this has on the pattern of periprosthetic femoral fracture.

Materials and methods

A total of 131 consecutive patients with proximal femoral periprosthetic fractures after hip replacement were identified at a university-affiliated hospital in Melbourne, Australia, between January 2005 and September 2015. The inclusion criteria for this study were the diagnosis of a periprosthetic proximal femoral fracture. The exclusion criteria were: intraoperative fractures, periprosthetic fractures of revision surgery, a lack of medical records or radiographs to support the diagnosis of periprosthetic fracture and inadequate preoperative radiographs such that cortical thickness could not be determined. This study was conducted in accordance with the hospital ethics committee for health research (approval QA/15/PH/6).

Of the 131 patients identified, 102 patients satisfied the criteria for inclusion into the study. Twenty patients were identified as having inadequate records, four had radiographs that could not be utilised for the recording of femoral cortical width, three had intraoperative fractures and two patients had fractures around prostheses from previous revision surgery.

We analysed patient medical records to collect data on age, gender, date of injury, time to surgery and comorbidities. Operative notes were assessed to confirm the presence or absence of loose stems for the purpose of classification. Radiographs were reviewed on the Picture Archiving and Communications System (PACS) in order to record the following: fixation—cemented or cementless; fracture classification according to the Vancouver classification (Fig. 1) of Duncan and Masri [7, 8]; and femoral cortical thickness.

Cortical thickness is difficult to measure in the setting of periprosthetic fracture. The cortical thickness ratio is measured by subtracting the medullary diameter from the femoral shaft diameter, and this is dependent on an intact femur. The known femoral head size was measured using PACS to confirm magnification for subsequent measurements. We therefore elected to measure the lateral cortex at a point 13 cm

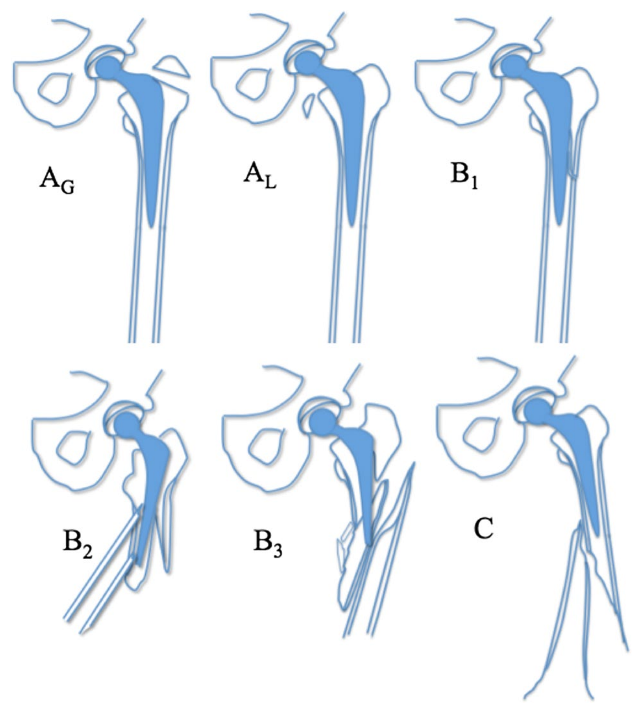

Fig. 1 Vancouver classification: AG fracture of the greater trochanter; AL fracture of the lesser trochanter; B1 fracture at the level of the stem with a stable prosthesis (difficult to see the lateral cortex break as is often the case); B2 fracture at the level of the stem with unstable prosthesis (Fig. 2); B3 fracture at the level of stem with unstable prosthesis as well as comminution or poor bone stock; C below the stem, stable prosthesis

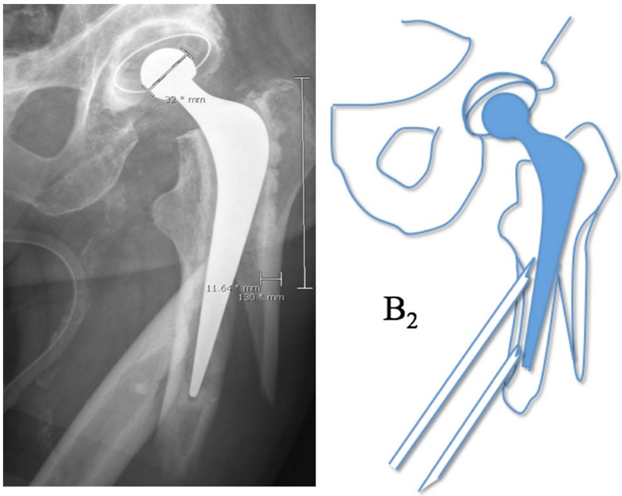

Fig. 2 Vancouver B2 fracture

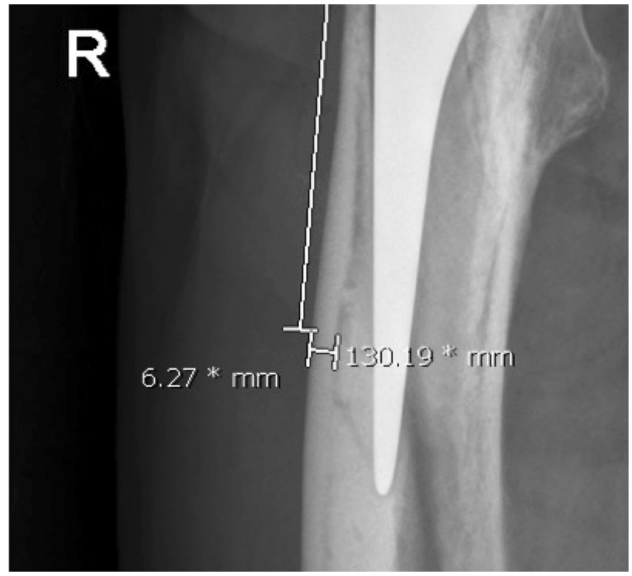

Fig. 4 Magnified view of cortex to be measured from Fig. 3

Fig. 3 A point 13 cm distal to the tip of the trochanter on the lateral cortex

distal to the tip of the greater trochanter (Figs. 3, 4). We were able to demarcate the cement and cortex interface at this point more accurately as proximal to this, the cement integration made improving accuracy less likely. If the fracture line ran through this point, we measured the intact cortex as close to this point as possible distal to the fracture.

Statistical analysis was performed using the Statistical Package for Social Sciences version 17.0 (SPSS Inc., Chicago, IL, USA). The data assessed demonstrated a normal distribution, and parametric tests were used to assess continuous variables for significant differences between groups. A student's *t* test, unpaired and paired, was used to compare linear variables between groups. Dichotomous variables were assessed using a Chi-square test. Receiver operating characteristic (ROC) curve analysis was used to identify a threshold (cut point) in cortical thickness that predicted the pattern of the periprosthetic fracture. The area under the ROC curve ranges from 0.5, indicating a test with no accuracy, to 1.0, where the test is perfectly accurate and identifying all satisfied patients. The threshold is equivalent to the point at which the sensitivity and specificity are maximal in predicting patient satisfaction [14]. Multinomial logistic regression analysis was used to adjust for confounding variables to assess the independent influence of cortical thickness on the risk of sustaining a Vancouver type A, B or C. A p value of < 0.05 was defined as significant.

Results

A total of 102 patients satisfied the inclusion/exclusion criteria. The patients included had the following demographic characteristics: mean age of 79.8 years ranging between 47 and 94 years; 44 patients were female (43%) and 58 were male (57%) (Table 1). There were 65 cemented prostheses and 37 cementless prostheses. Twenty-six Vancouver A

Table 1 Demographic, fixation and Vancouver type periprosthetic fracture

Patient	Mean or *N* (%)
Age	79.8
Gender	
Male	58 (56.9)
Female	44 (43.1)
Fixation	
Cemented	65 (63.8)
Cementless	37 (36.2)
Vancouver type	
Type A	26 (25.4)
Type B	70 (68.8)
Type C	6 (5.8)

Table 2 Comparison of type of fixation, cortical thickness and fracture pattern

	Less than 5 mm	5–7 mm	Greater than 7 mm	Total
Cemented				65 (64%)
Vancouver A	3 (38%)	3 (14%)	0 (0%)	
Vancouver B	3 (38%)	16 (76%)	35 (97%)	
Vancouver C	2 (24%)	2 (10%)	1 (3%)	
Total	8 (12%)	21 (33%)	36 (55%)	
Cementless				37 (36%)
Vancouver A	9 (64%)	3 (50%)	8 (47%)	
Vancouver B	5 (46%)	3 (50%)	8 (47%)	
Vancouver C	0 (0%)	0 (0%)	1 (6%)	
Total	14 (38%)	6 (16%)	17 (46%)	

fractures were identified, 70 type B fractures and six type C periprosthetic fractures. Six different stem types were identified in the cementless group, while the cemented group was much more homogenous, with 62 Exeter stems, two accolade C stems and one Spectron stem.

Cortical thickness was divided into three groups: a cortical thickness of less than 5 mm; a thickness of 5–7 mm; and a third group with a cortical thickness greater than 7 mm. This enabled categorical analysis to be performed. Twenty-two (21.6%) femurs had a cortical thickness less than 5 mm, 27 (26.5%) had a cortical thickness from 5 to 7 mm and 53 (52.0%) femurs had a diameter greater than 7 mm. The percentage of cemented and cementless femora with Vancouver type fractures are outlined in Table 2.

The pattern of periprosthetic fractures around cemented stems was significantly ($p < 0.001$ Chi-square) influenced by the femoral cortical thickness (Table 3), with a thinner cortical thickness associated with a type A fracture pattern. Cemented stems with a width of < 5 mm had an equal chance of being a type A or type B (38%); however, with increasing cortical thickness, the risk of a Vancouver type B fracture increased (97%), whereas the risk of a Vancouver type A fracture decreased (0%) (Fig. 5).

In contrast, assessment of the cementless femoral stem group demonstrated no significant ($p = 0.82$ Chi-square) association between femoral cortical thickness and fracture pattern. The rate of Vancouver type fracture pattern remained relatively constant when assessed based on the cortical thickness group (Fig. 6).

The variation between cemented and cementless stem fixation and the cortical thickness for Vancouver type A fractures is illustrated in Fig. 7. A comparison of the rate of Vancouver type A fracture patterns for cemented and cementless groups based on cortical thickness demonstrates a significantly decreased risk for the cemented group with a cortical thickness of > 7 mm (Table 4).

ROC curve analysis of the cemented group demonstrated that cortical thickness was a significant predictor of the pattern of the periprosthetic fracture (Fig. 8), with an area under the curve (AUC) of 89.2% (95% confidence intervals (CI) 79.6–98.7%, $p = 0.002$). The identified threshold value of 6.3 mm or less offered a sensitivity of 83.3% and a specificity of 78.9% in predicting a type A fracture. Using this threshold, patients with a cortical thickness of 6.3 mm or less were significantly more likely to sustain a Vancouver type A fracture (OR 18.9, 95% CI 2.0–166.7, $p < 0.001$) when compared to patients with a cortical thickness of > 6.3 mm. In contrast, ROC curve analysis did not find cortical thickness to be a predictor of fracture pattern in the cementless group (Fig. 9), with an AUC of 54.7% (95% CI 35.9–73.6%, $p = 0.62$). Using the same threshold value identified for the cemented group of 6.3 mm, there was no significant influence on the fracture pattern (OR 1.5, 95% CI 0.4–5.5).

Multinomial logistic regression analysis was used to adjust for confounding variables [age, gender, group (cemented and cementless)] when assessing the influence

Table 3 Stem fixation, cortical thickness and the percentage of Vancouver type A fracture patterns

Group	< 5 mm	5–7 mm	> 7 mm
Cemented (%)	38%	76%	97%
Cementless (%)	36%	50%	47%
Odds ratio (95% CI)	1.01 (0.18–6.54)	3.2 (0.48–21.17)	39.38 (4.34–356.84)
p value	0.64	0.32	< 0.001

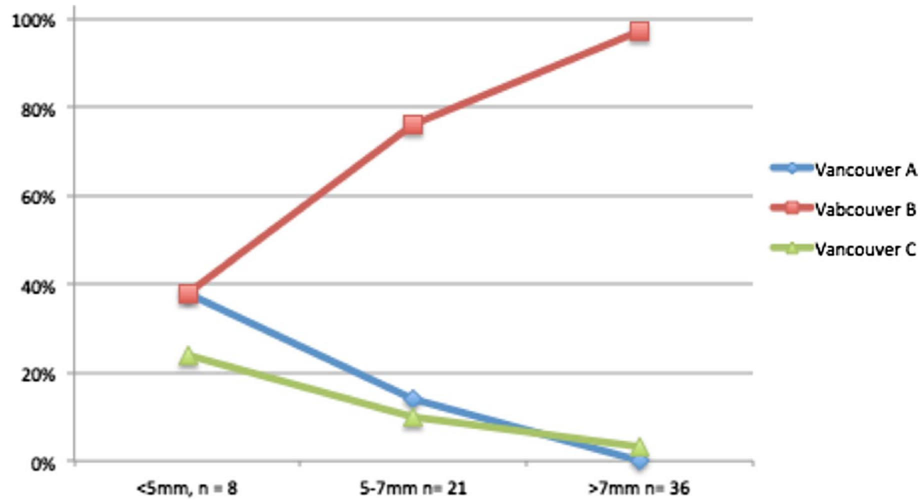

Fig. 5 Vancouver type fracture as a percentage between the cortical thickness groups for cemented prostheses

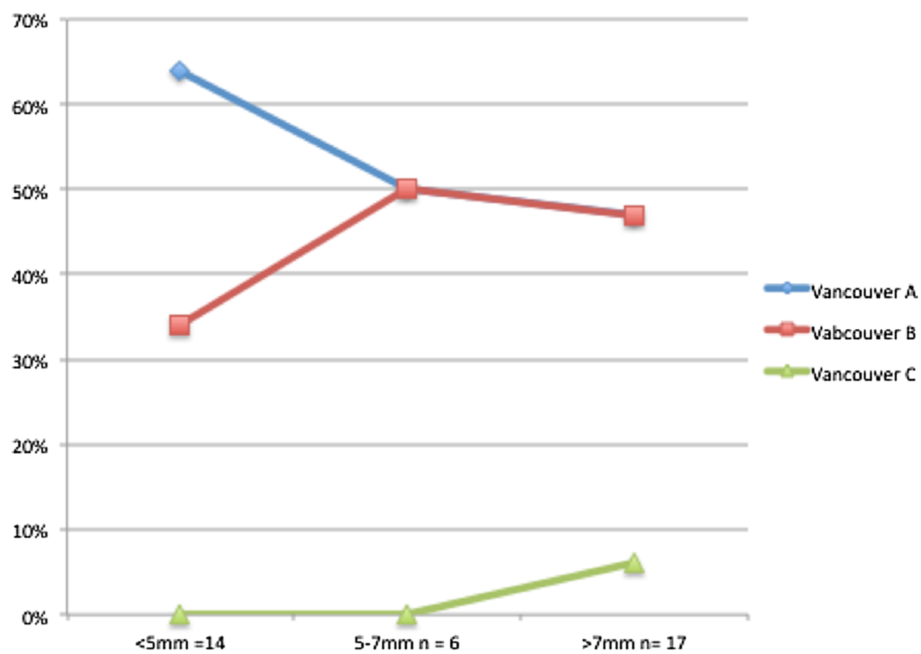

Fig. 6 Vancouver type fracture as a percentage between the cortical thickness groups for cementless prostheses

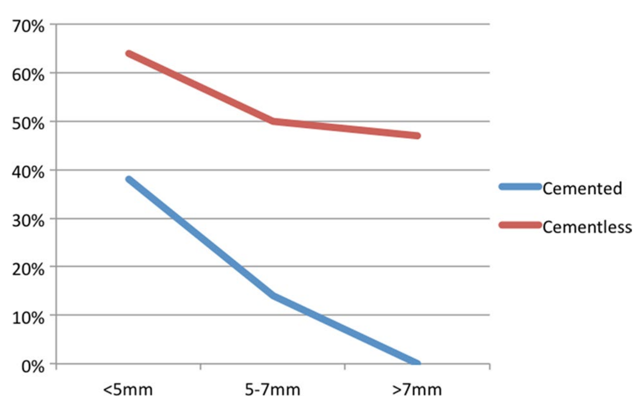

Fig. 7 Percentage of Vancouver A fracture patterns by cortical thickness: cemented versus cementless

Table 4 Percentage of type A fracture patterns, cemented versus cementless

	< 5 mm, $n = 12$ (%)	5–7 mm, $n = 6$ (%)	> 7 mm, $n = 8$ (%)
Cemented—Vancouver A	38	14	0
Cementless—Vanvcouver A	64	50	47

of cortical thickness on the risk of sustaining a Vancouver type A, B or C. A cortical thickness of 6.3 mm or less was a significant predictor of a type A fracture (OR 3.28, 95% CI 1.06–10.16, $p = 0.04$) relative to those sustaining a type B fracture. Interestingly, the cemented group were

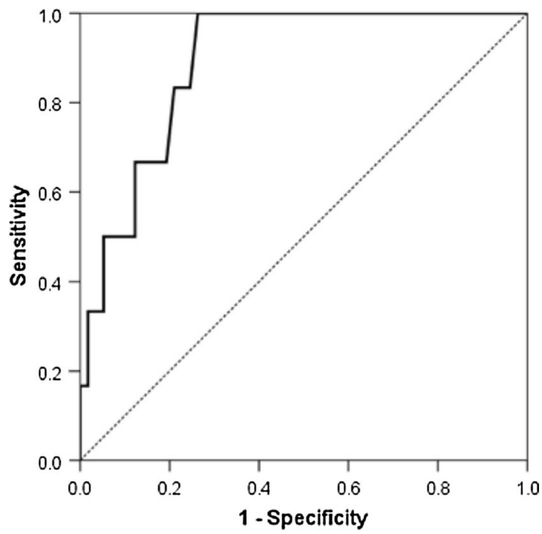

Fig. 8 ROC curve predicting type A fractures according to cortical thickness for the cemented group

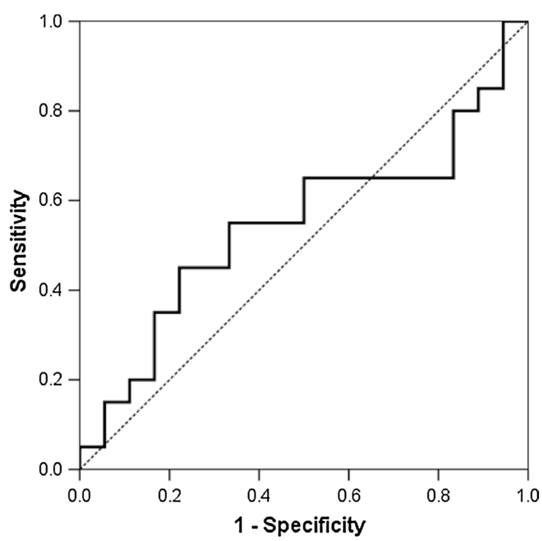

Fig. 9 ROC curve predicting type A fractures according to cortical thickness for the cementless group

significantly (OR 0.12, 95% CI 0.04–0.36, $p < 0.001$) less likely to sustain a type B fracture relative to a type A fracture.

Discussion

There was an 81% increase in the rate of primary total hip joint replacements reported in the Australian Orthopaedic National Joint Replacement Registry (AONJRR) from 2003 to 2015. In the 2016 annual report from the AONJRR, the primary total conventional hip replacement reason for revision was fracture in 18.7% of cases [15]. In the same report, fracture was the third most common reason for revision, behind loosening/lysis and dislocation, respectively, for conventional hip replacement.

In this study, we describe the periprosthetic fracture patterns observed in three groups of femoral cortical thickness in both cemented and cementless stems. In particular, we highlight the role of cortical thickness in cemented stems, demonstrating a decreasing incidence of metaphyseal Vancouver A fractures with increasing femoral cortical thickness, a feature not observed in cementless stems. The ability of a femur to resist fracture depends on the size, spatial architecture and distribution of bone, its intrinsic material properties and the loads applied. The length of the cemented stem has been reported to influence the torque required to fracture [12]. Another biomechanical study has demonstrated that large-body polished tapered cemented stems require more torque to failure than their small-body counterparts [13]. We postulate that length and width of the femoral stem, fixation type and host bone cortical thickness affect torque fracture, fracture energy required and pattern of periprosthetic fracture. While torque forces and direct lateral force on the femur by trauma will still induce type B periprosthetic fractures in a range of femoral cortical thicknesses, we have seen a decrease in metaphyseal Vancouver A fracture patterns with increased cortical thickness in cemented stems. This may be due to the ability of the metaphyseal bone to withstand fracture mechanisms associated with type A fracture patterns, which are different from those responsible for type B and type C fracture patterns.

While trabecular bone adds to the integrity of the metaphysis, it is the distribution of cortical bone that is believed to be critical in determining a femur's resistance to fracture [16]. When studying femoral neck fractures, cracking of the cortex in the femoral neck or trochanter is most often the first point of failure [17]. While excellent long-term outcomes are reported in cementless stems, proximal stress shielding is present in most cases, even with newer stem designs [18]. We surmise that cemented stems in femurs with cortical bone > 6.3 mm are less likely to sustain metaphyseal periprosthetic Vancouver A fractures due to the absence of the stress shielding seen in cementless stems, and the thicker femoral cortical bone width (> 6.3 mm). The ability to withstand a Vancouver A fracture in these femora results in an overwhelming majority (97%) of fracture patterns being Vancouver type B.

Femoral geometry has been established as a contributing factor for early periprosthetic fracture as Gromov et al. [19] concluding that Dorr C type femurs are an independent risk factor following hip replacement when using double-tapered cementless stems. To date, this is the first study that has researched cortical thickness as an independent risk factor for periprosthetic fracture pattern.

The current study was limited by its design. The data retrieved on cortical thickness were from anteroposterior radiographs. There is evidence that cortical thickness is critical in determining femoral resistance to fracture [20], and there are now CT techniques with the ability to determine cortical thickness down to 0.3 mm [21]. With advancements in metal suppression, this is an appealing option for measuring cortical thickness; CT, however, is not always clinically justified.

Conclusion

Cortical thickness influenced the periprosthetic fracture pattern around cemented femoral stems, but this was not observed with cementless stems. Type A fracture patterns were significantly more likely to occur with a cortical thickness of 6.3 mm or less around cemented stems.

Compliance with ethical standards

Conflict of interest The author(s) declare that they have no competing interests.

Ethical approval This study was conducted in accordance with the hospital ethics committee for health research (approval QA/15/PH/6).

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