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HIP

Influence of femoral morphology and canal fill ratio on early radiological and clinical outcomes of uncemented total hip arthroplasty using a fully coated stem

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Aims

The diversity of femoral morphology renders femoral component sizing in total hip arthroplasty (THA) challenging. We aimed to determine whether femoral morphology and femoral component filling influence early clinical and radiological outcomes following THA using fully hydroxyapatite (HA)-coated femoral components.

Methods

We retrospectively reviewed records of 183 primary uncemented THAs. Femoral morphology, including Dorr classification, canal bone ratio (CBR), canal flare index (CFI), and canal-calcar ratio (CCR), were calculated on preoperative radiographs. The canal fill ratio (CFR) was calculated at different levels relative to the lesser trochanter (LT) using immediate postoperative radiographs: P1, 2 cm above LT; P2, at LT; P3, 2 cm below LT; and D1, 7 cm below LT. At two years, radiological femoral component osseointegration was evaluated using the Engh score, and hip function using the Postel Merle d'Aubigné (PMA) and Oxford Hip Score (OHS).

Results

CFR was moderately correlated with CCR at P1 ($r = 0.44$; $p < 0.001$), P2 ($r = 0.53$; $p < 0.001$), and CFI at P1 ($r = -0.56$; $p < 0.001$). Absence of spot welds (n = 3, 2%) was associated with lower CCR ($p = 0.049$), greater CFI ($p = 0.017$), and lower CFR at P3 ($p = 0.015$). Migration (n = 9, 7%) was associated with lower CFR at P2 ($p = 0.028$) and P3 ($p = 0.007$). Varus malalignment (n = 7, 5%), predominantly in Dorr A femurs ($p = 0.028$), was associated with lower CFR at all levels ($p < 0.05$). Absence of spot welds was associated with lower PMA gait ($p = 0.012$) and migration with worse OHS ($p = 0.032$).

Conclusion

This study revealed that femurs with insufficient proximal filling tend to have less favourable radiological outcomes following uncemented THA using a fully HA-coated double-tapered femoral component.

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Keywords: Total hip arthroplasty, Fully coated stem, Femoral morphology, Filling, Canal fill ratio, Osseointegration

Article focus

- To determine whether early clinical and radiological outcomes following uncemented total hip arthroplasty (THA) are influenced by femoral morphology or femoral component filling.

Key messages

- Femurs with either proximally flared or distally narrowed canals, or with insufficient proximal filling tend to have less favourable radiological outcomes.
- The authors believe that femoral morphology affects femoral component filling, which subsequently influences osseointegration that could later compromise clinical scores.
- It is essential to optimize proximal femoral component sizing and filling, which may

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require specific templating strategies and/or implant designs for extreme morphotypes.

Strengths and limitations

- To the authors' knowledge, this study is the first to investigate the effect of femoral morphology and femoral component filling on early outcomes following THA, using an uncemented femoral component fully coated with hydroxyapatite in an unselected Caucasian population.
- Canal fill ratio (CFR) was calculated by dividing the width of the femoral component by the width of the intramedullary bone canal at different time intervals. Filling thresholds for adequate osseointegration could not be established due to a small number of hips with failed osseointegration. However, based on this study successful osseointegration (presence of spot welds but absence of femoral component migration/malalignment) of this femoral component seems to be obtained with a filling threshold greater than 70% at 2 cm below the femoral lesser trochanter.

Introduction

Over the last century, innovations and enhancements in total hip arthroplasty (THA) have led to considerable improvements in functional outcomes and implant longevity, with 50% of THAs expected to survive beyond 25 years.[1,2] Although satisfactory outcomes have been reported for cemented THA,[3,4] implanting uncemented femoral components has become increasingly popular as it preserves femoral bone stock and grants adequate primary stability, as well as long-term osseointegration.[5]

Although uncemented THA offers several biomechanical advantages, the choice of femoral component size can be challenging as oversizing could induce stress shielding or periprosthetic fractures,[6,7] notably in females and Dorr C femurs,[8] while undersizing may compromise osseointegration[9–15] and lead to femoral component subsidence[13,16] or malalignment.[13,17] The diversity of femoral morphology makes it all the more difficult to optimize filling in the proximal and distal diaphysis simultaneously. In a recent study, Nam et al[18] reported that lower canal-calcar ratio (CCR) and higher distal femoral component filling are associated with thigh pain in the first postoperative year. Similarly, Ishii et al[19] found that Japanese women with narrow diaphyseal canals or increased canal flare index (CFI; champagne flute femurs) are susceptible to failure of osseointegration at two postoperative years. They also observed suboptimal radiological changes when femoral component filling is excessive distally, particularly if insufficient proximally. It is worth noting, however, that both studies evaluated proximally coated femoral components, for which the mechanisms of primary fixation may differ from those of fully coated femoral components.[20]

The purpose of this study was therefore to determine whether femoral morphology and femoral component filling influence early clinical and radiological outcomes following THA, using an uncemented femoral component fully coated with hydroxyapatite (HA) in an unselected and gender-balanced Caucasian population. The hypothesis was that high CFI and low canal fill ratio (CFR) would be associated with poor femoral component osseointegration and lower functional outcomes.

Methods

Patients. The authors retrospectively reviewed the records of 183 consecutive hips (172 patients) that underwent primary THA between February 2013 and August 2015, using the same uncemented femoral component (Hype; SERF, Décines, France), in standard or lateralized version, and the same acetabular component (Hype) with ceramic-on-ceramic bearings (BIOLOXdelta; CeramTec, Plochingen, Germany). The authors excluded hips operated for avascular necrosis (AVN) of the femoral head (n = 14), rheumatoid arthritis (n = 7), preoperative femoral neck fracture (FNF, n = 3), intraoperative femoral fracture (n = 2), post-traumatic arthritis (n = 1), and osteochondritis (n = 1; Figure 1). For the remaining 155 hips (145 patients), the indications for surgery were primary osteoarthritis (n = 134, 87%) and secondary osteoarthritis due to mild dysplasia (n = 16, 10%) or acetabular protrusion (n = 5, 3%).

The cohort comprised 73 men (75 hips) and 72 women (80 hips), with a mean age of 61.4 years (SD 8.6) and a median age of 63.0 (interquartile range (IQR) 57.0 to 67.0) at index surgery (Table I). Patients were stratified according to their preoperative walking ability using the Charnley classification,[21] which was of grade A for 111 hips (71%), grade B for 39 hips (25%), grade C for four hips (3%), and unspecified for one hip (1%). Their preoperative American Society of Anaesthesiologists (ASA)[22,23] mean and median scores were 1.8 (SD 0.6) and 2.0 (IQR 1 to 2), respectively.

Surgery. All procedures were performed by two experienced surgeons at two different centres. The anterolateral approach (Röttinger) was used by one surgeon (FB) in 132 hips (85.2%), while the posterior approach was used by the other surgeon (OR) in 23 hips (14.8%) (Table II). The design rationale for this double-tapered femoral component is to obtain initial mechanical stability by press-fitting the compacted cancellous bone all around the femoral component. All patients received the same uncemented components. The Hype femoral component is made of titanium (TA6V), coated with porous titanium proximally and with 80 μm of HA over its entire intramedullary surface. The Hype acetabular component is also made of titanium (TA6V) and coated with 150 μm of porous titanium and 80 μm of HA.

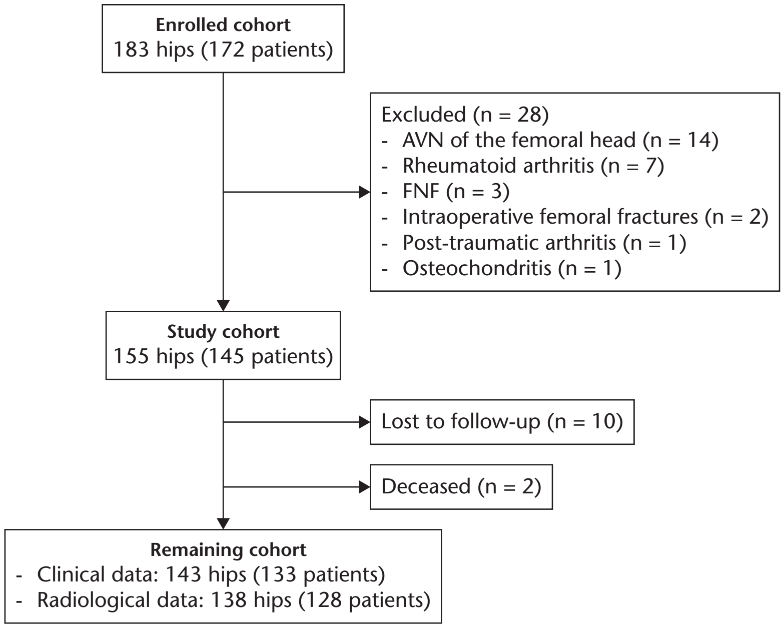

Fig. 1

Study flowchart detailing initial cohort, exclusions, losses to follow-up, deaths, and final cohorts evaluated clinically and radiographically. AVN, avascular necrosis; FNF, femoral neck fracture.

Table I. Preoperative patient characteristics and femoral morphology in the original cohort (n = 155 hips)

Variable	Data
Baseline characteristic	
Mean age at index operation, yrs (SD) (median; IQR)	61.4 (8.6) (63.0; 57.0 to 67.0)
Mean body mass index, kg/m² (SD) (median; IQR)	27.5 (4.3) (27.4; 24.4 to 30.5)
Mean ASA score (SD) (median; IQR)	2 (1) (2; 1 to 2)
Male sex, n (%)	75 (48)
Operation on the right hip, n (%)	76 (49)
Medical history, n (%)	55 (35)
Surgical history, n (%)	51 (33)
Aetiology, n (%)	
Centered osteoarthritis	134 (87)
Minor dysplasia (Crowe I)	16 (10)
Acetabular protrusion	5 (3)
Charnley grade, n (%)	
A	111 (71)
B	39 (25)
C	4 (3)
[missing]	1 (1)
Femoral morphology	
Dorr type, n (%)	
A	37 (24)
B	111 (72)
C	5 (3)
[missing]	2 (1)
Mean canal bone ratio (SD) (median; IQR)	
Frontal	0.43 (0.06) (0.43; 0.39 to 0.46)
Lateral	0.52 (0.08) (0.52; 0.47 to 0.57)
Mean canal-calcar ratio (SD) (median; IQR)	0.44 (0.06) (0.44; 0.40 to 0.48)
Mean canal flare index (SD) (median; IQR)	3.42 (0.56) (3.36; 3.07 to 3.75)

ASA, American Society of Anaesthesiologists; IQR, interquartile range.

Clinical assessment. Preoperative clinical data were retrieved to collect patient activity level using the Devane grade[24] and the Postel Merle d'Aubigné (PMA) score (worst = 0; best = 18).[25] Patients were contacted by mail or telephone to update their records at two or more years of follow-up. In all, 11 patients (12 hips) who had attended routine follow-up visits within the year preceding data collection, and who therefore had completed clinical and radiological assessments at follow-up of ≥ 21 months, were not recontacted as their existing records were deemed adequate for analysis. From the original cohort of 155 hips (145 patients), none were revised, two hips (two patients) died with their original components in place for reasons unrelated to their THA, and ten hips (ten patients) were considered lost to follow-up. The final cohort of 143 hips (133 patients) with their original components in place were evaluated using the Devane activity grade, PMA score, and Oxford Hip Score (OHS; worst = 60, best = 12).[26–28] All patients provided informed consent for the use of their data for research and publications, and institutional review board approval was therefore not required for this study.

Radiological assessment. Preoperative frontal weight-bearing hip radiographs were retrieved to analyze the femoral morphology according to the Dorr classification,[29] as well as several anatomical parameters including the frontal canal bone ratio (CBR),[30] CFI,[31] and CCR (Figure 2).[32] Preoperative lateral weight-bearing hip radiographs were also used to measure the lateral CBR. The intramedullary canal width was measured at four levels relative to the

Table II. Intraoperative data in the original cohort (n = 155 hips)

Variable	Data
Surgical approach, n (%)	
Anterolateral (Röttinger)	132 (85)
Posterior	23 (15)
Intraoperative complication	0 (0)
Femoral component type, n (%)	
Standard offset	55 (35)
Lateralized offset	100 (65)
Head size, n (%)	
28 mm	5 (3)
32 mm	62 (40)
36 mm	88 (57)
Median femoral component size (incremental) (IQR)	4 (1 to 8)
Median cup diameter (mm) (IQR)	51 (45 to 61)

IQR, interquartile range.

lesser trochanter (LT): P1, 2 cm above the tip of the LT; P2, at the level of the tip of the LT; P3, 2 cm below the tip of the LT; and D1, 7 cm below the tip of the LT.[19]

Immediate postoperative frontal weight-bearing hip radiographs were acquired to assess femoral component width at the four different levels (P1, P2, P3, and D1) and to calculate the CFR at each level, by dividing the width of the femoral component by the width of the intramedullary bone canal.

Postoperative frontal weight-bearing hip radiographs were assessed at a minimum follow-up of two years for 138 hips (128 patients), to evaluate the femoral component osseointegration using the Engh score (worst = –27.5, best = +22.0), which comprises fixation and stability categories.[33] Adequate femoral component fixation is characterized by the absence of radiolucent lines around its intramedullary surface and the presence of spot welds, while adequate femoral component stability is defined by the absence of pedestals below the tip of the femoral component, calcar atrophy, radiolucent lines, femoral component migration < 5 mm, and particle shedding. The question in the Engh questionnaire regarding

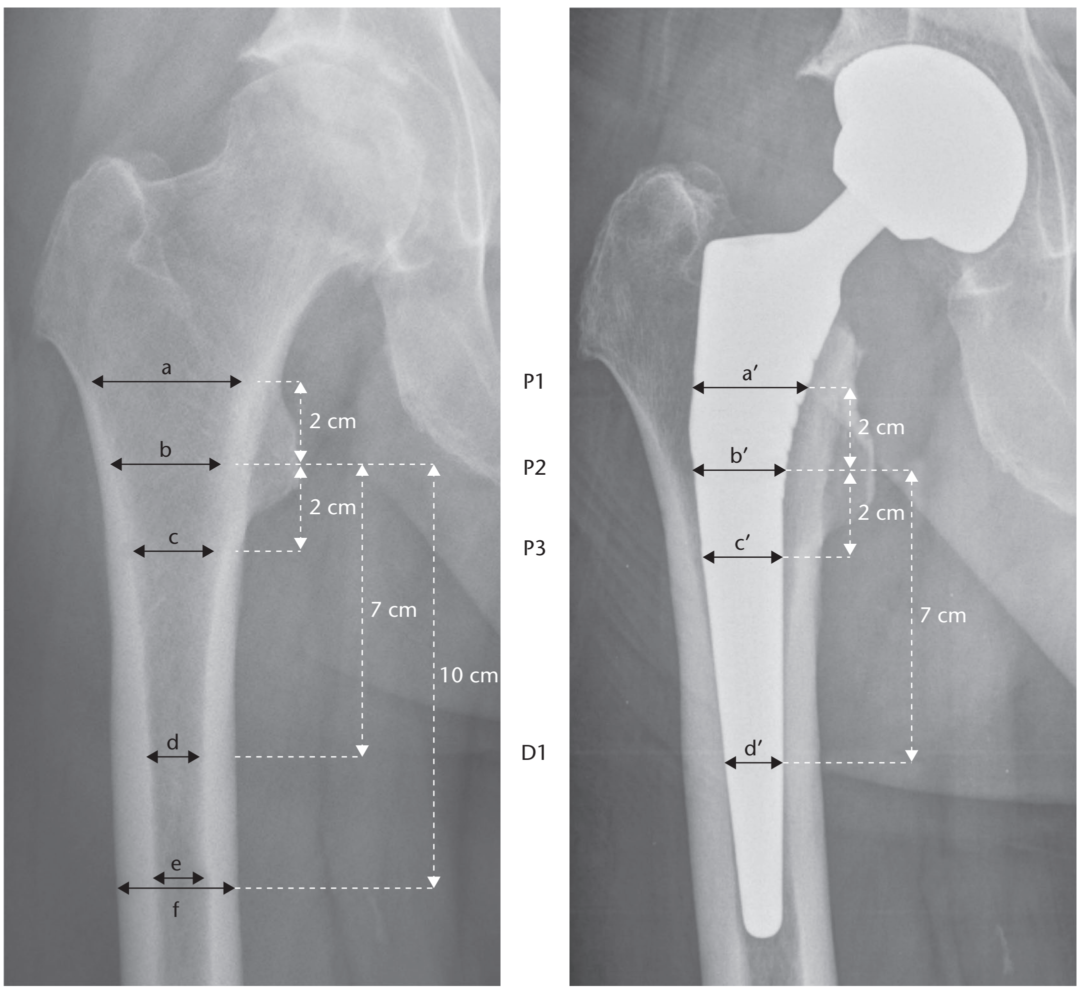

Fig. 2

Frontal radiological measurements (taken from a 63-year-old male) of: femoral anatomical parameters, including canal bone ratio (CBR = e/f), canal flare index (CFI = a/e), and canal-calcar ratio (CCR = e/b); and canal fill ratios (CFR) at 2 cm above the lesser trochanter (P1 = a′/a), at the lesser trochanter (P2 = b′/b), 2 cm below the lesser trochanter (P3 = c′/c), and 7 cm below the lesser trochanter (D1 = d′/d).

radiolucent lines in non-HA-coated zones was left blank (unanswered) as the femoral component studied is HA-coated over its entire intramedullary surface. The authors also evaluated postoperative femoral component alignment within the femoral canal, which was arbitrarily defined as neutral if within ± 5°.

All radiological analyses and interpretations were performed by a single junior surgeon (AD) using a digital DICOM viewer (Centricity; General Electric, Boston, Massachusetts, USA).

Statistical analysis. All radiological measurements were repeated on 20 random hips by two junior surgeons (AD, LP). The level of agreement was then determined using intraclass correlation coefficients (ICCs)[34] for continuous data and Gwet's AC[35] for categorical data, which can be interpreted as follows: < 0.40 (poor); 0.40 to 0.59 (fair); 0.60 to 0.74 (good); 0.75 to 1.00 (excellent). Interobserver repeatability was excellent for preoperative measurements (lowest ICC = 0.93; 95% confidence interval (CI) 0.85 to 0.97) and immediate postoperative CFR (lowest ICC = 0.97; 95% CI 0.94 to 0.99), and good for femoral Dorr type (Gwet's AC = 0.71; 95% CI 0.48 to 0.94) and postoperative Engh score (ICC = 0.65; 95% CI 0.35 to 0.83).

Based on the findings of Ishii et al,[19] who found the CCR to be lower by a mean of 0.12 (SD 0.08) in hips with failed osseointegration (prevalence 5%) than in those with adequate fixation (prevalence 95%), the minimum sample size needed to detect the significance of such a difference with statistical power of 90% was 102 hips.[19]

The Shapiro-Wilk test was used to verify the normality of distributions. For non-normally distributed quantitative data, significance of differences among groups was determined using the Mann-Whitney U test. For normally distributed quantitative data, significance of differences among groups was determined using the independent-samples *t*-test. For qualitative data, significance of differences among groups was determined using Fisher's exact test. For continuous variables, correlations were analyzed using Pearson's correlation coefficients. Univariate linear regressions were performed to test associations of three outcomes (Engh score, PMA score, and OHS) with femoral morphology, CFR, and surgical parameters. Statistical analyses were performed using R v. 3.5.2 (The R Foundation for Statistical Computing, Vienna, Austria). Any p-values < 0.05 were considered statistically significant.

Results

Femoral morphology. The mean preoperative frontal CBR was 0.43 (SD 0.06), mean CFI was 3.42 (SD 0.56), and mean CCR was 0.44 (SD 0.06). The mean preoperative lateral CBR was 0.52 (SD 0.08). The frontal and lateral CBR were strongly correlated (r = 0.776; p < 0.001).

Femoral component filling. Immediately after surgery, femoral component filling varied considerably, with mean CFR ranging from 56.9% at P1 (SD 8.4%) to 84.2% at D1 (SD 11.4%) (Table III). The CFR was moderately correlated with preoperative femoral morphology, notably CCR at P1 (r = 0.44; p < 0.001) and P2 (r = 0.53; p < 0.001), as well as CFI at P1 (r = –0.56; p < 0.001).

Table III. Postoperative radiological evaluation

Variable	Data
Immediately after surgery (155 hips)	
Mean canal fill ratio, % (SD) (median; IQR)	
At 2 cm above the LT (P1)	56.9 (8.4) (56.7; 52.5 to 60.2)
At the LT (P2)	68.1 (8.0) (67.7; 63.3 to 73.3)
At 2 cm below the LT (P3)	73.7 (8.5) (73.1; 67.2 to 79.0)
At 7 cm below the LT (D1)	84.2 (11.4) (84.3; 77.3 to 91.3)
Mean proximal-distal matching ratio (SD) (median; IQR)	
P1/D1	68.6 (12.8) (67.1; 60.9 to 73.7)
P2/D1	82.0 (11.7) (80.4; 73.3 to 88.7)
P3/D1	88.7 (12.8) (86.9; 78.7 to 95.7)
At last follow-up (138 hips, mean 2.9 yrs (SD 1.0))	
Femoral component alignment, n (%)	
Neutral (within ± 5°)	130 (94)
Varus	7 (5)
[missing]	1 (1)
Mean Engh score (SD) (median; IQR)	20.2 (2.8) (22.0; 19.0 to 22.0)
Mean fixation (SD) (median; IQR)	
Radiolucent lines (HA zone)	0.0 (0.0) (0.0; 0.0 to 0.0)
Spot welds	4.8 (1.2) (5.0; 5.0 to 5.0)
Mean stability (SD) (median; IQR)	
Radiolucent lines (non-HA zone)	N/A
Pedestals	2.5 (0.5) (2.5; 2.5 to 2.5)
Calcar modelling	2.0 (1.4) (3.0; 0.0 to 3.0)
Radiolucent line deterioration	2.5 (0.0) (2.5; 2.5 to 2.5)
Migration	2.5 (2.0) (3.0; 3.0 to 3.0)
Particle shedding	1.0 (0.0) (1.0; 1.0 to 1.0)

IQR, interquartile range; HA, hydroxyapatite; LT, lesser trochanter; N/A, not available.

Radiological outcomes at last follow-up. For the 138 hips (128 patients) evaluated radiologically at a mean 2.9 years (SD 1.0; 1.8 to 5.6), osseointegration was excellent with a mean Engh score of 20.2 (SD 2.8; 11.0 to 22.0) (Table III). Univariate linear regressions revealed that Engh scores significantly increased with frontal CBR (beta, 11.37; p = 0.002), lateral CBR (beta, 8.60; p = 0.006), and CCR (beta, 8.24; p = 0.024), as well as CFR at P2 (beta, 9.43; p = 0.002), P3 (beta, 10.96; p < 0.001), and D1 (beta, 5.15; p = 0.015) (Table IV).

Absence of spot welds was observed in three hips (2.2%) and was significantly associated with lower CCR (p = 0.049), greater CFI (p = 0.017), and lower CFR at P3 (p = 0.025) (Table V). Calcar atrophy was absent in 48 hips (35%), predominantly Dorr A femurs (p = 0.001), and was associated with lower frontal and lateral CBR (p = 0.001 and p < 0.001, respectively), as well as lower CFR at P2, P3, and D1 (p = 0.003, p = 0.002, and p = 0.024, respectively). Femoral component migration > 5 mm was observed in nine hips (7%), which subsided by 8 ± 3 mm (6 to 13) and was significantly associated with lower CFR at P2 (p = 0.028) and P3 (p = 0.007) (Table VI).

Table IV. Univariate regression analysis of postoperative radiological score (Engh score) and clinical score (Oxford Hip Score and Postel Merle d'Aubigné)

Variable	Engh score		Oxford score		PMA score	
	β (95% CI)	p-value	β (95% CI)	p-value	β (95% CI)	p-value
Basic characteristic						
Age	0.00 (–0.06 to 0.06)	0.913	0.03 (–0.03 to 0.09)	0.313	–0.01 (–0.03 to 0.00)	0.134
Body mass index	–0.04 (–0.16 to 0.07)	0.440	0.04 (–0.08 to 0.16)	0.497	–0.01 (–0.03 to 0.02)	0.664
Surgical approach						
Anterolateral	Reference		Reference		Reference	
Posterior	–0.03 (–1.49 to 1.43)	0.970	–0.89 (–2.49 to 0.72)	0.276	0.00 (–0.45 to 0.45)	0.993
Femur morphology						
Dorr type						
A	–1.08 (–2.17 to 0.02)	0.055	0.43 (–0.79 to 1.65)	0.490	–0.25 (–0.58 to 0.09)	0.152
B	Reference		Reference		Reference	
C	1.60 (–0.93 to 4.13)	0.213	–0.51 (–3.37 to 2.34)	0.735	0.10 (–0.69 to 0.89)	0.808
Canal bone ratio						
Frontal	11.37 (4.30 to 18.43)	0.002	–2.81 (–10.89 to 5.27)	0.493	1.29 (–0.95 to 3.53)	0.257
Lateral	8.60 (2.51 to 14.69)	0.006	–2.07 (–8.88 to 4.76)	0.550	–0.50 (–2.40 to 1.41)	0.607
Canal-calcar ratio	8.24 (1.09 to 15.39)	0.024	–3.28 (–11.28 to 4.72)	0.419	0.61 (–1.61 to 2.83)	0.588
Canal flare index	–0.71 (–1.58 to 0.17)	0.112	0.22 (–0.73 to 1.17)	0.649	0.09 (–0.18 to 0.35)	0.516
Canal fill ratio*						
At 2 cm above the LT (P1)	5.66 (–2.76 to 14.08)	0.186	–1.09 (–10.16 to 7.97)	0.812	–2.46 (–4.95 to 0.03)	0.053
At the LT (P2)	9.43 (3.65 to 15.21)	0.002	–2.68 (–9.30 to 3.94)	0.425	0.31 (–1.52 to 2.15)	0.737
At 2 cm below the LT (P3)	10.96 (5.55 to 16.36)	< 0.001	–1.34 (–7.54 to 4.87)	0.671	–0.26 (–1.99 to 1.47)	0.770
At 7 cm below the LT (D1)	5.15 (1.00 to 9.29)	0.015	–0.65 (–5.29 to 3.99)	0.783	–0.64 (–1.93 to 0.65)	0.328
Proximodistal matching ratio						
P1/D1	–3.31 (–7.99 to 1.38)	0.165	0.20 (–4.99 to 5.39)	0.940	–0.32 (–1.77 to 1.12)	0.657
P2/D1	0.32 (–3.69 to 4.32)	0.877	–0.42 (–4.81 to 3.97)	0.851	0.56 (–0.66 to 1.78)	0.362
P3/D1	1.52 (–2.17 to 5.20)	0.417	–0.12 (–4.17 to 3.94)	0.954	0.34 (–0.78 to 1.47)	0.550

*Regression coefficient for an increase ratio of 100%.
CI, confidence interval; LT, lesser trochanter.

Table V. Preoperative and intraoperative data stratified by presence of spot welds and calcar modification at last follow-up (mean 2.9 years (SD 1.0))

Variable	Spot welds			Calcar modification		
	Yes (n = 134 hips)	No (n = 3 hips)	p-value	Atrophy (n = 90 hips)	No (n = 48 hips)	p-value
Basic characteristic						
Mean age at index operation, yrs (SD)	61.7 (8.3)	64.7 (2.1)	0.517	62.3 (7.6)	60.9 (9.2)	0.579
Mean body mass index, kg/m²	27.6 (4.3)	30.0 (3.0)	0.235	27.2 (4.1)	28.1 (4.8)	0.277
Surgical approach, n (%)			1.000			0.387
Anterolateral	117 (87.3)	3 (2.5)		78 (86.7)	43 (89.6)	
Posterior	17 (12.7)	0 (0.0)		12 (13.3)	5 (10.4)	
Femur morphology						
Dorr type, n (%)			0.252			0.001
A	32 (23.9)	2 (66.7)		14 (15.5)	20 (41.7)	
B	97 (72.4)	1 (33.3)		71 (78.9)	28 (58.3)	
C	5 (3.7)	0 (0.0)		5 (5.6)	0 (0.0)	
Mean canal bone ratio (SD)						
Frontal	0.43 (0.07)	0.36 (0.06)	0.058	0.44 (0.07)	0.41 (0.05)	0.001
Lateral	0.52 (0.08)	0.49 (0.03)	0.436	0.54 (0.07)	0.48 (0.07)	< 0.001
Mean canal-calcar ratio (SD)	0.44 (0.07)	0.37 (0.04)	0.049	0.45 (0.07)	0.43 (0.06)	0.064
Mean canal flare index (SD)	3.42 (0.54)	4.15 (0.21)	0.017	3.40 (0.55)	3.51 (0.54)	0.318
Canal fill ratio*						
At 2 cm above the LT (P1)	56.2 (5.7)	50.3 (3.1)	0.052	56.6 (5.8)	55.3 (5.4)	0.301
At the LT (P2)	68.1 (8.0)	60.8 (2.9)	0.061	69.4 (8.1)	65.2 (7.1)	0.003
At 2 cm below the LT (P3)	73.6 (8.4)	63.2 (3.5)	0.025	75.0 (7.7)	70.3 (8.9)	0.002
At 7 cm below the LT (D1)	83.9 (11.3)	76.2 (11.9)	0.264	85.2 (10.7)	80.8 (12.0)	0.024
Mean proximodistal matching ratio (SD)*						
P1/D1	68.0 (10.1)	67.4 (14.2)	0.713	67.2 (9.4)	69.7 (11.5)	0.245
P2/D1	82.1 (11.9)	81.6 (17.2)	0.803	82.2 (10.9)	82.3 (13.9)	0.714
P3/D1	88.9 (13.1)	83.9 (9.4)	0.547	89.1 (12.0)	88.4 (14.8)	0.534

(Continued)

Table V. (Continued)

Variable	Spot welds			Calcar modification		
	Yes (n = 134 hips)	No (n = 3 hips)	p-value	Atrophy (n = 90 hips)	No (n = 48 hips)	p-value
Radiological and clinical evaluation†						
Mean Oxford Hip Score (SD)	13.5 (3.0)	13.7 (2.9)	0.945	13.3 (2.2)	14.0 (4.1)	0.820
Mean Postel Merle d'Aubigné score (SD)	17.7 (0.6)	17.0 (1.7)	0.437	17.7 (0.7)	17.7 (0.7)	0.698
Pain	5.8 (0.5)	5.7 (0.6)	0.319	5.9 (0.3)	5.8 (0.6)	0.963
Mobility	5.9 (0.3)	6.0 (0.0)	0.642	5.9 (0.3)	5.9 (0.2)	0.937
Gait	5.9 (0.3)	5.3 (1.2)	0.012	5.9 (0.4)	6.0 (0.2)	0.919

*Immediately after surgery.
†At last clinical follow-up (mean 3.7 years (SD 0.8)).
LT, lesser trochanter.

Table VI. Preoperative and intraoperative data stratified by femoral component migration and misalignment at last follow-up (mean 2.9 years (SD 1.0))

Variable	Femoral component migration			Femoral component alignment		
	No (n = 129 hips)	Yes (n = 9 hips)	p-value	Neutral (n = 130 hips)	Varus (n = 7 hips)	p-value
Basic characteristic						
Mean age at index operation, yrs (SD)	61.9 (7.7)	61.2 (14.4)	0.727	61.7 (8.4)	63.0 (3.1)	0.883
Mean body mass index, kg/m^2	27.5 (4.3)	28.2 (5.1)	0.888	27.5 (4.4)	27.5 (4.2)	0.877
Surgical approach, n (%)			0.354			0.616
Anterolateral	114 (88.4)	7 (77.8)		113 (86.9)	7 (100.0)	
Posterior	15 (11.6)	2 (22.2)		17 (13.1)	0 (0.0)	
Femur morphology						
Dorr type, n (%)			1.000			0.028
A	32 (24.8)	2 (22.2)		28 (21.5)	5 (71.4)	
B	92 (71.3)	7 (77.8)		97 (74.6)	2 (28.6)	
C	5 (3.9)	0 (0.0)		5 (3.9)	0 (0.0)	
Mean canal bone ratio (SD)						
Frontal	0.43 (0.07)	0.41 (0.06)	0.434	0.43 (0.06)	0.40 (0.08)	0.116
Lateral	0.52 (0.08)	0.51 (0.06)	0.670	0.53 (0.08)	0.48 (0.06)	0.151
Mean canal-calcar ratio (SD)	0.44 (0.06)	0.42 (0.08)	0.380	0.44 (0.06)	0.42 (0.10)	0.197
Mean canal flare index (SD)	3.43 (0.53)	3.51 (0.75)	0.907	3.43 (0.54)	3.53 (0.75)	0.319
Canal fill ratio*						
At 2 cm above the LT (P1)	56.3 (5.6)	55.2 (6.6)	0.549	56.4 (5.6)	51.3 (5.7)	0.029
At the LT (P2)	68.3 (8.1)	63.0 (4.6)	0.028	68.5 (7.7)	58.7 (8.7)	0.008
At 2 cm below the LT (P3)	73.8 (8.5)	67.1 (4.0)	0.007	73.8 (8.4)	65.8 (5.3)	0.011
At 7 cm below the LT (D1)	83.9 (11.5)	80.0 (7.8)	0.273	84.1 (11.2)	73.6 (7.6)	0.009
Mean proximodistal matching ratio (SD)*						
P1/D1	68.1 (10.1)	69.7 (11.5)	0.695	68.1 (10.2)	70.3 (10.7)	0.625
P2/D1	82.6 (12.1)	79.4 (9.9)	0.472	82.5 (11.9)	80.0 (11.9)	0.482
P3/D1	89.3 (13.2)	84.4 (8.7)	0.275	88.9 (13.1)	90.1 (9.4)	0.618
Radiological and clinical evaluation†						
Mean Oxford Hip Score (SD)	13.4 (3.0)	14.8 (2.7)	0.032	13.6 (3.1)	12.0 (0.0)	0.052
Mean Postel Merle d'Aubigné score (SD)	17.7 (0.7)	17.6 (0.5)	0.136	17.7 (0.7)	18.0 (0.0)	0.162
Pain	5.8 (0.5)	5.8 (0.4)	0.439	5.8 (0.5)	6.0 (0.0)	0.291
Mobility	5.9 (0.3)	5.8 (0.4)	0.055	5.9 (0.3)	6.0 (0.0)	0.471
Gait	5.9 (0.4)	6.0 (0.0)	0.506	5.9 (0.4)	6.0 (0.0)	0.561

*Immediately after surgery.
†At last clinical follow-up (mean 3.7 years (SD 0.8)).
LT, lesser trochanter.

Table VII. Clinical evaluation at last follow-up (mean 3.7 years)

Variable	Preoperative (n = 155 hips)	At last follow-up (n = 143 hips)
Mean Devane activity grade (SD) (median; IQR)	3.0 (0.9) (3; 2 to 4)	3.7 (0.9) (4; 3 to 4)
Mean PMA score (SD) (median; IQR)	12.3 (2.4) (13; 11 to 14)	17.6 (0.9) (18; 18 to 18)
Pain	2.1 (1.3) (2; 1 to 3)	5.8 (0.5) (6; 6 to 6)
Mobility	5.1 (1.0) (5; 5 to 6)	5.9 (0.3) (6; 6 to 6)
Gait	5.1 (1.4) (6; 4 to 6)	5.9 (0.5) (6; 6 to 6)
Mean OHS (SD) (median; IQR)	N/A	13.6 (3.1) (12; 12 to 14)

N/A, not available; OHS, Oxford Hip Score; PMA, Postel Merle D'Aubigné.

Varus femoral component malalignment was noted in seven hips (5.1%), predominantly Dorr A femurs ($p = 0.028$), and was associated with lower CFR at all levels (P1, $p = 0.029$; P2, $p = 0.008$; P3, $p = 0.011$; D1, $p = 0.009$). Varus femoral component malalignment was never associated with femoral component migration > 5 mm.

Clinical outcomes at last follow-up. For the 143 hips (133 patients) evaluated clinically at a mean 3.7 years (SD 0.8), the mean Devane activity grade improved from 3.0 (SD 0.9) preoperatively to 3.7 (SD 0.9) postoperatively, and the mean PMA score improved from 12.3 (SD 2.4) preoperatively to 17.6 (SD 0.9) postoperatively (Table VII).

The mean OHS was 13.6 (SD 3.1) at final follow-up. Absence of spot welds was associated with lower mean PMA gait sub-scores (5.3 (SD 1.2) vs 5.9 (SD 0.3); $p = 0.012$), and femoral component migration was associated with higher (worse) mean OHS (14.8 (SD 2.7) vs 13.4 (SD 3.0); $p = 0.032$). Univariate linear regressions revealed no associations between femoral morphology and clinical scores, nor between CFR and clinical scores (Table IV).

Discussion

The use of uncemented femoral components in THA has increased steadily over recent decades, and several authors have demonstrated the importance of adequate femoral component filling within the femoral canal to optimize radiological[9–15] and clinical outcomes.[18] The choice of femoral component size – the principal determinant of femoral component filling – can be challenging because of the variability of femoral morphology and femoral component designs.[36] This study therefore aimed to determine whether femoral morphology and femoral component filling influence early clinical and radiological outcomes following THA, using an uncemented femoral component fully coated with HA in an unselected and gender-balanced Caucasian population. Femurs with proximally flared or distally narrowed canals, as well as lower filling, were associated with suboptimal radiological changes two years after THA. The hypothesis that high CFI and low CFR would be associated with poor outcomes is partly confirmed, with direct influence on femoral component osseointegration but not on clinical scores.

In the present series, osseointegration at two years was satisfactory for most cases, despite the absence of spot welds in three hips (2%). In accordance with the findings of Ishii et al,[19] spot welds were only absent in flared femurs (high CFI and low CCR), which could be due to insufficient proximal femoral component filling (low CFR). Mismatch in proximal-distal filling is known to compromise osseointegration of proximally HA-coated femoral components. Cooper et al[10] observed that stove pipe femurs (low CFI) tended to require larger femoral components, which were too filling distally and less filling proximally. Conversely, Ishii et al[19] reported that flared femurs (high CFI) had excessive distal filling, probably because their cohort comprised exclusively Japanese women, known to have more narrow and flared canals than Caucasian femurs.[37] Interestingly, we observed no associations between mismatch in proximal-distal filling and absence of spot welds. Still, our results suggest that even when using a fully HA-coated femoral component with adequate distal filling, insufficient proximal filling can compromise osseointegration, particularly in femurs with flared and narrow canals. Anatomical, short, shortened, or custom femoral components may therefore be useful to optimize proximal filling in extreme morphotypes, which could enhance femoral component stability, osseointegration, and survival.[15,38] However, there is little evidence of their efficacy in the long term.[39,40]

Calcar atrophy, suggesting adequate distal stability of the femoral component,[33] was observed in two-thirds of the series. However, absence of calcar modification was observed mainly in Dorr A femurs, with narrow canals and lower proximal and distal CFR, so care should be taken not to overinterpret this lack of bone remodelling as failure of osseointegration. Femoral component migration > 5 mm was noted in nine hips (6.5%) and was only associated with lower femoral component filling at and below the LT, which corroborates with other published studies that found a negative correlation between femoral component filling and femoral component subsidence.[11,13,14,16] It is interesting to note that femoral component migration > 5 mm was not associated with femoral morphology, indicating that it is only due to femoral component undersizing or insufficient filling. Furthermore, varus tilt was observed in seven hips (5%), predominantly Dorr A femurs, and was associated with lower CFR at all levels.

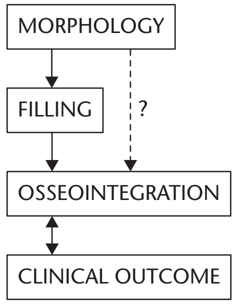

Fig. 3

Associations between femoral morphology, femoral component filling, postoperative osseointegration, and postoperative clinical outcomes.

Although several authors found similar associations,[13,17] varus malalignment had no apparent radiological or clinical consequences at four years.[41,42]

The present study revealed no direct associations between clinical scores and either patient morphology or CFR. Such associations are difficult to detect because of limited follow-up and statistical collinearity between femoral morphology and femoral component filling. Analysis of our postoperative outcomes revealed, however, that the absence of spot welds affected gait, and femoral component migration was associated with worse OHS. While cause-and-effect relationships cannot be ascertained from the present study, the authors do not believe that femoral morphology affects osseointegration directly and independently from femoral component filling, and rather contend that femoral morphology affects femoral component filling. This subsequently influences osseointegration, which may in turn compromise clinical scores (Figure 3).

The present study has several limitations typical of retrospective investigations, including missing preoperative radiological and clinical data. Although our sample size was deemed sufficient to detect morphological differences between hips with failed or adequate fixation, it was not possible to establish filling thresholds for adequate osseointegration, due to a small number of hips with failed osseointegration. However, based on this study, successful osseointegration (presence of spot welds but absence of femoral component migration/malalignment) of this femoral component seems to be obtained with a filling threshold greater than 70% at 2 cm below the LT (P3) (Tables V and VI). We calculated the CFR based on a previously published method,[19] by dividing the width of the femoral component by the width of the intramedullary bone canal at different time intervals, which may be slightly influenced by magnification or femoral rotation mismatch. Moreover, given that the femoral component has a quadrilateral cross section, any obliquity in orientation of the radiograph tube can make the implant appear wider than it truly is, which could slightly increase the CFR. While the frontal and lateral preoperative CBRs are strongly correlated, indicating consistent distal femoral morphology in both directions, the authors did not assess postoperative radiological parameters in the sagittal plane and therefore cannot confirm adequate circumferential femoral component osseointegration or alignment. Last, we may need a longer follow-up to find statistically significant associations with clinical scores, therefore we will continue to follow this series for years to come.

In conclusion, this study revealed that femurs with insufficient proximal filling tend to have less favourable radiological outcomes following uncemented THA using a fully HA-coated double-tapered femoral component. Although cause-and-effect relationships cannot be ascertained, the authors believe that femoral morphology affects femoral component filling. This subsequently influences osseointegration, which could later compromise clinical scores. The present findings emphasize the importance of optimizing proximal femoral component sizing and filling, which may require specific templating strategies and/or implant designs for extreme morphotypes.

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