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Low rate of periprosthetic femoral fracture with the Hueter anterior approach using stems cemented according to the 'French paradox'

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Aims

The aim of this retrospective study was to assess the incidence of early periprosthetic femoral fracture (PFF) associated with Charnley-Kerboull (CK) femoral components cemented according to the 'French paradox' principles through the Hueter anterior approach (HAA) in patients older than 70 years.

Methods

From a prospectively collected database, all short CK femoral components implanted consecutively from January 2018 to May 2022 through the HAA in patients older than 70 years were included. Exclusion criteria were age below 70 years, use of cementless femoral component, and approaches other than the HAA. A total of 416 short CK prostheses used by 25 surgeons with various levels of experience were included. All patients had a minimum of one-year follow-up, with a mean of 2.6 years (SD 1.1). The mean age was 77.4 years (70 to 95) and the mean BMI was 25.3 kg/m^2 (18.4 to 43). Femoral anatomy was classified according to Dorr. The measured parameters included canal flare index, morphological cortical index, canal-calcar ratio, ilium-ischial ratio, and anterior superior iliac spine to greater trochanter (GT) distance.

Results

Among the 416 THAs, two PFFs (0.48% (95% confidence interval 0.13 to 1.74)) were observed, including one Vancouver type B2 fracture 24 days postoperatively and one intraoperative Vancouver type B1 fracture. Valgus malalignment and higher canal bone ratio were found to be associated with PFF.

Conclusion

This study demonstrated that short CK femoral components cemented according to the French paradox were associated with a low rate of early PFF (0.48%) in patients aged over 70 years. Longer follow-up is warranted to further evaluate the rate of fracture that may occur during the bone remodelling process and with time.

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Introduction

Early periprosthetic femoral fracture (PFF) following primary total hip arthroplasty (THA) is an increasing concern that has been reported more often with cementless implants and through the Hueter anterior approach (HAA).[1-4] It can be assumed that a significant proportion of these early fractures are probably undiagnosed intraoperative fractures. As such, patients with a PFF have an 11% increased risk of mortality within the first year.[5] They also require complex revision procedures, with a higher risk of complications and readmission as well as impaired function compared to uncomplicated primary hip arthroplasty.[6,7] Some projection models have indicated that the number of PFFs is expected to rise by a mean of 4.6%

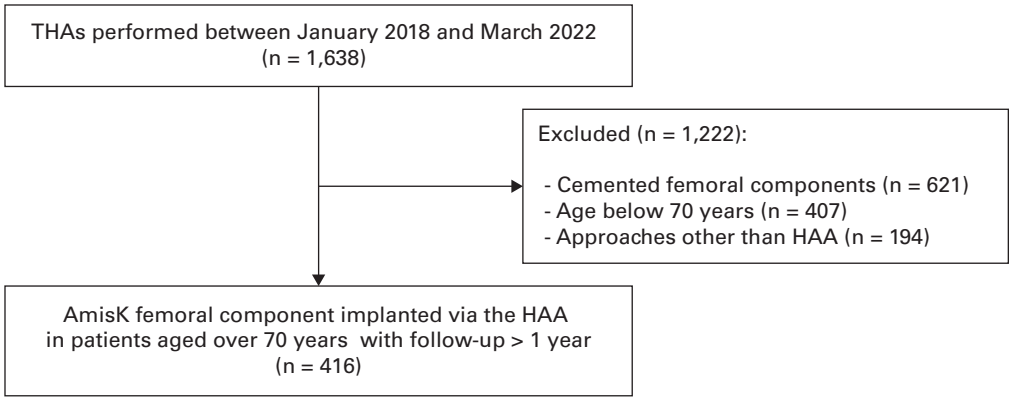


Fig. 1

Study flowchart. HAA, Hueter anterior approach; THA, total hip arthroplasty.

Table I. The characteristics of the patients.

Parameter	Value
Hips, n	416
Mean age, yrs (SD; range)	77.4 (5.4; 70 to 95)
Female, %	72.8
ASA grade, n	
I	137
II	186
III	96
Side, n (%)	
Right	212 (51)
Left	204 (49)
Mean BMI, kg/m² (SD; range)	25.3 (4.7; 18.4 to 43)
Mean follow-up, yrs (SD)	2.6 (1.1)
Aetiology, n (%)	
Primary osteoarthritis	336 (80.8)
Femoral neck fracture	59 (14.2)
Avascular necrosis	20 (4.8)
Oncological	1 (0.2)
Acetabular component, n	
Standard cementless	215
Standard cemented	92
Dual-mobility cementless	82
Dual-mobility cemented	27

ASA, American Society of Anesthesiologists; SD, standard deviation.

Table II. The characteristics of the patients with periprosthetic femoral fracture.

Parameter	Patient 1	Patient 2
Age, yrs	74	75
Sex	Female	Female
ASA grade	II	I
Side	Left	Right
BMI, kg/m²	21.8	24.1
Aetiology	Avascular necrosis	Primary osteoarthritis
Radiological findings		
CFI	2.6	2.9
MCI	2.3	2.5
CCR	0.6	0.6
IIR	2.8	2.2
CBR	0.5	0.6
ASIS to GT, mm	91.3	102
Dorr type	B	B
Stem axis (+ varus)	-0.7	-3.1
Type of fracture	Vancouver B2	Vancouver B1

ASA, American Society of Anesthesiologists; ASIS to GT, anterior superior iliac spine to greater trochanter distance; CBR, canal bone ratio; CCR, canal to calcar ratio; CFI, canal flare index; IIR, ilium-ischial ratio; MCI, morphological cortical index.

every decade over the next 30 years, and thus will represent a major medical and economic burden in the decades to come.[8]

To reduce the risk of PFF, some surgeons use cemented femoral components. However, PFFs have also been reported in association with some taper-slip (TS) design cemented femoral components when compared to composite beam (CB) prostheses.[9-13] The primary risk factor for fracture is older age, due to a higher prevalence of osteoporosis.[13,14]

At our institution, we routinely use a short Charnley-Kerboull (CK) (AmisK; Medacta, Switzerland) femoral component (12% reduction in length compared to the standard length component) cemented according to the 'French paradox' principle, which has shown results comparable to a standard-length CK prosthesis, with femoral component subsidence of less than 1 mm.[15] The aim of this retrospective study was to assess the incidence of early PFF after a minimum of one-year follow-up with a short CK femoral component implanted through HAA in a high-risk group of patients older than 70 years, and to identify demographic or radiological parameters associated with the risk of fracture.

Methods

Study cohort and type of study. From a prospectively collected database, we retrospectively reviewed all THAs with short CK femoral component performed from January 2018 to March 2022 through the HAA in patients older than 70 years. This was the only cemented femoral prosthesis used during the study period. A flowchart of the study including inclusion and exclusion criteria, and the total number of THAs performed during the study period, is provided in Figure 1. Standard demographic

Table III. Factors associated with periprosthetic femoral fracture.

Variable	Periprosthetic fracture		p-value
	Yes	No	
Mean age, yrs (SD)	74.5 (0.7)	77.4 (5.4)	0.531*
Mean BMI, kg/m² (SD)	22.9 (1.6)	25.3 (4.7)	0.441*
ASA grade, n (%)			0.234†
I	1 (50)	136 (32)	
II	1 (50)	185 (45)	
III	0	96 (23)	
Sex, n (%)			0.412†
Male	0	113 (27.3)	
Female	2 (100)	301 (72.7)	
Side, n (%)			0.935†
Right	1 (50)	211 (51)	
Left	1 (50)	203 (49)	
Dorr type, n (%)			0.217†
A	0	240 (57.5)	
B	2 (100)	174 (42)	
C	0	2 (0.5)	
Aetiology, n (%)			0.031†
Primary osteoarthritis	1 (50)	335 (81)	
Femoral neck fracture	0	59 (14.2)	
Avascular necrosis	1 (50)	19 (4.6)	
Oncological	0	1 (0.2)	
Mean IIR (SD)	2.5 (0.5)	2.7 (0.3)	0.697†
Mean ASIS-GT (SD)	96 (7)	101 (13)	0.654†
Mean CFI (SD)	2.7 (0.2)	3.4 (0.6)	0.081†
Mean CCR (SD)	0.6 (0.01)	0.5 (0.08)	0.082†
Mean CBR (SD)	0.55 (0.02)	0.4 (0.08)	0.045†
Mean MCI (SD)	2.4 (0.2)	2.8 (0.4)	0.135†
Mean stem axis (SD)	-1.9 (1.6)	0.1 (1.4)	0.041†

*Mann-Whitney U test.
†Chi-squared test.
ASA, American Society of Anesthesiologists; ASIS-GT, anterior iliac spine to greater trochanter distance; CBR, canal bone ratio; CFI, canal flare index; IIR, ilium-ischial ratio; MCI, morphological cortical index; SD, standard deviation.

data were recorded. All patients gave informed consent and institutional review board approval was obtained.

A total of 416 hips in 416 patients met the inclusion criteria. None were lost to follow-up, and all had a minimum of one-year follow-up. The cohort study included 303 (72.8%) female and 113 (27.2%) male patients. The mean age was 77.4 years (standard deviation (SD) 5.4), and the mean follow-up was 2.6 years (SD 1.1). Demographic details are summarized in Table I.

Surgical details. All patients were operated on through the HAA with the use of the Hueter's interval,[16] shifting over the sheath of the tensor fascia lata to avoid damaging the lateral femoral cutaneous nerve. This interval was first described for hip arthroplasty by Robert and Jean Judet[16] in 1950. Patients were positioned in the supine position with the procedures performed with or without the help of a specialist positioning table that allows hip extension to access the femoral canal, as per surgeons' preference. A total of 25 surgeons were involved in the study, with varying levels of surgical experience, from first-year junior staff to senior staff joint arthroplasty surgeons with over 20 years of practice. Overall, 20 surgeons used the positioning table for 287 hips and five used a regular operating table for 129 hips. Except for the use of a table, all surgeons used the same surgical technique including identical retractors and operative steps.

Of note, none of the surgeons had more than five years of experience with the use of the HAA. However, all participating surgeons had been trained using this femoral component during their surgical residency. Preoperative 2D digitized templating was performed using proprietry software (mediCAD; mediCAD Hectec, Germany) in order to estimate the optimal size of the femoral component, permitting a line-to-line cementing technique that includes the use of a canal-filling stem with a thin cement mantle.

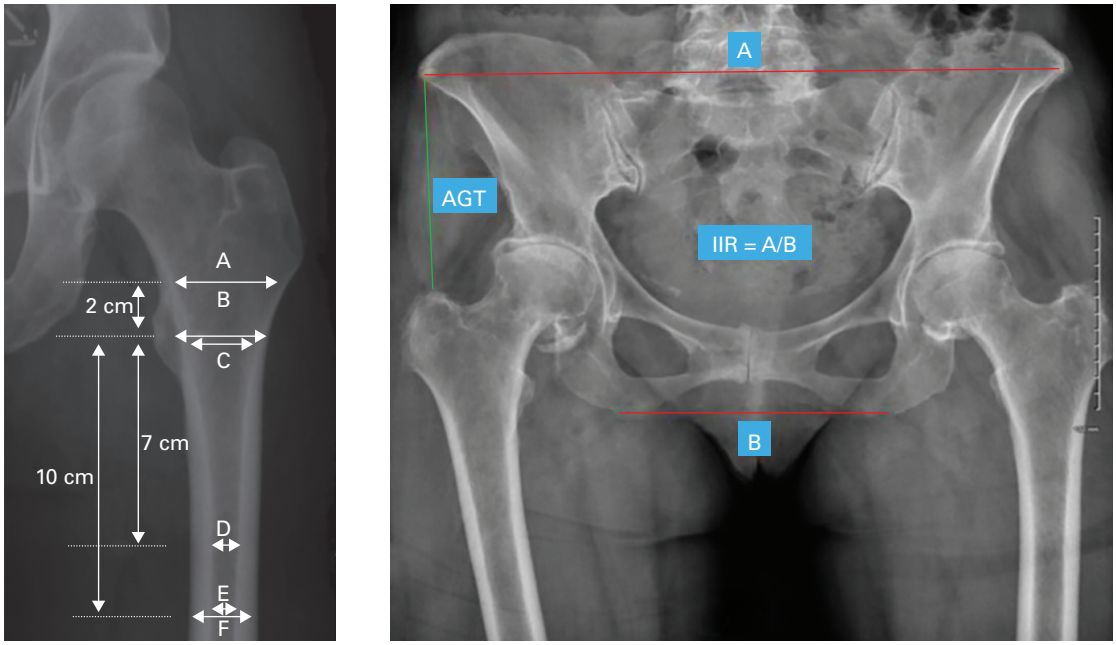
In all cases, acetabular component insertion was performed before femoral preparation. Both standard and dual-mobility components were used (Table I). Then, the leg was externally rotated and either extended (with positioning table) or adducted (regular table). The femur was prepared using sequential broaches and hollow reamers when needed, to allow diaphyseal cancellous bone removal and obtain rotational stability of the broach (Supplementary Figure a) as tested manually. The selected component which was cemented line-to-line was the same size as that of the last broach, in accordance with the French paradox principles,[17] based upon a thin cement mantle between the femoral component and the cortical bone.

An absorbable cement plug was inserted, and the femoral canal was thoroughly washed with saline solution and then dried. Cementing was then performed with CMW type-1 bone cement with gentamicin (Depuy, UK) using a syringe or a cement injection gun, while a suction drainage was placed into the canal close to the plug. The drain was then removed and the femoral prosthesis inserted with the same anteversion used for the last broache, and inserted until the collar was seated on the calcar. No intraoperative radiograph was performed to check for PFF or femoral perforation, though a visual check was performed.

In all hips, a short CK femoral component was used.[15,18] This double-tapered (5.9°) femoral component is made of M30NW stainless steel, and has a highly polished surface (roughness Ra value of 0.04 μm) with a quadrangular section. This component was available in five sizes, with a component length (shoulder to tip) ranging from 90 mm to 115 mm and a neck length ranging from 24 mm to 56 mm. For each neck length, the femoral component was available in two or three sizes to accommodate variations in the dimensions of the medullary canal (Supplementary Figure b).

Standard wound closure was performed and patients were allowed to walk fully weightbearing later on the day of surgery. Patients were discharged home or to a rehabilitation centre on postoperative day one or two, and then assessed in the outpatient clinic with physical examination and radiographs at six weeks, six months, one year, and then yearly thereafter.

Evaluation. A radiological analysis was performed to evaluate properative hip anatomy. Radiological measurements were performed on anteroposterior pelvis and femur radiographs using a proprietry software (PACS; Carestream, USA). These included endosteal width at four different anatomical points and external cortical diameter at two points. The central anatomical femoral axis was used as a reference point for horizontal



a b

Fig. 2

a) Method of measuring canal flare index (CFI), morphological cortical index (MCI), canal calcar ratio (CCR), and canal bone ratio (CBR). CFI = A/E, MCI = B/D, CCR = E/C, CBR = E/F. b) Method of measuring ilium-ischial ratio (IRR) and distance from anterior-superior iliac spine (ASIS) to tip of the greater trochanter (GT). IRR = A/B.

plane measurements, and the centre of the lesser trochanter as the reference point for the vertical measurements (Figure 2). Measurements were made parallel to and perpendicular to these reference points. We measured the width of the endosteal canal at 2 cm proximal to the lesser trochanter, at the lesser trochanter, 7 cm distal to the lesser trochanter, and 10 cm distal to the lesser trochanter. We measured the external canal diameter at the lesser trochanter and at 10 cm distal to the lesser trochanter. The horizontal distance between the anterior superior iliac spines and ischium was recorded. These measurements were used to calculate the canal flare index (CFI), morphological cortical index (MCI), calcar-calcar ratio (CCR), canal bone ratio (CBR), ilium-ischial ratio (IIR), and anterior superior iliac spine (ASIS) to greater trochanter distance.[19] The alignment of the femoral component, referenced from the axial alignment of the femur, was assumed to be neutral within 3° from colinearity. The Dorr classification[20] was also recorded, and any fractures were classified according to the Vancouver classification.[21]

The primary measure for outcome was the incidence of PFF in the study cohort at final follow-up. We also aimed to identify demographic, surgical, or radiological parameters that were associated with an increased risk of PFF.

Statistical analysis. Continuous variables were described using the mean, SD, and ranges. Categorical variables were presented with total count and percentages. The reported incidence of PFF was defined as the ratio between the number of fractures and the the total number of hips operated in the cohort. This gave an incidence with a confidence interval (CI). The chi-squared and Fisher's exact tests were used to test for differences between categorical variables, and the non-parametric Mann-Whitney U test was used for continuous variables. Significance was set at $p = 0.05$. All analysis was performed using SPSS for Windows v. 27 (IBM, USA), and the data were reviewed by a statistician.

Results

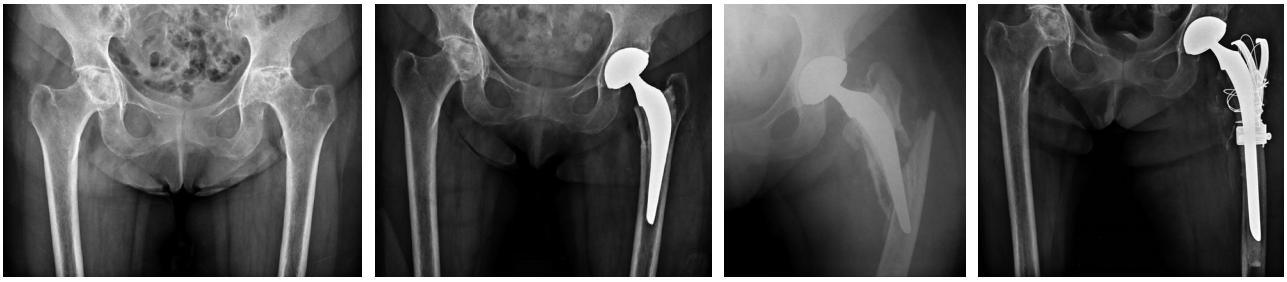
Radiological results. Radiological results of the series, including the morphological parameters, the stem axis, and femoral anatomy according to Dorr, are provided in Supplementary Table i.

Fracture rate. Of the 416 THAs, two (0.48% (95% CI 0.13 to 1.74)) early PFFs were observed. The first fracture was a Vancouver type B2 fracture that was diagnosed 24 days postoperatively, following a fall (Figure 3), and the second one was an intraoperative Vancouver type B1 fracture. The patients' characteristics are detailed in Table II. The patient with Vancouver B2 fracture required femoral revision using a long cemented femoral component performed through a transtrochanteric approach. The intraoperative B1 Vancouver fracture was treated with cerclage wire with no further complications.

Factors associated with PFF. Factors associated with PFF were the aetiology ($p = 0.031$), the valgus stem alignment ($p = 0.042$), and a higher CBR ($p = 0.045$, all chi-squared test). These are summarized in Table III.

Discussion

PFF following primary THA is a devastating complication that has been reported at a higher rate in the aged population and with the use of the direct anterior approach. The aim of



a b c d

Fig. 3

a) Preoperative anteroposterior (AP) view of the pelvis in a 75-year-old female with bilateral avascular necrosis of the femoral head. b) Immediate postoperative AP radiograph showing a cemented component with a non-optimal cement mantle. c) AP radiograph performed at postoperative day 24, showing a Vancouver type B2 fracture following a fall. d) AP radiograph performed after revision of the femoral component using a long cemented prosthesis through a transtrochanteric approach.

the current study was therefore to evaluate the risk of fracture in this worst-case scenario using short CK femoral components cemented according to the French paradox. Under these circumstances, our study found an early rate of femoral fracture of 0.48% after a mean follow-up of 2.6 years.

This study has limitations. First, its retrospective design could have led to inaccurate reporting and loss of data. We used a prospective computerized database that helped us to gather accurate information, no patient was lost to follow-up, and the main outcome was robust. Second, the series is small, but no other data have been reported on this specific cementing technique with these implants, and other series reported in the literature using various implants include a similar number of patients. Third, the follow-up is short, but it is in line with the objective of the current study. Fourth, from the 416 hips included, only two were Dorr type C morphology, which has been reported as a risk factor for femoral fracture. However, some patients treated for femoral neck fracture (FNF) who are at higher risk for PFF were also included. We treated 427 patients with FNF seen at our department during the study period; only 59 (16%) were included in the current study, as the remaining 368 patients were treated with hemiarthroplasty. Fifth, it is difficult to draw definitive conclusions on risk factors for PFF with only two PFFs detected in the study group. Finally, the mean BMI in our patients was lower than that in most reported studies, which might make the results less generalizable.

There are numerous reports in the literature recording an overall lower rate of PFF with cemented femoral components, compared to cementless prostheses. An analysis from the latest American Joint Replacement Registry compared the fracture rate of 266,040 cementless to 13,012 cemented femoral components, and found a higher risk of fracture with cementless prostheses, with a hazard ratio (HR) of 7.7 for patients aged over 65 years.[22] Another registry-based study from the Mayo Clinic included 16,696 primary THAs and found a global PFF rate of 3.3%, with uncemented fixation being a significant and modifiable risk factor (HR 2.5).[23]

To the best of our knowledge, the early fracture rate using CK femoral components, cemented according to the French paradox technique, has never been reported. When analyzing the results of cemented femoral components, the reported studies concerned exclusively examined TS or CB designs. TS designs were found to have a higher risk of early PFF compared to CB designs (Supplementary Table ii).[11,12,24,25] A recent meta-analysis compared 294,540 patients who received a CB femoral component with 618,481 who received a TS design. The patients were classified as low and high risk for PFF. The relative incidence of PFF was 3.14 and 9.87 for the TS group versus the CB group, in the low- and high-risk groups, respectively.[26] It is notable that the fracture rates for the same femoral component can fluctuate widely from one study to another, demonstrating that other factors may play an significant role in the occurrence of PFF.

There are some in vitro data available in the literature that may explain the lower rate of PFF observed with CB versus TS femoral components, as well as the results reported in the current study. The principle of the French paradox technique is based upon diaphyseal cancellous bone removal in order to achieve canal filling, hence a stable prosthesis prior to cementing. Janssen et al[27] observed in an in vitro study that canal-filling components produced fewer cement fractures and less rotation than undersized femoral components. Cement mantles surrounded by trabecular bone produced more cement fractures and implant rotation than cement mantles surrounded by cortical bone. Furthermore, Scheerlink and Casteleyn[28] demonstrated that removing weak cancellous bone favours a direct load transfer to the cortex that is biomechanically stronger bone. Sevaldsen et al[29] similarly reported that a cemented Corail component seemed to settle earlier with the line-to-line technique when compared to standard cementing, and with a lower rate of migration into retroversion. Thus, the principle itself of the French paradox cementing technique could explain a higher torque required to generate a fracture, due to increased stiffness of the femoral prosthesis construct. Takegami et al[30] conducted an in vitro biomechanical study comparing fracture torque and strain values for the CK, CPT, and Versys (collared polished) femoral prostheses. They found a significant difference in fracture torque between the three component types ($p = 0.036$). The median fracture torque for the CPT femoral component in particular was significantly lower than that for the CK prosthesis (CPT 164.5 Nm vs CK 200.5 Nm; $p = 0.046$). The

strain values for the CPT component were higher than those for the other two prostheses at the most proximal site. According these authors, and others,[30,31] cobalt-chromium alloy material, polished surface finish, acute-square proximal prosthesis geometry, and the absence of a collar may be associated with lower fracture torque, which may be related to increased risk of PFF in some TS designs. Likewise, in cementless components,[32] the collar may have a protective effect with cemented implants. Additionally, the TS principle, which allows for migration of the stem within the cement mantle as a consequence of the viscoelastic properties of bone cement, may increase stress at the bone-cement interface, thereby potentially increasing the risk of fracture.

In the current study, higher CBR and a valgus component alignment were associated with two observed PFFs. These factors could potentially correspond and lead to an undersized femoral component and therefore a poor French paradox technique, potentially allowing component subsidence and femoral fracture. Coronal malalignment and high CBR have been linked to an increased risk of PFF in other studies evaluating cemented and cementles femoral components.[19,25,33,34] We observed primary osteoarthritis (OA) and avascular necrosis of the femoral head to be associated with PFF. While it seems difficult to explain, especially for primary OA, other studies have reported similar data.[17,35]

This study demonstrated that short CK femoral components cemented according to the French paradox using the HAA were associated with an extremely low rate of early PFF in patients aged over 70 years. The observed PFF rate in this study is in the range of the best rates of other reported studies, even though 25 different surgeons with various levels of experience undertook the surgical procedures, pointing towards a reproducible technique. Longer follow-up is warranted to evaluate further rate of fracture.

Take home message

- Cemented stems according to the French paradox are associated with a low rate of early fracture in primary total hip arthroplasty in patients aged over 70 years.
- Longer follow-up is warranted to evaluate further rate of fracture.

Supplementary material

An intraoperative photograph showing the rasp used, an anteroposterior radiograph showing a stem cemented line-to-line, a detailed table indicating the radiological results for the entire cohort, and a table of the main comparative studies of taper slip and composite beam cemented stems.

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