■ HIP

Periprosthetic femoral fracture following hip arthroplasty

WHICH COMPONENT DESIGN AND FIXATION METHOD HAS THE LOWEST RISK OF REOPERATION?

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Aims

Periprosthetic femoral fracture (PPFF) is a major complication following hip arthroplasty. This study examined the influence of femoral component design and fixation method on the risk of reoperation for PPFF.

Methods

We analyzed data on femoral component type use for primary hip arthroplasty stems reported to the Norwegian Arthroplasty Register and the Norwegian Hip Fracture Register from 1 January 2005 to 31 December 2023. The study included 187,576 well-documented femoral components used in hemi- and total hip arthroplasties which were assessed by Cox regression. The femoral components were categorized into five groups: 1) cemented composite beam (n = 30,415), and two types of cemented polished taper-slip components; 2) double-tapered (n = 52,255); 3) triple-tapered (n = 13,894), and two types of uncemented femoral components; 4) wedged collarless (n = 38,389); and 5) wedged collared (n = 40,853). Endpoint was reoperation for PPFF (revisions and osteosyntheses).

Results

A total of 1,398 femoral components (0.7%) were reported with a reoperation due to PPFF. The risk of reoperation was significantly higher for cemented double-tapered (adjusted hazard rate ratio (aHRR) 4.0 (95% CI 3.1 to 5.2), cemented triple-tapered (aHRR 4.0 (95% CI 2.9 to 5.6)), uncemented wedged collarless (aHRR 7.3 (95% CI 5.6 to 9.5)), and uncemented wedged collared (aHRR 3.5 (95% CI 2.6 to 4.6)) components compared to cemented composite beam components. Cemented triple-tapered prostheses exhibited a similar risk of reoperation (aHRR 1.0 (95% CI 0.8 to 1.3)) to cemented double-tapered components. Uncemented wedged collarless prostheses were associated with a higher risk of PPFF (aHRR 2.1 (95% CI 1.8 to 2.5)) compared to uncemented wedged collared designs.

Conclusion

To minimize the risk of PPFF, cemented composite-beam femoral components should be the surgeon's preferred choice. If cementing is not an option, uncemented wedged collared components are the best alternative. Opting for a cemented triple-tapered design does not improve outcomes compared to double-tapered component.

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Introduction

Periprosthetic femoral fracture (PPFF) after hip arthroplasty is a severe complication associated with increased morbidity, increased mortality, and decreased quality of life.[1,2]

PPFFs have been ominously called "the next fragility fracture epidemic", and "a rising tide of hip arthroplasty failure" has been predicted.[3] The problem is likely to become prevalent, as hip arthroplasty is undertaken in younger patients who will live with their arthroplasties for decades, and in older and frailer patients with more comorbidities and poor bone stock.[4] In addition, displaced femoral neck fractures in elderly patients are most frequently treated with a hemiarthroplasty (HA) rather than internal fixation.[5] This contributes to a high proportion of elderly patients having hip prostheses and being at risk of sustaining a PPFF.

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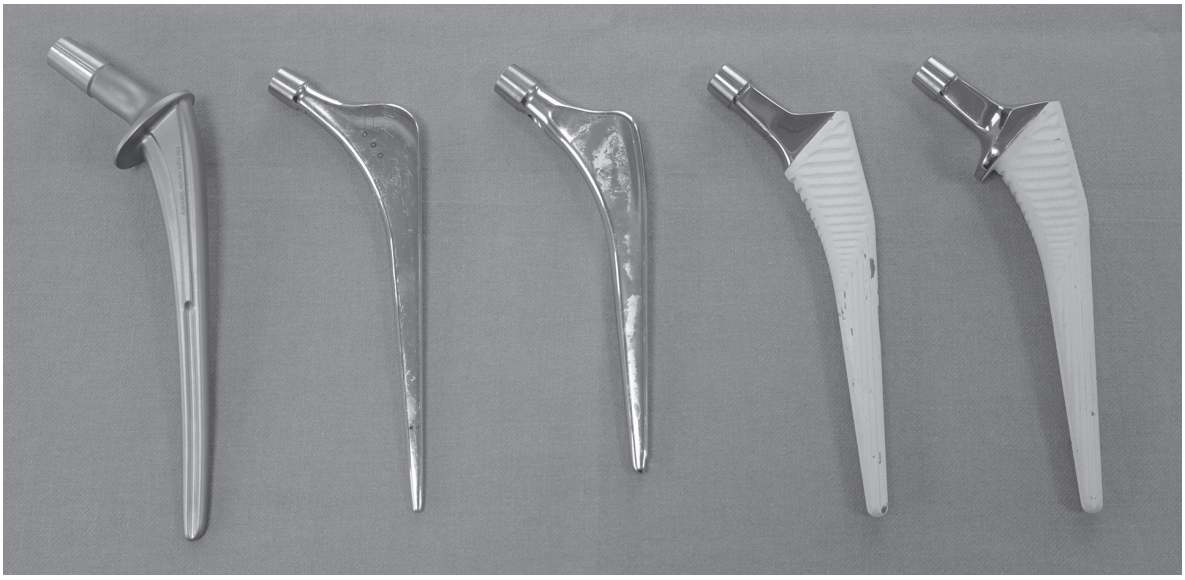

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Fig. 1

The most common femoral component from each of the five component design and fixation method groups. a) Cemented composite beam (Lubinus SPII; Waldemar Link, Germany). b) Cemented double-tapered (Exeter; Stryker, USA). c) Cemented triple-tapered MS-30 (Zimmer Biomet, USA). d) Uncemented wedged collarless (Corail, DePuy Synthes). e) Uncemented wedged collared (Corail, DePuy Synthes).

Table I. Patient characteristics and distribution of risk factors in the femoral component design and fixation method groups.

Risk factors	Cemented composite beam	Cemented double-tapered	Cemented triple-tapered	Uncemented wedged collarless	Uncemented wedged collared
Female, n (%)	21,477 (71)	36,751 (69)	10,206 (73)	29,964 (61)	24,240 (59)
Median age, yrs (IQR)	78 (72 to 84)	78 (71 to 84)	79 (73 to 85)	66 (58 to 74)	68 (60 to 75)
Mean ASA grade (SD)	2.4 (0.7)	2.4 (0.7)	2.5 (0.7)	2.0 (0.7)	2.1 (0.6)
Indication for primary hip arthroplasty, n (%)					
Osteoarthritis	15,401 (51)	23,167 (43)	5,857 (42)	32,288 (66)	30,297 (74)
Inflammatory hip disease	416 (1)	525 (1)	151 (1)	719 (1)	696 (2)
Acute hip fracture	11,863 (39)	24,824 (47)	6,981 (50)	6,962 (14)	4,947 (12)
Complications after hip fracture	1,321 (4)	1,746 (3)	412 (3)	1,863 (4)	740 (2)
Osteonecrosis of the femoral head	535 (2)	795 (4)	261 (1)	1,246 (11)	924 (7)
Complications after childhood hip disease	708 (2)	1,928 (1)	163 (2)	5,669 (3)	3,027 (2)
Other diagnosis	171 (1)	270 (1)	69 (1)	412 (1)	122 (1)
Register (type of arthroplasty), n (%)					
Hip Arthroplasty Register (THA)	19,673 (65)	30,363 (57)	7,788 (56)	43,226 (88)	36,756 (90)
Hip Fracture Register (HA)	10,742 (35)	22,892 (43)	6,106 (44)	5,933 (12)	4,097 (10)
Primary hip arthroplasties, n (%)	30,415 (16)	53,255 (28)	13,894 (7)	49,159 (26)	40,853 (22)

ASA, American Society of Anesthesiologists; HA, hemiarthroplasty; THA, total hip arthroplasty.

PPFF is now one of the most common causes of failure in the otherwise successful story of total hip arthroplasty (THA).[1,2,5]

The Norwegian Arthroplasty Register (NAR) and the Norwegian Hip Fracture Register (NHFR) include information on a high number of THAs and HAs, with data granularity down to catalogue number of implants, from a national population. The NAR and the NHFR now also register all reoperations, rather than just revisions.[5] Hence, these registers are well suited for the study of reoperation for PPFF.

The Bone and Joint Journal has highlighted aspects of PPFF in a series of important papers and editorials, challenging both surgeons in their choice of implants for their patients, and arthroplasty registers in how they report and record data regarding PPFF.[4,6,7] As a result, we have assessed the NAR and the NHFR for all reoperations for PPFF and investigated the associations with femoral component design and fixation method.

Our objective was to assess associations between the five most common femoral component designs and fixation methods with

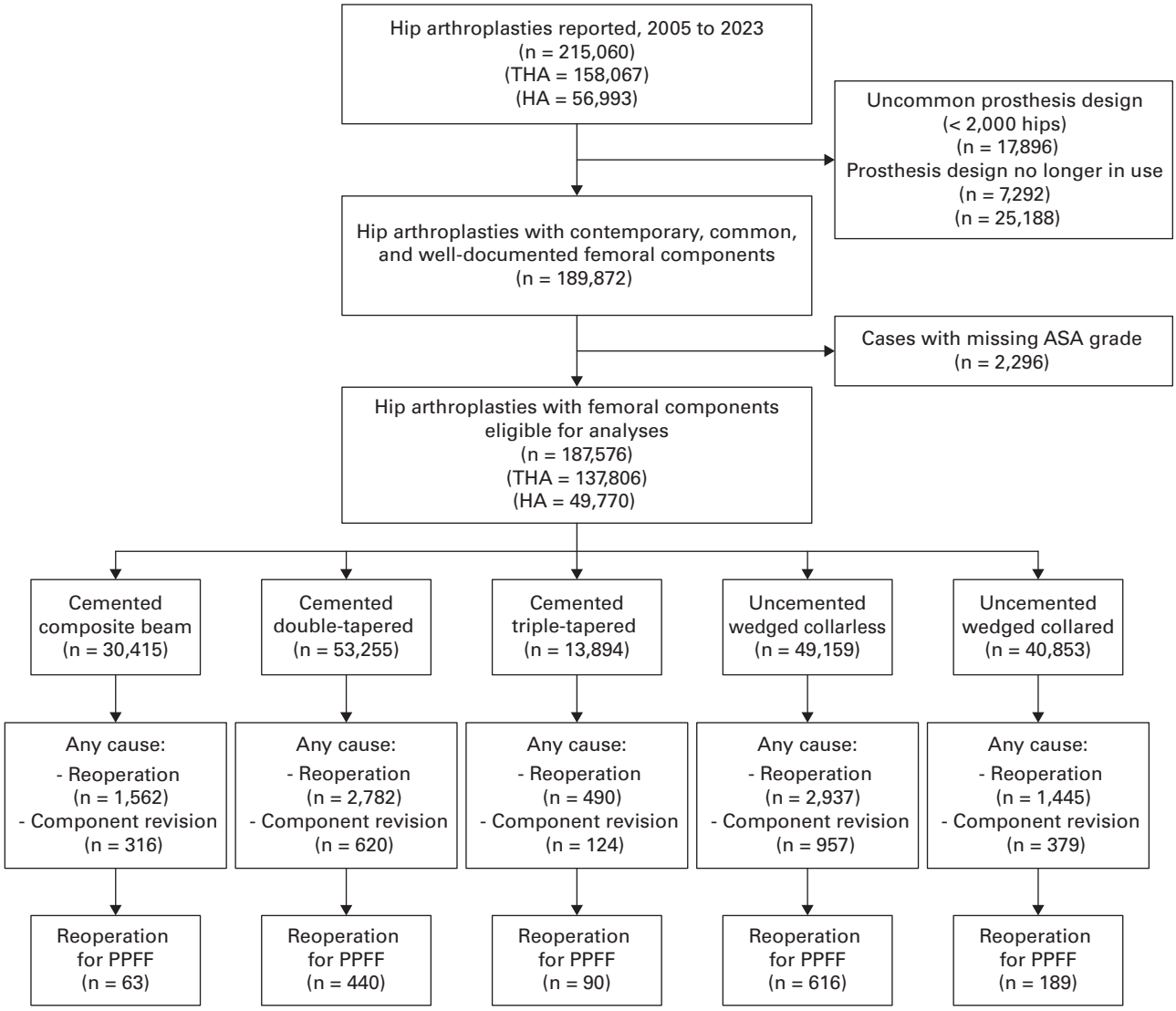

Fig. 2

Flowchart of inclusion and exclusion of cases and femoral components (hips) in the Norwegian Arthroplasty Register and the Norwegian Hip Fracture Register, divided iinto component design and method of fixation groups, and with subsequent outcomes. ASA, American Society of Anesthesiologists; HA, hemiarthroplasty; THA, total hip arthroplasty.

the risk of reoperation for PPFF. The femoral components were categorized into five groups: 1) cemented composite beam, the two types of cemented polished taper-slip (PTS) components; 2) double-tapered; 3) triple-tapered, and two uncemented designs; 4) wedged collarless; and 5) wedged collared.[8,9] Our primary question was: what component design and fixation method has the lowest risk of reoperation for PPFF? Secondarily, are there differences between the two main principles of cemented hip femoral component fixation (composite beam and PTS), or between the two groups of PTS designs (double- and triple-tapered)? What is the protective effect of a calcar collar in uncemented components?

Methods

Materials. We explored data on primary hip arthroplasty femoral components from THAs and HAs registered in the NAR and the NHFR between 1 January 2005 and 31 December 2023. We assessed components in patients of both sexes and all ages.

Since its inception in 1987, the NAR has registered detailed information on primary THAs and THA revisions, with the addition of reoperations with osteosynthesis for PPFF alone in 2016.[5,10] The NHFR has registered detailed information on primary hip artrhroplasties for proximal femoral fractures and all subsequent reoperations since 2005.[5,11] Both the NAR and the NHFR collect data on patients' identity, date of operation, indication for primary arthroplasty or reoperation, laterality, exact type of implant, method of fixation, and other surgery-related factors in a uniform manner. In addition, information on patient-related factors like sex, age, and comorbidities (American Society of Anesthesiologists (ASA) grade)[12] is registered.[5,10,11] The unique identification number of each Norwegian

Table II. Common, contemporary, and well-documented femoral component brands used in the cases included. Individual brands and designs and fixation method groups are presented.

Component design and fixation method	Brand	ODEP rating	Manufacturer	Stems, n	Median follow-up, yrs (IQR)	Grouped median follow-up (IQR)
Cemented composite beam	Lubinus SPII	15 A*	Waldemar Link, Germany	23,845	2.9 (1.0 to 6.8)	3.7 (1.3 to 8.7)
	Spectron EF	15 A*	Smith + Nephew, UK	6,570	9.5 (4.3 to 14.7)	
Cemented double-tapered	Exeter	15 A*	Stryker, USA	50,676	4.6 (1.7 to 8.7)	4.6 (1.7 to 8.5)
	CPT	15 A*	Zimmer Biomet, USA	2,579	4.4 (1.2 to 6.0)	
Cemented triple-tapered	C-Stem	15 A*	DePuy Synthes, USA	8,510	2.0 (0.8 to 3.6)	2.0 (0.8 to 3.8)
	MS-30	15 A*	Zimmer Biomet, USA	5,384	2.1 (0.8 to 4.1)	
Uncemented wedged collarless	Corail collarless	15 A*	DePuy Synthes, USA	38,289	7.9 (4.4 to 11.3)	7.5 (3.9 to 11.0)
	Filler	10 A*	Biotechni, France	5,270	8.2 (4.7 to 11.8)	
	POLARSTEM	10 A*	Smith + Nephew, UK	2,847	2.8 (1.1 to 6.2)	
	Accolade 2	10 A	Stryker, USA	2,753	4.9 (2.7 to 7.4)	
Uncemented wedged collared	Corail collared	15 A*	DePuy Synthes, USA	40,853	4.2 (1.7 to 7.3)	4.2 (1.7 to 7.3)
Total				187,576	4.8 (1.8 to 8.8)	

ODEP, Orthopaedic Data Evaluation Panel.

citizen links the primary arthroplasties to any subsequent procedures, and the National Population Register provides information on death or emigration.

The definition of revision in the registers is removal or exchange of any of the prosthesis parts. The definition of a reoperation for PPFF is any surgical procedure after primary arthroplasty (including revision and/or osteosynthesis with plates, screws, and/or cerclages), with PPFF reported as the cause. The NAR has 97% completeness of reporting of primary THAs, 91% reporting of any revisions, and 100% coverage of Norwegian hospitals, whereas the NHFR has 92% completeness of reporting of primary HAs, 88% reporting of reoperations, and 100% coverage of Norwegian hospitals.[5,10,11]

Ethics. The study, including the registration and merging of data, was performed confidentially, with patient consent, according to Norwegian and EU data protection rules, and approved by the Regional Ethical Committee West (REK 2024-710016). The NAR and NHFR have licences from the Norwegian Data Protection Authority (reference numbers 03/00058-15/JTA (issued on 24 January 2017) and 2004/1658-2 SVE/- (issued on 3 January 2005)), respectively.

Femoral components and fixation method. The included femoral components were classified into five groups: 1) cemented composite beam, 2) cemented double-tapered, 3) cemented triple-tapered, 4) uncemented wedged collarless, and 5) uncemented wedged collared (Figure 1). The composite beam components are designed to achieve rigid fixation at the interfaces between the femoral component, cement, and bone, and mostly have a collar and a rougher surface (the 'shape-closed' principle).[8] The PTS components are intended to subside within the cement mantle, allowing for the viscoelastic properties of bone cement, which in turn should be rigidly fixed to the bone to form a bone-cement envelope (the 'force-closed' or 'loaded taper' principle).[8] These components are therefore polished on the surface and tapered in shape, either two-dimensionally (double-tapered) or three-dimensionally (triple-tapered). Uncemented femoral components are initially fixed by rigid contact to proximal femur (most commonly wedging) before a secondary fixation through bone ingrowth, often stimulated by hydroxyapatite.[9] Some wedged uncemented designs have the option of a collar to relieve some of the wedging load on the proximal femur and reduce rotatory forces, and thereby improve primary fixation.[13,14]

We included common, contemporary, and well-documented femoral components, regardless of the acetabular component or articulation (Table I). A femoral component was considered common when used in more than 2,000 THAs/HAs during the study period (2005 to 2023), and contemporary if still in use. A femoral component was considered well-documented if the Orthopaedic Data Evaluation Panel (ODEP) rating was 10 A or higher.[15] The selection of cases is presented in Figure 2.

In total, 187,576 cases were eligible for analyses, 137,806 cases from the NAR and 49,770 cases from the NHFR.

Statistical analysis. Kaplan-Meier (KM) and adjusted Cox regression survival analyses were performed. Outcome was any reported reoperation for PPFF (revision of the femoral component and/or osteosynthesis). Femoral component revision for any cause was a secondary outcome to control for differences in causes of failure. All cases were followed until their first reoperation for PPFF, reoperation for other causes, date of death or emigration of the patient, or until end of follow-up on 31 December 2023. Adjusted hazard rate ratios (aHRRs), as an expression for relative risk, were estimated comparing the five component groups.

We adjusted for sex, age, ASA grade, and indication for primary arthroplasty in the analyses. In addition, adjustments for year of primary arthroplasty were performed to adjust for potential time-dependent confounding (improved reporting, changes in surgical strategy, etc).

The femoral components in each of the five groups had similar geometry, but were not identical in design. We therefore compared the 11 different femoral component brands separately. Sub-analyses were performed for the period 2016 to 2023, since this was the period in which not only revisions but also reoperations, including osteosyntheses, were reported to the NAR. In addition, sub-analyses were performed for hip arthroplasties (THAs and HAs) due to acute hip fractures only, since this group was suspected to be prone to PPFF.

Potential overestimation of the incidence of reoperation through the effect of competing risks (death and reoperation) is

Table III. Risk of reoperation for periprosthetic femoral fracture (PPFF) in the component design and fixation method groups. Individual brands and femoral component design and fixation method groups are presented.

Stem	Total, n	Reoperated for PPFF, n (%)	aHRR (95% CI)	Adjusted 10-yr reoperation rate, % (95% CI)*
Cemented composite beam		63 (0.2)	1	
Lubinus SPII	23,845	42 (0.2)	1	0.3 (0.1 to 0.4)
Spectron EF	6,570	21 (0.3)	1.3 (0.7 to 2.2)	0.3 (0.1 to 0.5)
Cemented double-tapered		440 (0.8)	4.0 (3.1 to 5.2)	
Exeter	50,676	407 (0.8)	4.1 (3.0 to 5.7)	1.4 (1.2 to 1.6)
CPT	2,579	33 (1.3)	7.0 (4.4 to 11.0)	1.6 (0.8 to 2.5)
Cemented triple-tapered		90 (0.6)	4.0 (2.9 to 5.6)	
C-Stem	8,510	52 (0.6)	4.2 (2.8 to 6.4)	0.8 (0.5 to 1.2)
MS-30	5,384	38 (0.7)	4.5 (2.9 to 6.9)	1.8 (0.3 to 3.3)
Uncemented wedged collarless		616 (1.3)	7.3 (5.6 to 9.5)	
Corail collarless	38,289	502 (1.3)	8.0 (5.8 to 11.0)	2.3 (1.8 to 2.8)
Filler	5,270	63 (1.2)	6.5 (4.4 to 9.7)	1.6 (0.8 to 2.4)
POLARSTEM	2,847	31 (1.1)	9.2 (5.8 to 14.6)	0.9 (0.3 to 1.5)
Accolade 2	2,753	20 (0.7)	6.9 (4.0 to 11.7)	1.2 (0.4 to 2.0)
Uncemented wedged collared		189 (0.5)	3.5 (2.6 to 4.6)	
Corail collared	40,853	189 (0.5)	3.7 (2.7 to 5.2)	0.7 (0.5 to 0.9)
Total, n	187,576	1,398 (0.7)		

*An underestimate since not all cases have complete ten-year follow-up.
aHRR, adjusted hazard rate ratio.

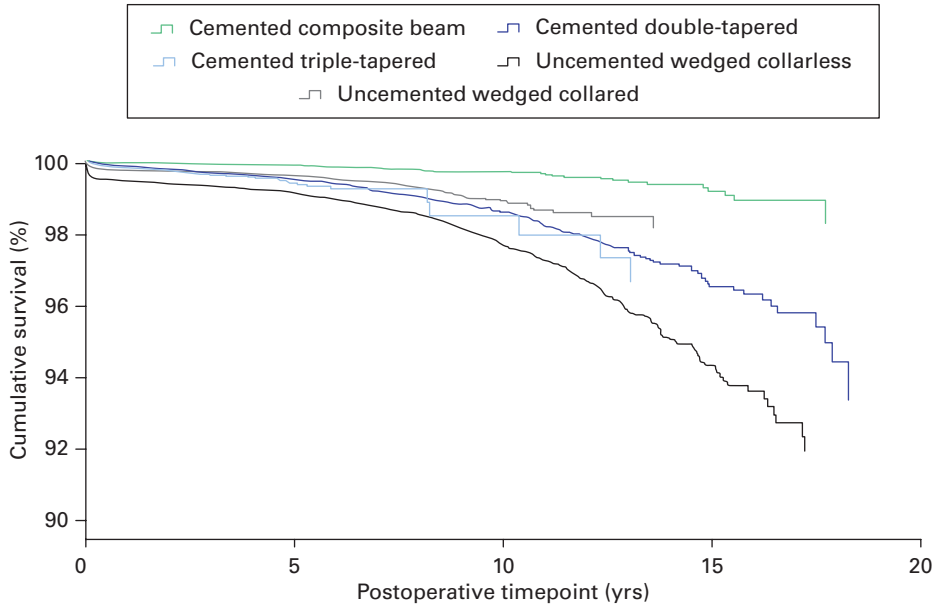

Fig. 3

Cox survival curves for reoperation for periprosthetic femoral fracture for the femoral component design and fixation method groups. The survival curves are adjusted for sex, age, American Society of Anesthesiologists grade, indication for primary arthroplasty, and year of primary surgery.

unlikely in large register studies, when considering other causes of reoperation as competing risk.[16] We chose to use KM and Cox for the present analyses. However, we expected competing risk analyses, with reoperation for any cause other than PPFF and death as a competing risk, to verify the limited influence of competing risk in the context of the present study.[16]

The 95% CIs were calculated for survival probabilities and risks, and CIs not including 1.0 were considered statistically significant. We used SPSS v. 29.0 (IBM, USA) and RStudio v. 2024.12.1+563 (Posit, USA) statistical software packages for analyses, and the study was performed in accordance with the STROBE statement, and in concordance with the guidelines for statistical analyses of arthroplasty register data.[17,18]

Results

We included 187,576 hips in 156,931 patients. Of the included femoral components, 137,806 (73%) were THAs registered in the NAR and 49,770 (27%) were HAs registered in the NHFR.

Table IV. Risk of reoperation for periprosthetic femoral fracture by femoral component design and fixation method, with one column with the respective groups as reference, for direct comparisons between groups.

Component design and fixation method	Risk of reoperation for periprosthetic femoral fracture (aHRR (95% CI))				
	Cemented composite beam*	Cemented double-tapered*	Cemented triple-tapered*	Uncemented wedged collarless*	Uncemented wedged collared*
Cemented composite beam	1	0.3 (0.2 to 0.3)	0.3 (0.2 to 0.3)	0.1 (0.1 to 0.2)	0.3 (0.2 to 0.4)
Cemented double-tapered	4.0 (3.1 to 5.2)	1	1.0 (0.8 to 1.3)	0.5 (0.5 to 0.6)	1.1 (1.0 to 1.4)
Cemented triple-tapered	4.0 (2,9 to 5.6)	1.0 (0.8 to 1.3)	1	0.5 (0.4 to 0.7)	1.2 (0.9 to 1.5)
Uncemented wedged collarless	7.3 (5.6 to 9.5)	1.8 (1.6 to 2.1)	1.8 (1.4 to 2.3)	1	2.1 (1.8 to 2.5)
Uncemented wedged collared	3.5 (2.6 to 4.6)	0.9 (0.7 to 1.0)	0.9 (0.7 to 1.1)	0.5 (0.4 to 0.6)	1

*Reference.
aHRR, adjusted hazard rate ratio.

Table V. Risk of reoperation for periprosthetic femoral fracture (PPFF) in the design and fixation method groups relative to time after primary arthroplasty. Risk estimates are adjusted for sex, age, American Society of Anesthesiologists grade, indication for primary arthroplasty, and year of primary surgery.

Component design and fixation method	Stems, n	0 to 6 mths postoperatively		6 mths to 5 yrs postoperatively		5 to 10 yrs postoperatively		10 to 19 yrs postoperatively	
		Reoperations for PPFF, n	aHRR (95% CI)	Reoperations for PPFF, n	aHRR (95% CI)	Reoperations for PPFF, n	aHRR (95% CI)	Reoperations for PPFF, n	aHRR (95% CI)
Cemented composite beam	30,415	22	1	13	1	14	1	14	1
Cemented double-tapered	53,255	77	2.0 (1.3 to 3.3)	179	6.7 (3.8 to 11.8)	114	4.2 (2.4 to 7.4)	70	3.9 (2.2 to 7.0)
Cemented triple-tapered	13,894	38	2.8 (1.7 to 4.8)	44	7.6 (4.1 to 14.3)	5	4.0 (1.4 to 11.0)	38	2.7 (0.8 to 9.6)
Uncemented wedged collarless	49,159	205	9.7 (6.2 to 15.3)	105	5.4 (3.0 to 9.8)	189	7.4 (4.3 to 12.8)	117	7.6 (4.3 to 13.5)
Uncemented wedged collared	40,853	93	4.4 (2.7 to 7.0)	39	2.5 (1.3 to 4.7)	48	3.5 (1.9 to 6.4)	9	2.4 (1.0 to 5.7)
Total	187,576	435		380		370		213	

aHRR, adjusted hazard rate ratio.

In total, 9,216 of the cases (4.9%) underwent reoperated for all causes during follow-up, 2,396 of cases (1.3%) were revised for any other cause than PPFF, and 1,398 (0.7%) were reoperated for PPFF. Median follow-up was 4.8 years (IQR 1.8 to 8.8).

The included components, with allocation to component design and fixation method group, are presented in Figure 2, and patient characteristics for the allocated patients are presented in Table I. The included component brands with the differences in follow-up are presented in Table II. Uncemented wedged collarless designs, which had the longest median follow-up, were mostly used in younger and healthier patients, and to a lesser extent in elderly patients with hip fractures (Tables I and II). Acute hip fractures were most often treated with cemented components, and PTS designs were more frequently employed than composite beam designs.

Femoral component design, fixation method, and risk of reoperation for periprosthetic femoral fracture. The risk of reoperation for PPFF for the five component and fixation method groups is presented in Table III, and the groups are illustrated in Figure 3.

The cemented composite beam femoral components had a very low risk of reoperation for PPFF. All other designs and methods of fixation had significantly higher risk of reoperation for PPFF compared to the cemented composite beam components. Compared to Lubinus SP II (Waldemar Link, Germany), the risk of reoperation for PPFF was higher for all other femoral component brands.

Table IV presents the risk of reoperation for PPFF with the five design groups, with the respective groups as reference, convenient for direct comparisons between the groups. Cemented triple-tapered components (aHRR 1.0 (95% CI 0.8 to 1.3)) had a similar risk of reoperation for PPFF to cemented double-tapered designs. Uncemented wedged collarless components (aHRR 7.3 (95% CI 5.6 to 9.5)) had the highest risk of reoperation for PPFF, compared to cemented composite beam designs. Uncemented wedged collarless components had twice the risk of reoperation for PPFF (aHRR 2.1 (95% CI 1.8 to 2.5)) of uncemented wedged collared designs.

Compared to cemented composite beam components, for all the other four designs and fixation methods, the increased risk of PPFF was sustained throughout the life of the femoral component/patient (Table V and Figure 4).

Separate analyses were performed for the indication of acute hip fracture, with similar results for cemented double- and

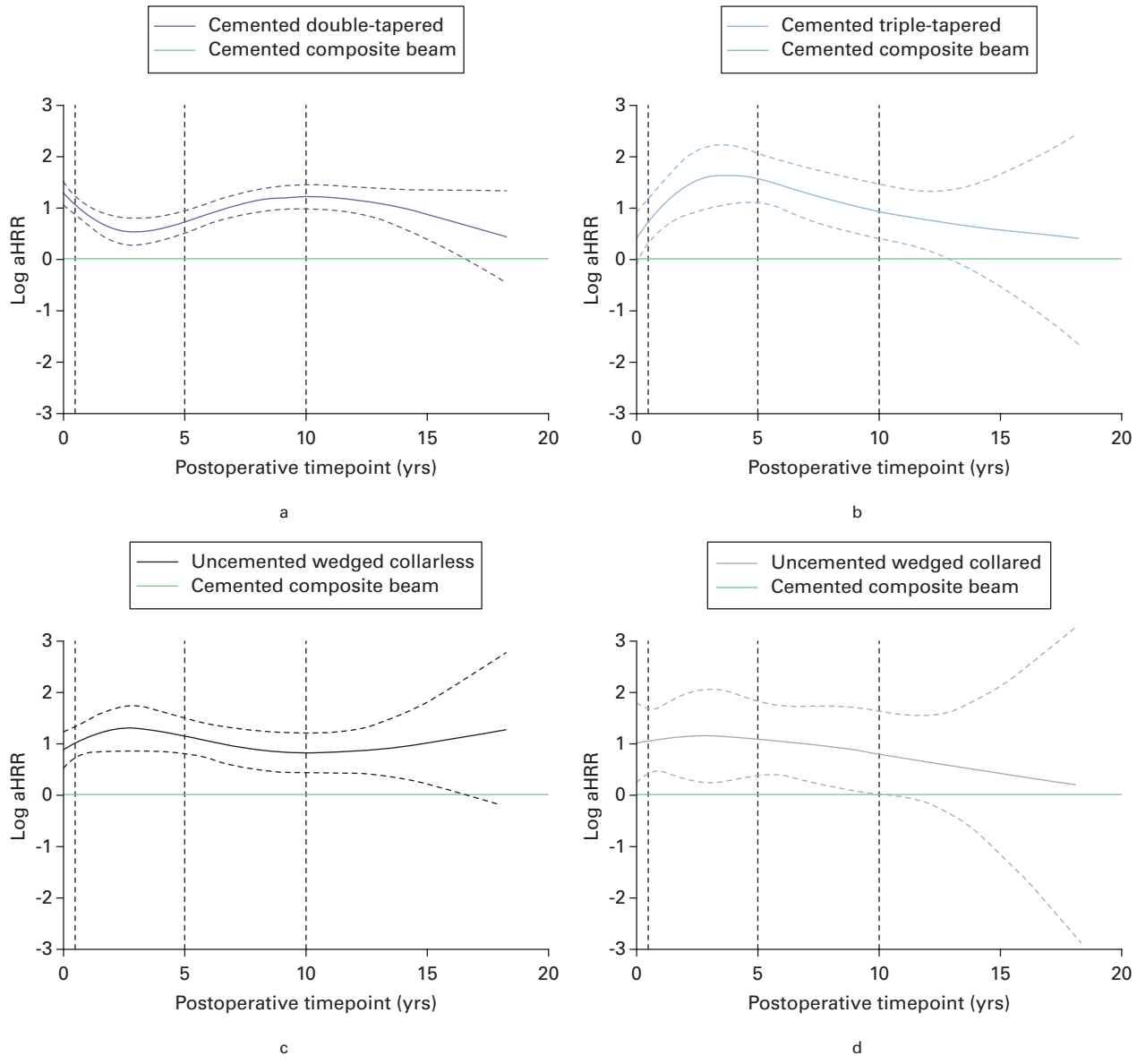

Fig. 4

Relationship between time after primary arthroplasty and the risk (Log adjusted hazard rate ratio (aHRR)) of reoperation for periprosthetic femoral fracture in the design and fixation method groups, with 95% CIs. The horizontal green line shows the reference risk (aHRR = 1) of cases with cemented composite beam components. The vertical lines indicate six months and five and ten years postoperatively, in which separate risk estimates have been assessed. We adjusted for sex, age, American Society of Anesthesiologists grade, indication for primary arthroplasty, and year of primary surgery in the analyses.

triple-tapered components, but worse results for the uncemented femoral components (Supplementary Table i). In addition, similar results were found in separate analyses for the period 2016 to 2023, when all reoperations (including osteosyntheses) were to be reported (Supplementary Table i).

Component design, fixation method, and risk of femoral component revision. All components included had less than 5% ten-year revision rate, confirming that all femoral components were performing well (Table VI). Compared to cemented composite beam designs, cemented double-tapered (aHRR 1.1 (95% CI 1.0 to 1.3)) and triple-tapered (aHRR 1.4 (95% CI 1.2 to 1.8)) components as well as uncemented wedged collarless designs (aHRR 1.4 (95% CI 1.2 to 1.6)) had higher risk of femoral component revision for any cause (Table VI). Uncemented wedged collared components (aHRR 1.0 (95% CI 0.9 to 1.2)) had similar risk of femoral revision for any cause, compared to cemented composite beam designs, but twice the risk (aHRR 1.9 (95% CI 1.5 to 2.3)) when excluding the composite beam Spectron EF (Smith & Nephew, UK) design, which is associated with osteolysis due to acetabular component design problems.[19] When fitting a competing risk model (Fine & Gray), with reoperation for any other reason than PPFF or death as

Table VI. Risk of femoral component revision for any cause, in the design and fixation method groups. Risk estimates for femoral revision and ten-year revision rates are adjusted for sex, age, American Society of Anesthesiologists grade, indication for primary arthroplasty, and year of primary surgery. Individual brands and component design and fixation method groups are presented.

Femoral component design and fixation method	Femoral component brands included	Stems, n	Femoral component revisions for any cause (%)	aHRR (95% CI)	Adj. ten-year femoral revision rate for any cause (%)*	Femoral revisions for any cause (%)	aHRR (95% CI)
Cemented composite beam	Lubinus SPII	23,845	109 (0.5)	1	1.1 (0.8 to 1.3)	316 (1.0)	1
	Spectron EF	6,570	207 (3.2)	3.8 (3.0 to 4.8)	3.7 (3.0 to 4.4)		
Cemented double-tapered	Exeter	50,676	571 (1.1)	2.1 (1.7 to 2.5)	1.8 (1.6 to 2.0)	620 (1.2)	1.1 (1.0 to 1.3)
	CPT	2,579	49 (1.9)	4.8 (3.4 to 6.7)	2.6 (1.7 to 3.4)		
Cemented triple-tapered	C-Stem	8,510	83 (1.0)	3.1 (2.3 to 4.1)	2.6 (0.7 to 4.6)	124 (0.9)	1.4 (1.2 to 1.8)
	MS-30	5,384	41 (0.8)	2.0 (1.4 to 2.9)	2.1 (0.9 to 3.3)		
Uncemented wedged collarless	Corail collarless	38,289	811 (2.1)	2.8 (2.3 to 3.5)	2.5 (2.3 to 2.7)	957 (2.0)	1.4 (1.2 to 1.6)
	Filler	5,270	66 (1.3)	1.6 (1.2 to 2.2)	1.4 (1.0 to 1.8)		
	POLARSTEM	2,847	35 (1.2)	2.7 (1.8 to 4.0)	2.2 (1.2 to 3.1)		
	Accolade 2	2,753	45 (1.6)	3.2 (2.3 to 4.6)	1.8 (1.2 to 2.3)		
Uncemented wedged collared	Corail collared	40,853	379 (0.9)	1.9 (1.5 to 2.3)	1.5 (1.3 to 1.7)	379 (0.9)	1.0 (0.9 to 1.2)
Total		187,576	2.396			2.396 (1.3)	

*An underestimate since not all cases have complete ten-year follow-up.
aHRR, adjusted hazard rate ratio.

Table VII. Risk of reoperation for periprosthetic femoral fracture (PPFF), in the design and fixation method groups, controlled for the competing risks, reoperation for other causes than PPFF (including cup reoperations), and death. Adjusted competing risk estimates by Fine & Gray regression (aSHR), with Cox regression for comparison. The risks are adjusted for sex, age, American Society for Anesthesiologists grade, indication for primary arthroplasty, and year of primary surgery.

Design and fixation method	Total, n (%)				Risk of reoperation for PPFF (95% CI)	
	Stems	Reoperation for PPFF	Other reoperations	Deaths	aSHR*	aHRR†
Cemented composite beam	30,415	63 (0.2)	1,499 (4.9)	12,500 (41)	1	1
Cemented double-tapered	53,255	440 (0.8)	2,342 (4.4)	24,070 (45)	4.0 (3.0 to 5.2)	4.0 (3.1 to 5.2)
Cemented triple-tapered	13,894	90 (0.6)	400 (2.9)	3,789 (27)	4.5 (3.2 to 6.2)	4.0 (2.9 to 5.6)
Uncemented wedged collarless	49,159	616 (1.3)	2,321 (4.7)	11,463 (23)	6.9 (5.3 to 9.0)	7.3 (5.6 to 9.5)
Uncemented wedged collared	40,853	189 (0.5)	1,256 (3.1)	6,550 (16)	3.2 (2.4 to 4.3)	3.5 (2.6 to 4.6)
Total	187,576	1,398 (0.7)	7,818 (4.2)	58,372 (31)		

*Fine & Gray regression analysis.
†Cox regression analysis.
aHRR, adjusted hazard rate ratio; aSHR, adjusted subdistribution hazard ratio.

competing risks, the results were similar to the Cox-estimated risks, indicating that the results were model robust (Table VII).

The risk of any femoral revision was higher for all component brands, compared to Lubinus SP II (Waldemar Link, Germany) (Table VI).

Trends in choice of femoral component design and fixation method. The time trends of femoral component choice are presented in Figure 5. During the latter part of the study period, there was an increased use of both cemented triple-tapered and cemented composite beam prostheses, especially in hip fracture patients. In addition, the use of uncemented wedged collared designs increased. The use of cemented double-tapered and uncemented wedged collarless designs decreased.

Discussion

The main finding of this register-based, observational study on well-documented femoral component designs was that cemented composite beam components should be the preferred choice in primary hip arthroplasty to protect against PPFF. These designs are associated both with reduced risk of reoperation for PPFF as well as reduced risk of femoral component revision for any cause. If cementing is not an option, uncemented wedged collared designs are the best alternative. Uncemented wedged collarless designs had the highest risk of reoperation for PPFF. Opting for cemented triple-tapered designs did not improve outcomes compared to double-tapered components. The risk of reoperation for PPFF remained higher for all the other four femoral component designs and fixation methods throughout the 19 years of follow-up, compared to cemented composite beam components.

Femoral component design and fixation method was highly associated with reoperation for PPFF in the present study. Since PPFF, together with infection, are the most common causes of reoperation when well-documented femoral components are used, and since the risk is lifelong, the risk of PPFF should, in our opinion, be a major factor when considering what design and fixation method to opt for in primary arthroplasty.[1,2]

For cemented femoral components there are two fundamentally different principles of fixation – composite beam and PTS – which differ both in design configuration and surface finish.[7] The risk of reoperation for PPFF was low for cemented composite beam components compared to all other designs

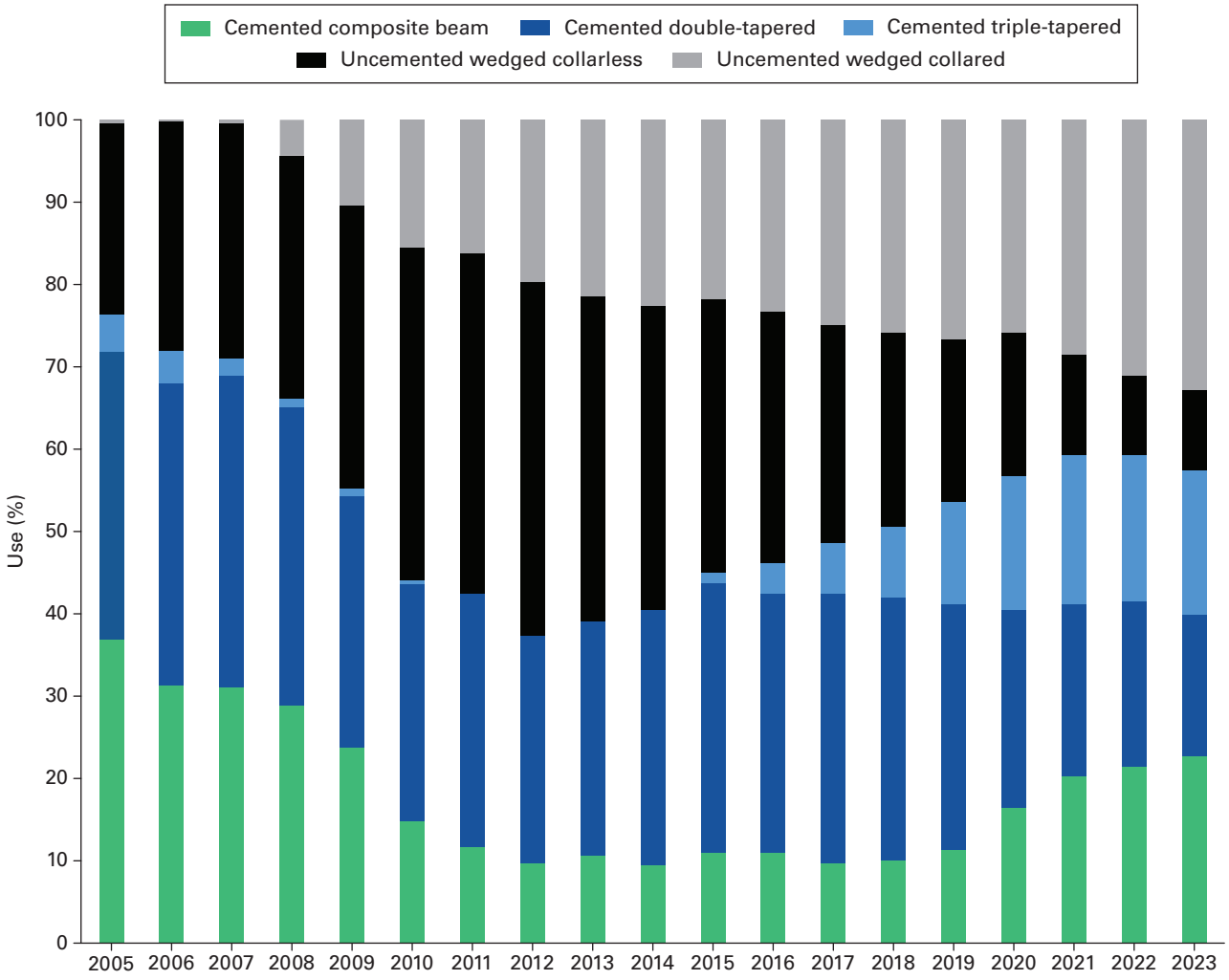

Fig. 5

Trends in use of design and fixation method of the included femoral components between 2005 and 2023.

and modes of fixation in the present study. There are several reports of composite beam designs having a lower risk of PPFF than cemented PTS designs.[7,20] Despite this, PTS femoral components remain the dominant design in cemented hip arthroplasty, and there are several countries where cemented composite beam designs are hardly used.[1,5,21] In addition, there are differences between cemented composite beam designs, and when excluding the Spectron EF (Smith & Nephew, UK) design, known for a high rate of osteolysis associated with the Reflection (Smith & Nephew) conventional all-poly acetabular component, the Lubinus SP II (Waldemar Link) alone had better results in the present study, as found by other researchers: Kristensen et al[20] have also reported superior results in several other composite beam designs with regard to PPFF in hip fracture patients.

Cemented double- and triple-tapered designs similarly had a four-times higher risk of reoperation for PPFF than cemented composite beam components. There were some variations in results within the design and fixation method groups. For example, Exeter (Stryker, USA) had lower risk of femoral component revision for any cause and reoperation for PPFF, compared to CPT (Zimmer Biomet, USA). However, the risk of reoperation for PPFF for each individual design was similar to the corresponding combined design and fixation method group they were categorized in.

The wedge design of cemented double- and triple-tapered (force-closed principle) PTS components may be less resistant to axial and torque forces than cemented composite beam designs, resulting in so-called ‘axe splitter fractures’ cleaving the ‘force-closed’ cement and bone envelope.[20,22]

Summarizing the results for cemented femoral components in this study, the Lubinus SPII had the lowest risk for PPFF and lowest risk of any cause femoral revision, illustrating that composite beam designs reduce the risk of reoperation for PPFF, without affecting the risk of “any cause” femoral component revision.

There is some debate about the sex and age groups for whom uncemented femoral components should be preferred over

cemented designs.[23] An uncemented component may appear to be preferable in active patients with good bone stock and long life expectancy. However, according to the present study, uncemented designs are associated with a lifelong, increased risk of PPFF compared to well-documented cemented designs. If choosing an uncemented femoral component, a collar has been shown to be protective against PPFF, possibly due to reduced torque force.[13,14,24] We found that the risk of reoperation for PPFF was doubled for collarless compared to collared uncemented femoral components. Even so, in uncemented arthroplasty, most femoral component designs are collarless.[21] In addition, for the collar to have a protective effect against PPFF in uncemented arthroplasty, Lamb et al[25] have shown that the femoral component needs to be implanted with the collar no more than 1 mm from the level of the femoral neck osteotomy.

As reoperations are relatively rare for well-documented femoral component designs, specific causes of reoperation, such as PPFF, may only be possible to study with some degree of granularity using large databases, such as national registers. We included a large number of cases with common, contemporary, and well-documented femoral component designs and detailed information on causes of reoperation and exact survival times. The effect sizes in the present study were increased several times, and therefore less susceptible to unknown confounding. This indicates that the findings are robust. Since the results were based on data from a nationwide primary HA and THA population, our findings should also have good external validity. The cemented composite beam designs have been widely used in Norway over many years, but to a lesser extent in other countries in later years. Changing to a new femoral component design and fixation method may have some degree of a learning curve. However, it is our opinion that if one design and method of fixation shows superior results for reducing the risk of PPFF or any cause femoral revision in certain patient groups, transient learning curve effects should not be a reason for not using a particular femoral component design or method of fixation.

Risk of PPFF increases with age, and cemented components were used in a high proportion in hip fracture patients. Cemented PTS designs were used more frequently in hip fracture patients, compared to cemented composite beam designs and uncemented components were only used in 10% to 15% of hip fracture patients. Even if we adjusted for these differences, there may be some residual confounding.[22]

The data for revision or reoperation for PPFF is, however, yet to be fully validated. There may be under-reporting of reoperations not involving revision of the femoral prosthesis.[2] This effect will be accentuated since reoperations such as osteosyntheses were not obliged to be reported to the NAR until 2015, in contrast to the NHBR.[5] This limitation may introduce bias, since femoral component design and mode of fixation may be associated with type of treatment of the PPFF. However, we have controlled for this by performing sub-analyses for the period 2016 to 2023 only. The results were similar, indicating minor influence of this potential bias. The uncemented wedged collared group consisted of the collared Corail design only. This may reduce the external validity of the results for this group. A study from the UK has found similar results also for other collared uncemented components.[24] We found an incidence of reoperation for PPFF of 0.7%. Others have found the 'true' incidence to be 0.8% to 1.2%.[2,26] This suggests that under-reporting in our data was not significant.

Selection bias and unknown confounding may therefore, to some degree, have influenced our results.[27] Patients who received uncemented femoral components, especially in the NAR, were in general younger and healthier than those who received cemented femoral prostheses. The use of cemented femoral components increased during the study period, both PTS and composite beam, due to advice from the NAR/NHFR.[28] In recent years, there has been a trend from PTS to composite beam designs. These changes during the study period, even when adjusting for year of primary surgery, may lead to some residual confounding.

Each femoral component design and method of fixation have a specific profile of causes for reoperation, are used in different patients and indications, and are combined with different acetabular components and articulations. Therefore, we performed competing risk analyses, in addition to adjusted Cox regression analyses, showing similar results. Hence, we consider that our findings were statistically robust.

Considering the number of cases (exposures and outcomes), size of the effect estimates, universal national coverage of hospitals, quality and completeness of the data, strict inclusion criteria, and the fact that we adjusted for several clinically important risk factors in the analyses, we expect the selection bias and unknown confounding to be minor, and the study to be without major systematic errors.

Cemented composite beam femoral components have the lowest risk of PPFF. If cementing the femoral component is not an option, then uncemented wedged collared components are the best uncemented alternative. Opting for cemented triple-tapered prostheses does not improve outcomes compared to double-tapered components. The increased risk of PPFF was sustained throughout the lifespan of the femoral component/patient for all designs compared to the cemented composite beam components. Surgeons should consider the risk of PPFF, not only at the time of surgery but also the sustained increased risk for the rest of the patient's life. There is a need for further research on whether to have a 'one for all' approach to the choice of femoral component in hip arthroplasty, or if specific designs and fixation methods should be chosen according to sex, age, and comorbidity.

Take home message

- Cemented composite beam femoral components have the lowest risk of periprosthetic femoral fracture (PPFF).
- If cementing the femoral component is not an option, then uncemented collared femoral components are the best uncemented alternative.
- Cemented triple-tapered femoral components do not have a lower risk of reoperation for PPFF than cemented double-tapered.

Supplementary material

Risk of reoperation for periprosthetic fracture for the indication of acute hip fracture; individual brands and femoral component design and fixation method groups are presented.

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