Unblinded Title Page

The Risk of Postoperative Periprosthetic Femoral Fracture After Total Hip Arthroplasty Depends More on Stem Design Than Cement Use: An Analysis of National Health Data from England

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Word count
2809

ABSTRACT

Background: In this study, we estimated the risk of surgically treated postoperative periprosthetic femoral fractures (POPFFs) associated with femoral implants frequently used for total hip arthroplasty (THA).

Methods: In this cohort study of patients who underwent primary THA in England between January 1, 2004, and December 31, 2020, POPFFs were identified from prospectively collected revision records and national hospital records. POPFF incidence rates, adjusting for potential confounders, were estimated for common stems. Subgroup analyses were performed for patients >70 years of age, with non-osteoarthritic indications, and with femoral neck fracture.

Results: POPFFs occurred in 0.6% (5,100) of 809,832 cases during a median follow-up of 6.5 years (interquartile range [IQR], 3.9 to 9.6 years). After cemented stem implantation, the majority of POPFFs were treated with fixation. Adjusted prosthesis time incidence rates (PTIRs) for POPFFs varied by stem design, regardless of cement fixation. Cemented composite beam (CB) stems demonstrated the lowest risk of POPFF. Collared cementless stems had an equivalent or lower rate of POPFF compared with the current gold standard of a polished taper slip cemented stem.

Conclusions: Cemented CB stems were associated with the lowest POPFF risk, and some cementless stem designs outperformed modern cemented stem designs. Stem design was strongly associated with POPFF risk, regardless of the presence of cement. Surgeons, policymakers, and patients should consider these findings when considering femoral implants in those most at risk for POPFF.

Level of evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Level of evidence: III (Retrospective cohort study)

INTRODUCTION

Post-operative periprosthetic femoral fracture (POPFF) after total hip arthroplasty (THA) requires complex surgery, which causes significant morbidity and mortality(1-3). The incidence of POPFF is increasing(4), and is projected to rise (5). POPFF is the leading cause of readmission following THA in the USA(6). Prevention of POPFF is a useful means of harm reduction.

POPFF can treated with either fixation and/or with revision surgery. Previous large registry studies have been limited to only revisions and do not include reoperation including fixation (7). Where outcome has included all reoperations (8), follow up has been insufficient to capture POPFF in cemented stems that typically occur three to six years after primary THA(9, 10). In addition, current evidence has lacked comparison of stem types and consistent reporting of all POPFFs irrespective of treatment method.

Stem choice at primary surgery is often determined by patient characteristics such as age and bone quality, and presents an opportunity to affect the patients' POPFF risk. Risk of early POPFF revision is greater after cementless stem implantation in comparison to cemented stems(11) and this has been supported by registry studies(7, 12). In addition, registry studies have suggested strong association between lower revision rates for POPFF and stem design features such as cemented composite beam stem (CB) design(13, 14) and cementless stem designs including calcar collar(12, 15), grit-blasted finish and double taper shape(15). Despite their statistical power, revision-based registry estimates underestimate the risk of POPFF associated with stem design when POPFF are treated with open reduction and internal fixation (ORIF). Recent clinical evidence has suggested that the risk of POPFF with modern cemented stems may be higher than with a collared cementless stem when both revision and fixation are recorded(16). These results need corroboration with larger data to ensure generalisability.

The aim of this study was to identify POPFF that undergo either internal fixation or revision by combining a large national arthroplasty registry with national hospital data to estimate the risk of POPFF associate with femoral implants used in THA.

Materials and Methods

Study design

This study was an observational cohort study using prospectively collected data from England. This study identified POPFF treated with revision and ORIF. Reporting is in accordance with STROBE(17) guidelines. This study did not receive funding from any source.

Data sources

The **National Joint Registry of England, Wales, and the Isle of Man (NJR)** records patient and surgical data for all THAs performed at hospitals in England, Wales Northern Ireland and the Isle of Man since 2003(18) with overall missing data estimated at 5.8%(19). The UK National Health Service (NHS) collects hospital episode statistics from care undertaken within the NHS. We included events recorded in either of these datasets to perform this analysis. Data was collected on every episode of patient care for all patients, including classification of disease, interventions, and procedures. Additional data on deprivation(20) and mortality were added by the relevant government departments. Patients within the NJR dataset were matched to all available subsequent hospital admissions by a unique national identifier by NHS digital. Implant variables were added using manufacturer data and linked to the dataset using implant catalogue codes.

Participants

Patients were eligible for the study if they had undergone a primary THA recorded in the **NJR** and had a matching hospital record in an English NHS hospital. To prevent miss-classification of POPFF which occurred as a result of intraoperative POPFF rather than a new injury,

revisions or fixation for POPFF which occurred within three months of any reported intraoperative fracture were excluded as per previous methodology(15). Formal reporting of intraoperative fractures was introduced on 01/04/2004 and therefore THAs performed prior to this date were excluded. This study used all primary THAs in the NJR implanted in England between 01/01/2004 to 31/12/2020.

Variables

Outcome

The primary outcome of this study was POPFF treated by either revision surgery or ORIF. Stem associated POPFF were only considered for stems where over 1000 implantations were recorded in the dataset. POPFF rates were reported as absolute values of incidence per 1000 prosthesis-years of observation (PTIR), an adjusted PTIR and as a relative risk (Hazard ratio [HR]). POPFF events were identified as operations or procedures following the primary THA comprising of a procedure code matching that for a THA revision operation(21) or ORIF, with a laterality code (OPCS) matching that of the primary THA, and an accompanying diagnosis code for femoral fracture recorded in the same episode of care (Appendix 1).

Patient and surgical variables

Patient and surgical variables were patient age (years), year of surgery, gender, American Society of Anaesthesiologists group, indication for surgery, surgical approach, computer guided surgery, minimally invasive surgery, surgeon grade (consultant versus non-consultant), operation funding, intraoperative fracture, hip order (unilateral, first of staged bilateral, second of staged bilateral of simultaneous bilateral), lead surgeon unique identifier, lead surgeon yearly volume, lead surgeon order (1 = first surgery performed by the surgeon.. .n = n^{th} surgery performed by surgeon), hospital unique identifier, hospital yearly volume.

Implant variables

Highly cross-linked polyethylene was defined as polyethylene which had been irradiated above 50 kGy(22). Variables included overall fixation design (PTS [polished taper slip stem], CB [composite beam] or cementless [CL]), construct fixation (cementless, cemented, hybrid, reverse hybrid), cup fixation, head size and bearing combination (metal on polyethylene [MoP], metal on highly cross-linked polyethylene [MoXLP], ceramic on polyethylene [CoP], ceramic on highly cross-linked polyethylene [CoXLP] or ceramic on ceramic [CoC]) and cement viscosity (high, medium, low, unknown and no cement). Where multiple designs existed under the same stem brand, stem brands were divided into unique design categories.

Statistical analysis

Normally distributed continuous variables were described using means with standard deviations (SD) and non-normally distributed continuous variables were expressed as median values with interquartile range (IQR). Comparisons of continuous variables were performed with Welch's t-tests, and categorical variables were compared with chi-square tests.

To adjust for selection bias during implant selection, PTIR for each stem design were adjusted for relevant confounding factors using a Cox survival model. Variable selection in the model used stepwise 10-fold cross-validation on random selection of 90% of all available data, using AIC as the discriminator between models. Final model performance was assessed using the C statistic (analogous to the area under the curve) on the remaining 10% of the dataset. Estimates of fixed effects in the final model were obtained by fitting the final model to all data. Model assumptions were assessed visually and maintained with stratification of variables and variable exclusion where necessary. Adjusted PTIR was estimated using prediction of expected events in a representative random sample of 10% of the whole dataset, where each patient was modelled to have a THA with a single stem. Hazard ratios for each femoral stem were estimated using the final model versus the gold standard stem (Exeter, Stryker, Kalamazoo, MI, USA) with 95% confidence intervals. To better understand the effect of stem selection choices in older patients, patients without hip osteoarthritis and in particular neck of femur fracture, subgroup analysis was performed. The analysis was repeated in entirety for three subgroups of patients aged over 70 years, non-osteoarthritis indication for THA, and THA for neck of femur fracture. All analyses were performed using R (v 4.20, R, Vienna, Austria).

RESULTS

Key outcomes

864,793 of 1,128,684 (70.3%) patients with primary THA performed between 01/01/2004 and 31/12/2020, were successfully matched. 809,832 were included in the primary analysis group after 54,961 exclusions (figure 1). Median follow up for non-revised cases (IQR) was 6.5 (3.9 to 9.6) years. The final cohort in the analysis did not differ significantly from all available patients in the NJR (SMD < 10%). Median age (IQR) of the final cohort was 71 (63 to 77) years, 61.3% (496,576 of 809,832) patients were women, and 88% of THA were performed for hip osteoarthritis alone. Baseline demographics are outlined in table 1.

2.8% (22,647/809,832) of patients underwent surgery for revision for any reason or fixation for POPFF. At ten years 20,694 reoperations for revision or fixation occurred giving a cumulative incidence of 3.6 % (95% CI 3.6 to 3.7%). 0.6 % (5100/809,832) of patients underwent surgery for POPFF (figure 2). At ten years 4,513 POPFF occurred giving a cumulative incidence of 0.9% (95% CI 0.9% to 0.9%). 2831 operations were fixation surgery, and 2269 operations were revision surgery. Of all the observed POPFF, 3350 were new diagnoses of POPFF identified using matched hospital records, including 2830 POPFF treated with fixation and 520 treated with revision, but occurring prior to the known outcome in the NJR dataset. Treatment with fixation was more commonly observed in patients with a cemented stem than patients with a cementless stem. POPFF occurred more frequently within the first few years of primary THA, with a greater number of POPFF events within the first year with a CL stem relative to those with a CB or PTS stem (figure 3).

POPFF estimates

51 unique stem brands were implanted 1000 times or more in 789,411 patients. The final Cox survival model was used to generate adjusted PTIR and HR values outlined in table 2. The

lowest adjusted PTIR for POPFF was observed following THA with CB stems and adjusted incidence of POPFF was similar between PTS and CL stems (Figure 4).

For patients over the age of 70 who underwent THR, the overall PTIR for any revision or POPFF fixation was 4.09 per 1000 prosthesis-years and the PTIR for POPFF was 1.31 per 1000 prosthesis-years. 32 stem brands were implanted more than 1000 times. Stem associated PTIR were estimated using a Cox model which included 381733 patients and 3166 events (Table 3). The lowest adjusted PTIR for POPFF was observed following THA with CB stems and highest after THA with CL stems (Figure 5).

For patients who underwent THA for any reason other than osteoarthritis, overall PTIR for any revision or POPFF fixation was 6.34 per 1000 prosthesis-years and PTIR for POPFF was 1.39 per 1000 prosthesis-years. 13 stem brands were implanted more than 1000 times. Stem associated PTIR were estimated using a Cox model which included 77,741 patients and 659 events (Table 4). The lowest adjusted PTIR for POPFF was observed following THA with CB stems and highest after THA with CL stems (Figure 6).

For patients who underwent THA for neck of femur fracture, overall PTIR for any revision or POPFF fixation was 7.38 per 1000 prosthesis-years and PTIR for POPFF was 2.19 per 1000 prosthesis-years. Five stem brands were implanted more than 1000 times. Stem associated PTIR were estimated using a cox model which included 27,627 patients and 296 events (Table 5). The lowest adjusted PTIR for POPFF was observed following THA with CS stems and highest after THA with PTS stems (Figure 7).

DISCUSSION

The incidence of POPFF found in this study was approximately double previous estimates in a similar cohort(9, 15) making POPFF the most common indication for major reoperation following THA. This is similar to studies using the Swedish Hip Arthroplasty register, where estimates of POPFF outcomes more than doubled after inclusion of non-revision outcomes of POPFF(10). Another key finding of this study is that stem associated risk of POPFF varies according to implant design, with the lowest risk of fixation or revision for POPFF occurring after implantation with a composite beam cemented stem.

In this study, large numbers of patients with POPFF after PTS stem implantation underwent fixation surgery without revision, which is a widely adopted technique with good outcomes(23- 25). This analysis illustrates the relatively poorer performance of PTS versus other stems for the endpoint of POPFF including both fixation and revision. A majority of cementless stems in this study were associated with a POPFF rate that was no worse than the gold standard cemented stem. Collared cementless stems were associated with a lower absolute incidence of POPFF and after adjustment an equal risk of POPFF than the gold standard cemented implant.

Historically, cementless stem fixation has been associated with a higher risk of POPFF (7, 11, 26-28), but evidence has not been robust enough to allow good comparison of modern implants. Large registry studies which found lower risk of POPFF after cemented stem fixation in cohorts where PTS stems are more common, have been limited to revisions(7). Where outcome has included all reoperations(8), follow up has been insufficient to capture POPFF in cemented stems, which typically occur three to six years after primary THA(9, 10). This study is the first to include both large numbers of patients with both revision and fixation surgery outcomes and sufficient follow up. The stem design group associated the lowest risk of POPFF was CB stems. Similar findings have been noted in other studies using registry data with revision(13) and all reoperation(14) as an endpoint. This is also in agreement with a recent metanalysis of comparative clinic trials, which found that the risk of POPFF following THA with a PTS stem was three times more likely than after a CB stem(29). **CB stems are associated with a lower risk of periprosthetic fractures relative to PTS stems(30), because of a lower incidence of unified classification system type B fractures which occur around the stem(14). This may be because there is less relative movement between CB implants and the surrounding cement necessary to generate the cortical strain in the proximal femur required for fracture.**

Subgroup analysis demonstrated larger overall incidence of POPFF and similar trends in stem associated POPFF risk. Surprisingly, the risk of POPFF for patients undergoing THA for NOF was lowest around cementless femoral stems. This may be due to the absence of CB stems in this group, and **the relatively better performance of collared cementless stems in comparison to** PTS stems in this subgroup. **However, these results should be treated with caution due to low confidence in the estimates.** Recent Cochrane review highlighted an increased risk of periprosthetic fracture in patients undergoing THA for neck of femur fracture based on a single prospective RCT(31, 32). The RCT was stopped at 18 months because of early complications in the cementless group, which reduced the chances of investigators observing complications from POPFF in the cemented stem group which may have occurred later.

Within the cementless group stems with calcar collar performed better than the same stem without a collar, which is in agreement with similar registry findings(15) and corroborating biomechanical research(33). There is still large variation in performance within cementless stems, perhaps reflection the differences in design features in this group. Within the PTS group stems made from cobalt chrome performed less well than stainless steel stems, which echoes previous findings in large registry studies(9). The

mechanism for this is still unclear and may be related in part to surgeon factors and or interaction between the stem surface and surrounding cement.

This study shows that POPFF accounts for a quarter of all reoperations and that there is large variation in risk of POPFF according to femoral stem design irrespective of whether the stem is fixed with cement or not. This refutes the historical approach of grouping stems by whether they are fixed with cement. Researchers and policy makers should consider whether classifying stems simply by presence of cement offers the utility required by the surgeons and patients they affect.

This study has provided the most complete large-scale data analysis of periprosthetic fractures. Despite rigorous data searching and linkage, cases may be missed through coding error which may affect the accuracy of these observations. Further work is required to understand the effect of all POPFF on overall implant performance and surgeons should use the breadth of clinical knowledge to maximise the overall success of THA in the patient they are treating. The results represent associations and not causation regardless of the strength of the findings and surgeons should look at the breadth of research findings for a more complete understanding. Further prospective clinical trials are required to assess the utility of stem choice in the reduction of POPFF in patients with THA. This study focused on POPFF requiring surgery in hospital and did not capture POPFF events which did not undergo surgery, either because patients did not need it or because it was not offered for other reasons. Further study is required to understand the burden of POPFF not treated by surgery on patients and the health service in general.

CONCLUSION

The true incidence of POPFF is double previous estimates based on revision surgery alone and accounts for a quarter of all major reoperations following primary THA. The majority of previously unrecorded POPFF occur after THA with a cemented polished taper slip stem. Wide variation in POPFF risk occurs regardless of cemented fixation or not. This paper challenges the conventional cement-centric stem classification approach and calls for more nuanced categorization to better predict stem performance.

Acknowledgements

*****Blinded by JBJS*****

We thank the patients and staff of all the hospitals who have contributed data to the National Joint Registry. ***Blinded by JBJS***

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FIGURE LEGENDS

Figure 1. Flow chart depicting the data sources, exclusions, and final dataset. THA indicates total hip arthroplasty, MoP indicates metal on polyethylene, MoXLP indicates metal on highly cross-linked polyethylene, CoP indicates ceramic on polyethylene, CoXLP indicates ceramic on highly cross-linked polyethylene, and CoC indicates ceramic on ceramic.

Figure 2. Stacked bar chart demonstrating numbers of patients with POPFF after THA with a cementless stem, cemented polished taper slip stem and with a cemented composite beam stem.

Figure 3. Proportion of POPFF occurring in each stem design category over time from primary THA.

Figure 4. Boxplot comparing adjusted PTIR for stems grouped by overall design group.

Figure 5. Boxplot comparing adjusted PTIR for stems grouped by overall design group in patients over the age of 70 years.

Figure 6. Boxplot comparing adjusted PTIR for stems grouped by overall design group for patients with non-osteoarthritic hip disease.

Figure 7. Boxplot comparing adjusted PTIR for stems grouped by overall design group for patients with neck of femur fracture.

Fig 1

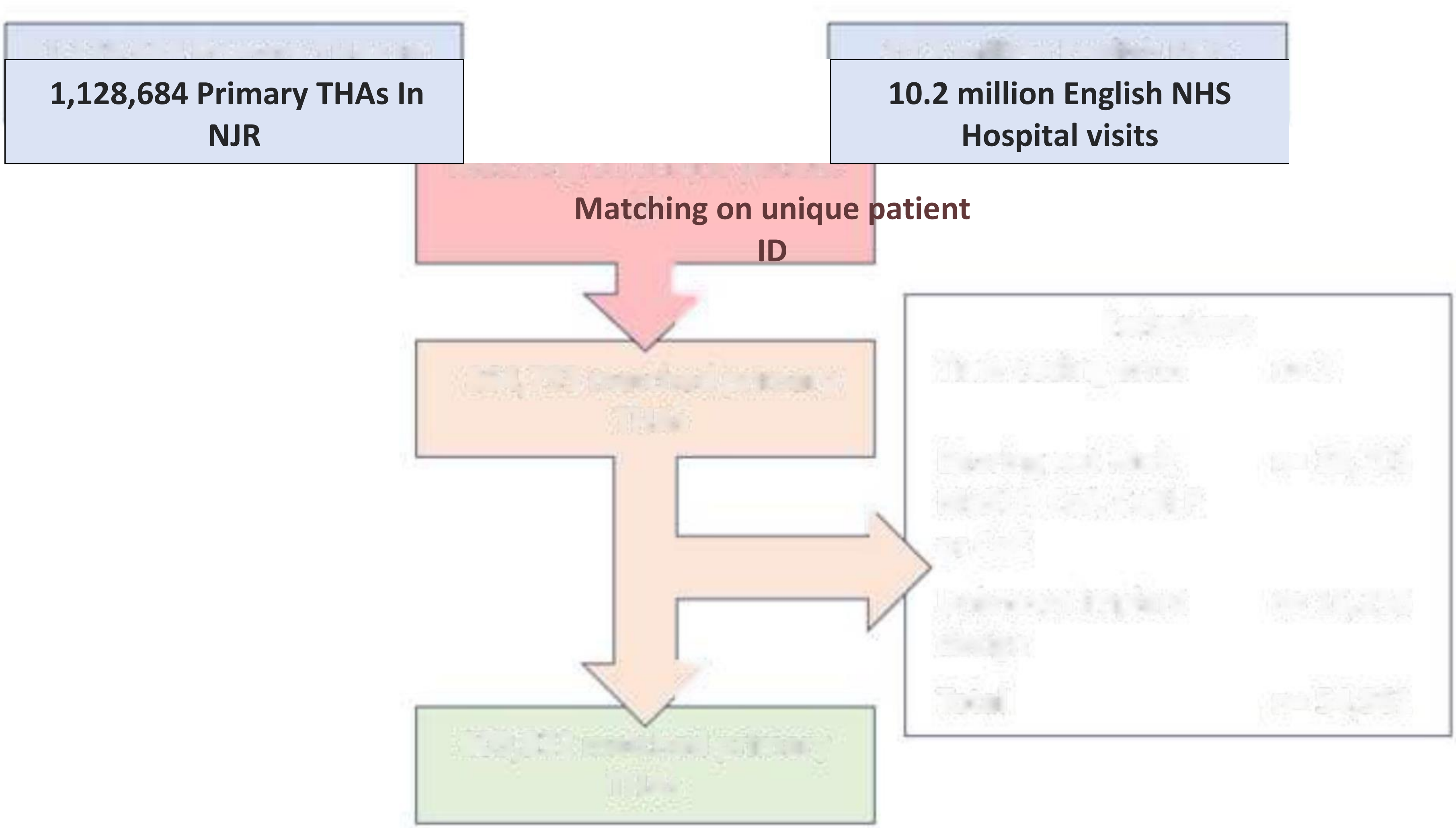
1,128,684 Primary THAs In NJR
10.2 million English NHS Hospital visits
Matching on unique patient ID

Fig 2

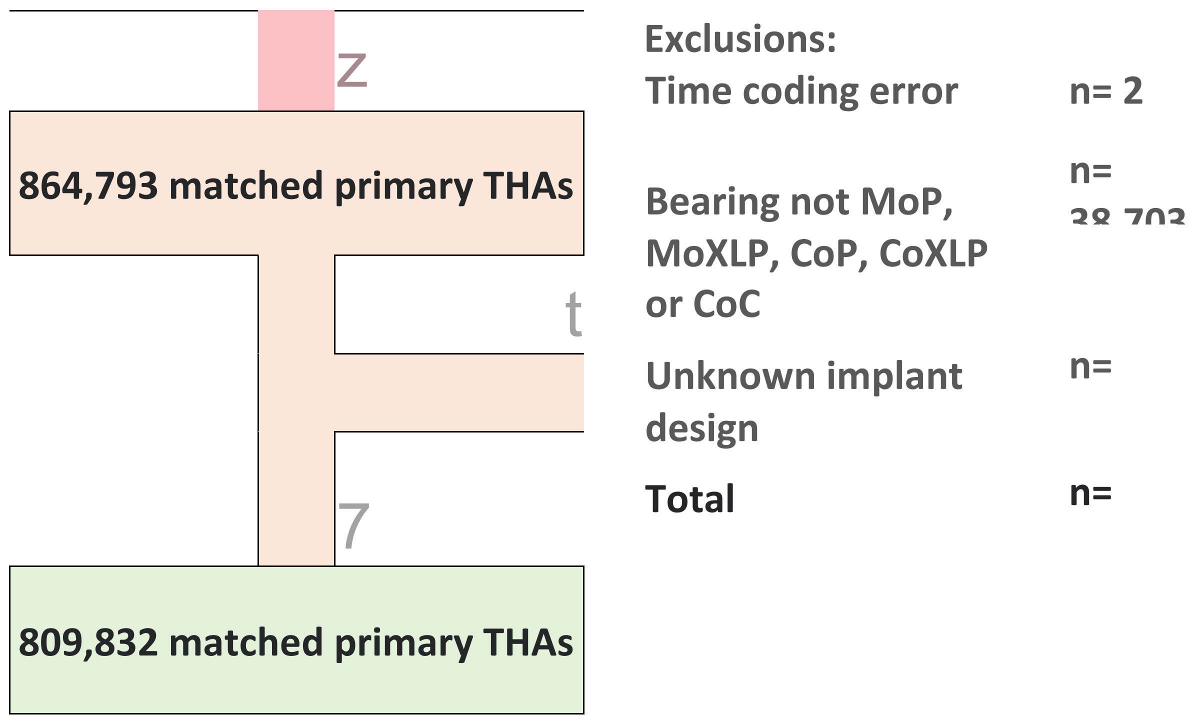
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Fig 2

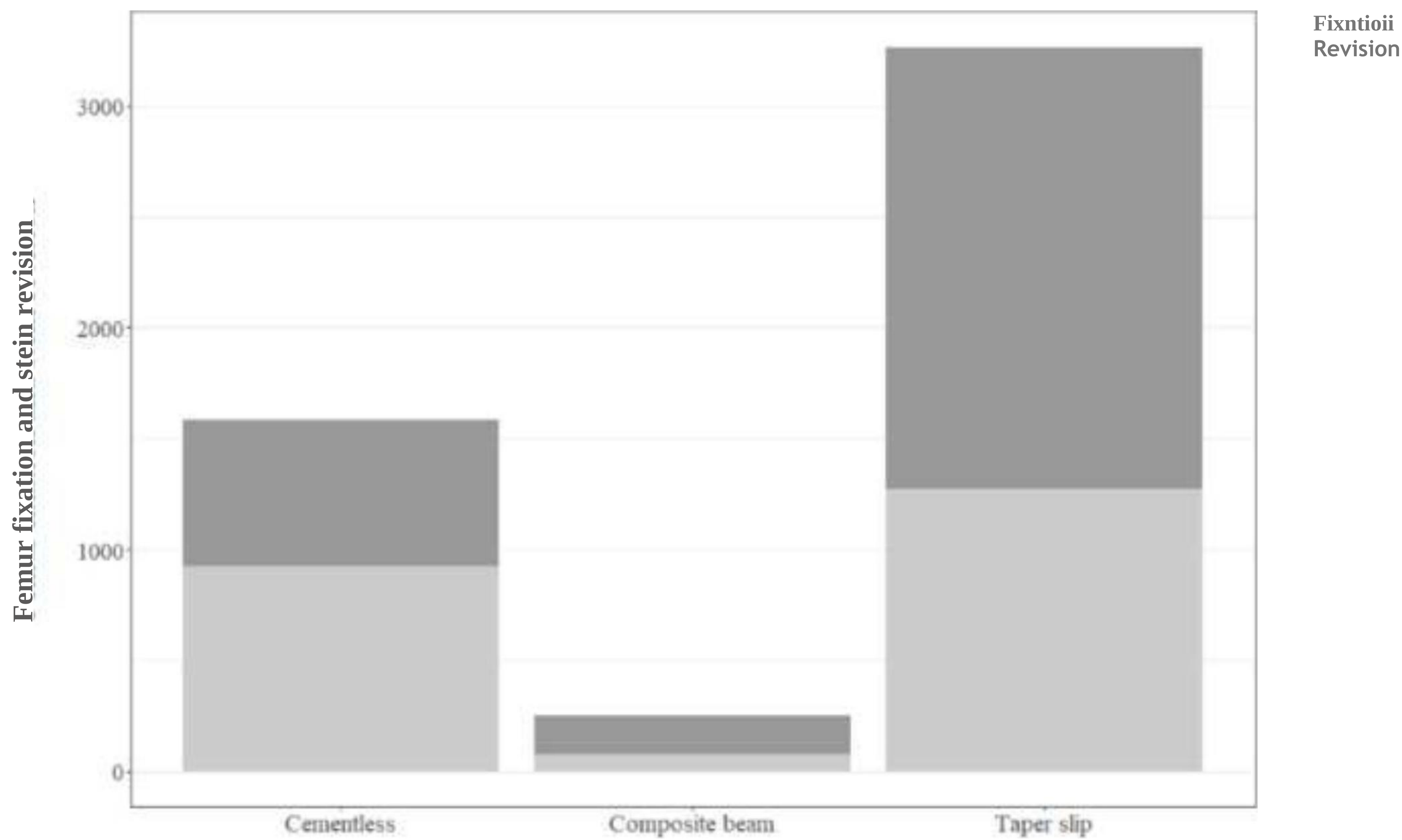
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Fig 3

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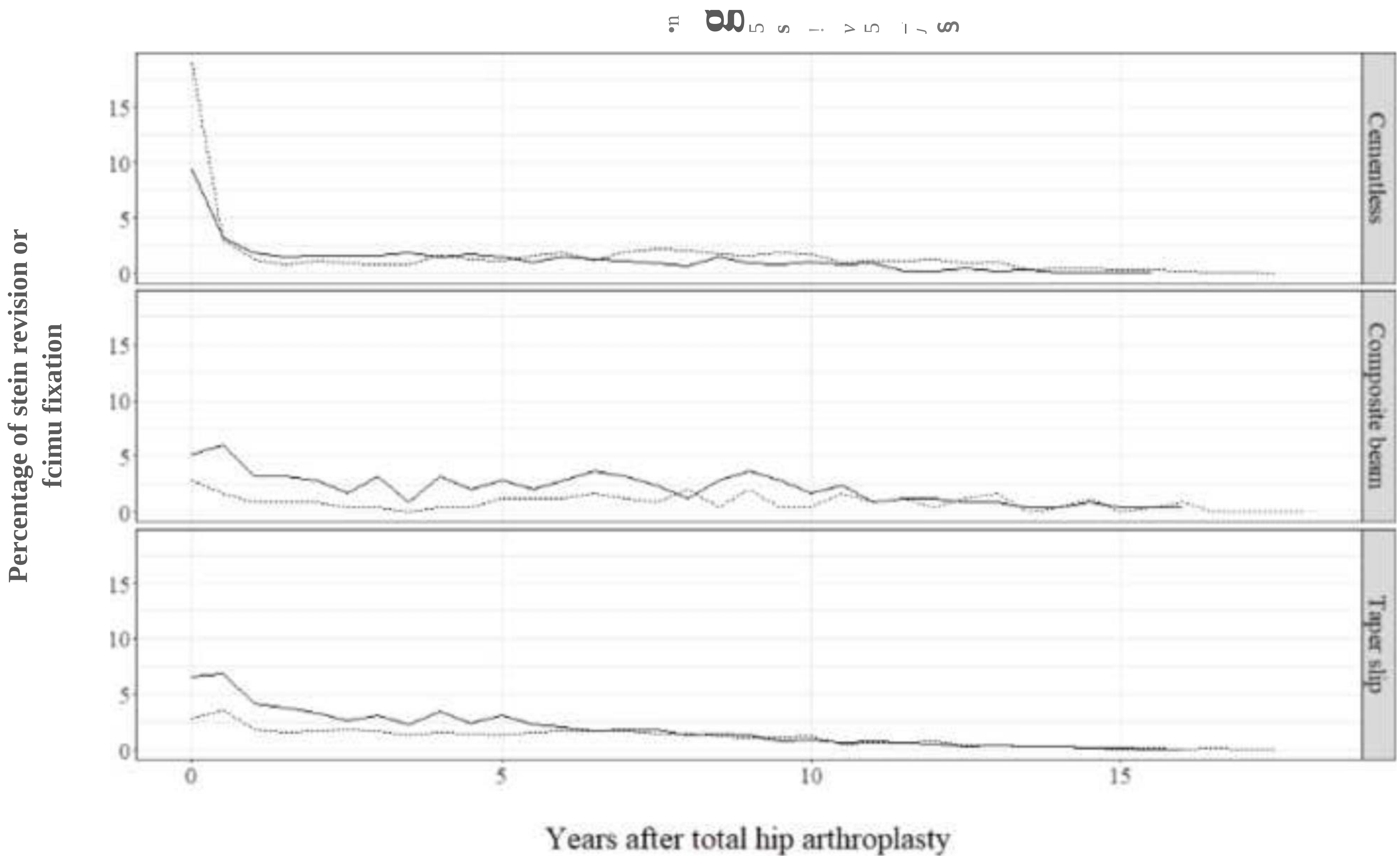
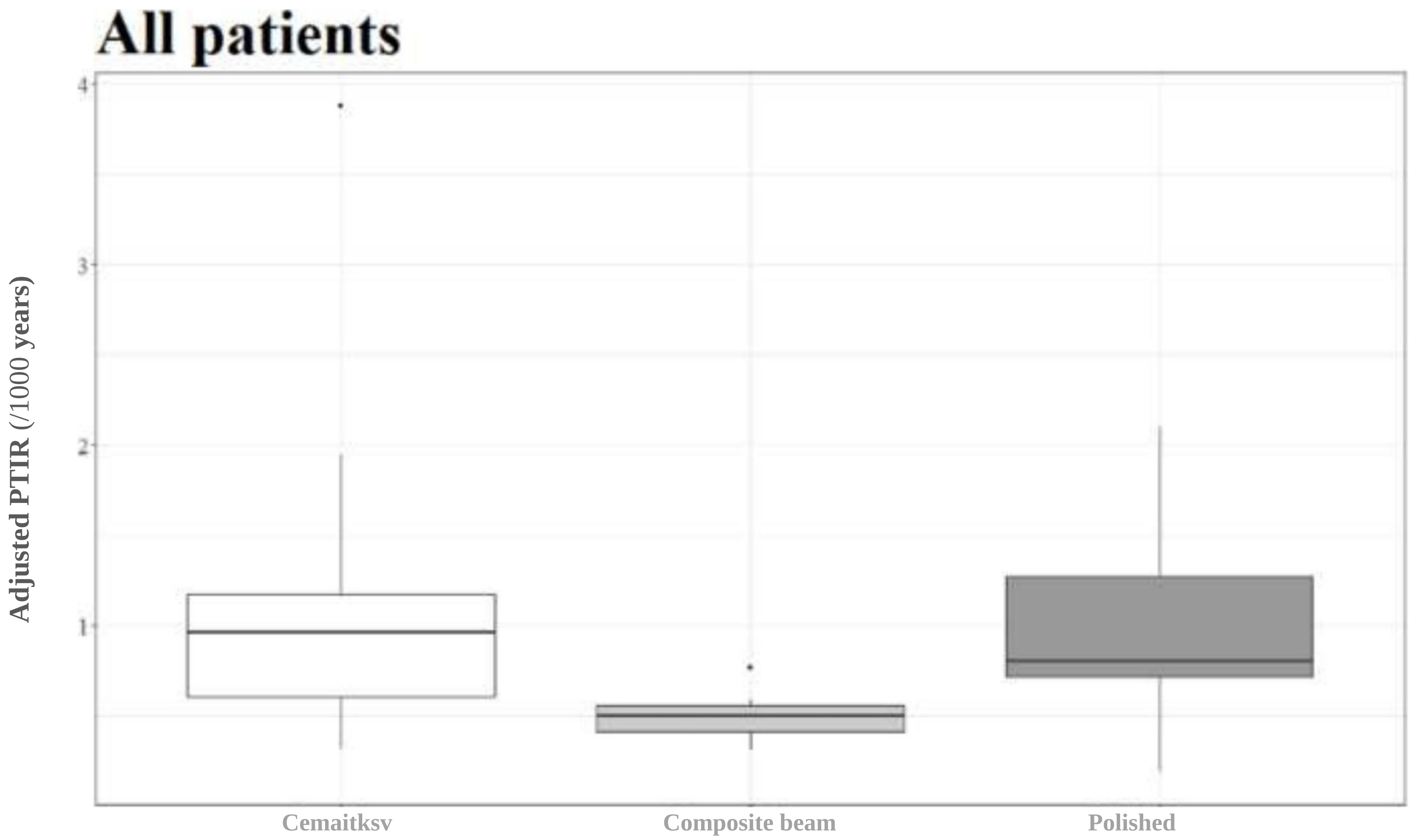


Fig 4


All patients
Adjusted PTIR (/1000 years)
4
3
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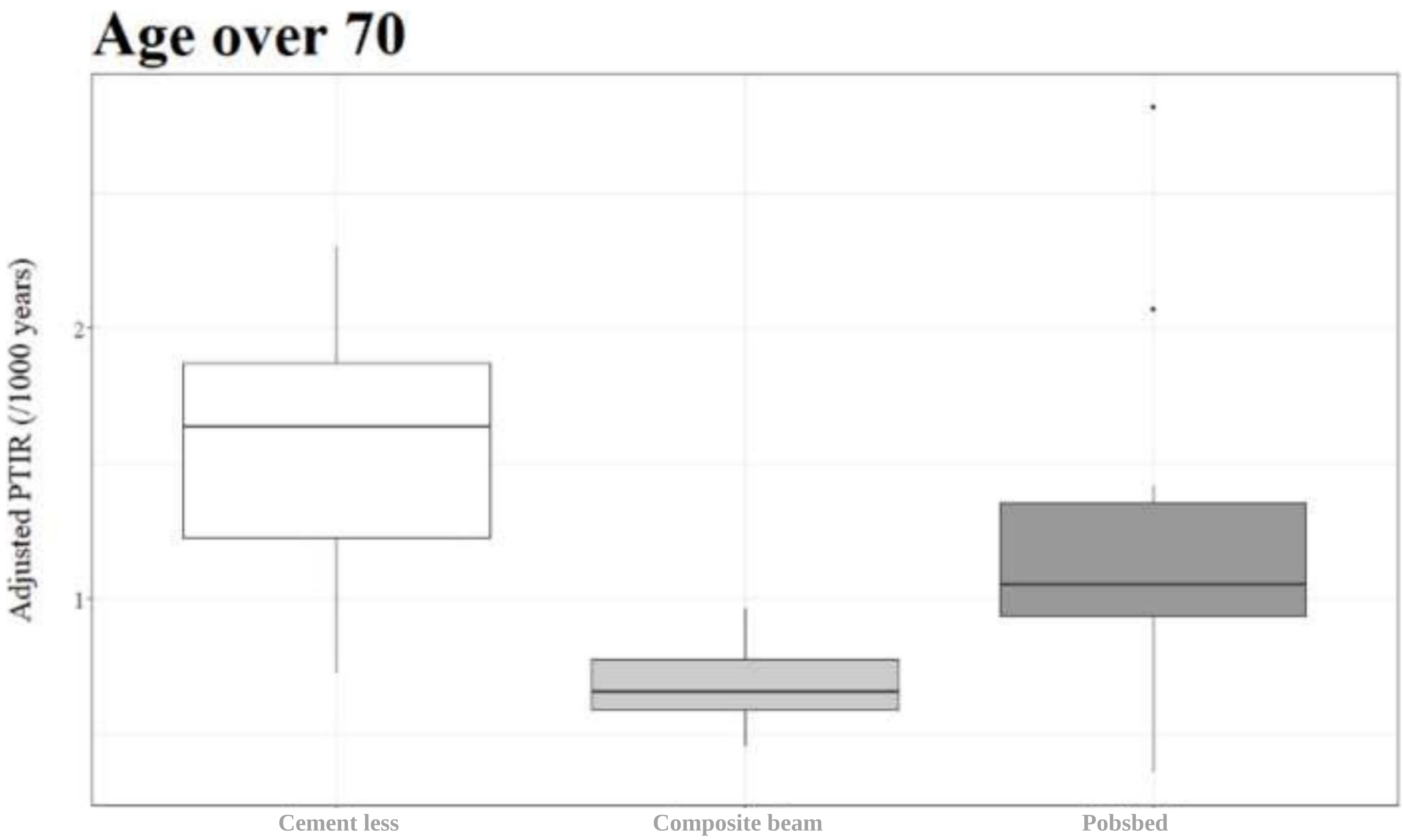
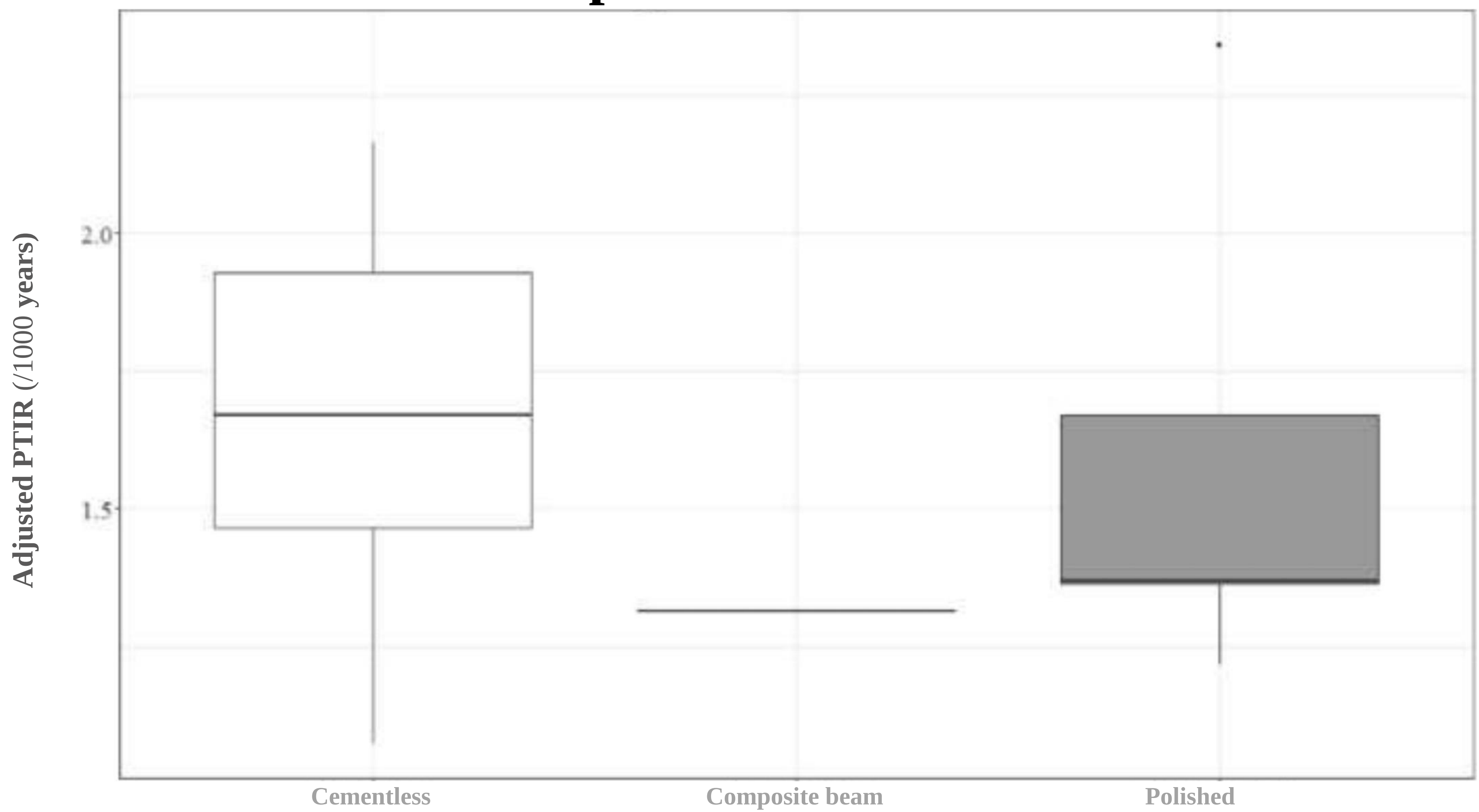
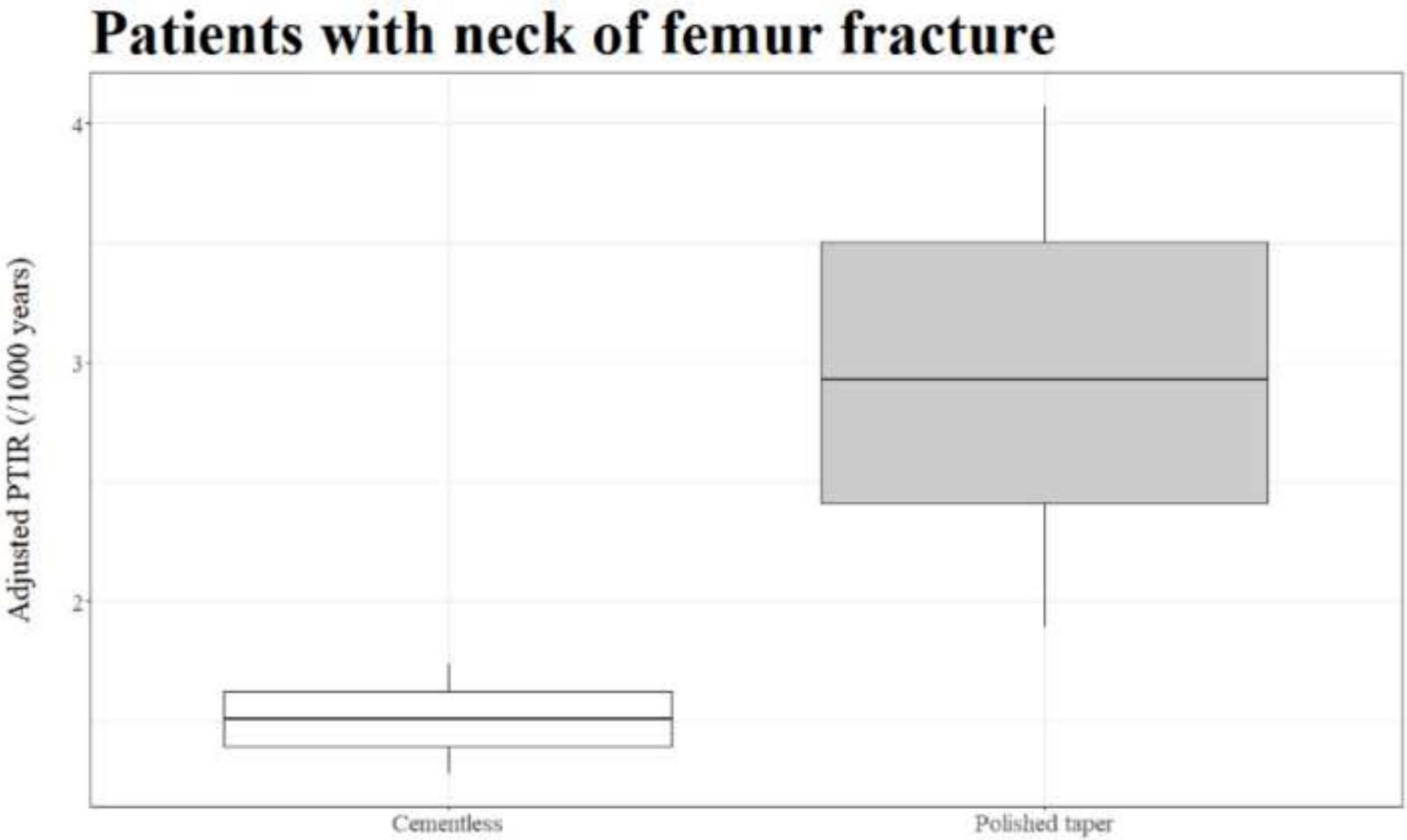
Composite beam
Polished

Fig 5


Age over 70
Adjusted PTIR (/1000 years)
2
1
Cement less
Composite beam
Pobsbed

Patients without hip osteoarthritis




Patients with neck of femur fracture
Adjusted PTIR (/1000 years)
4
3
2
Cementless
Polished taper

Tables document (WORD)

Table 1. Demographics of final dataset. ASA indicates American Society of Anaesthesiologists grade, THA indicates total hip arthroplasty, NOF indicates neck of femur fracture and AVN indicates avascular necrosis of the femoral head.

	level	Overall
n		**809832**
Age (Years) (median [IQR])		71.00 [63.00, 77.00]
Patient Gender (%)	Female	496576 (61.3)
	Male	313249 (38.7)
	Non-binary	7 (0.0)
ASA at primary THA (%)	1	101097 (12.5)
	2	556756 (68.7)
	3	146984 (18.1)
	4	4922 (0.6)
	5	73 (0.0)
Ethnicity (%)	White	688336 (85.0)
	Unknown	109167 (13.5)
	Non white	12329 (1.5)
Indication for primary THA (%)	Acute trauma including NOF	34856 (4.3)
	AVN	19802 (2.4)
	Chronic trauma	8802 (1.1)
	Inflammatory arthritis	10918 (1.3)
	Malignancy	1072 (0.1)
	Osteoarthritis	715289 (88.3)
	Other	5746 (0.7)
	Paediatric disease	13347 (1.6)
Approach (%)	Posterior	509285 (63.2)
	Anterolateral	264686 (32.8)
	Anterior	1917 (0.2)
	Trochanteric Osteotomy	2570 (0.3)
	Other	27894 (3.5)
Lead surgeon grade (%)	Consultant	657789 (81.2)
	Non consultant	152043 (18.8)
THA fixation (%)	Cemented	291392 (36.0)
	Cementless	297829 (36.8)
	Hybrid	195794 (24.2)
	Reverse Hybrid	24817 (3.1)
Head size (median [IQR])		32.00 [28.00, 32.00]
Bearing combination (%)	Metal on polyethylene	256397 (31.7)
	Ceramic on ceramic	102718 (12.7)
	Ceramic on polyethylene	35352 (4.4)
	Ceramic on highly cross-linked polyethylene	146804 (18.1)
	Metal on highly cross-linked polyethylene	268561 (33.2)

Table 2. incidence of POPFF in the whole dataset for stems implanted more than 1000 times, ordered by hazard ratio of POPFF. Dark grey indicates polished taper slip stem, light grey indicates composite beam stem and white indicates cementless stem. PTIR indicates patient time incidence rate (events per 1000 patient years), HR indicates hazard ratio, p indicates result of Wald test comparing HR to reference value (Exeter stem).

Stem brand	n	Events	Patient time (/1000yr)	PTIR (95%CI)	HR (95%CI)
Avanteon Cemented	1581	1	7.42	0.14 (0.01-0.75)	0.26 (0.04-1.81), p=0.17
Furlong Cemented	1061	4	9.11	0.44 (0.12-1.12)	0.38 (0.14-1.03), p=0.06
Muller -Biomet	2526	11	23.80	0.46 (0.23-0.83)	0.42 (0.23-0.76), p<0.01
Tri -Lock BPS	2963	5	19.91	0.25 (0.08-0.59)	0.43 (0.16-1.16), p=0.10
Polarstem collared	1830	1	5.15	0.19 (0.01-1.08)	0.46 (0.06-3.29), p=0.44
CCA SS Cemented	1682	6	12.92	0.47 (0.17-1.01)	0.53 (0.24-1.18), p=0.12
SP II Cemented	1717	10	16.20	0.62 (0.30-1.14)	0.55 (0.28-1.05), p=0.07
Muller Straight	3544	14	24.70	0.57 (0.31-0.95)	0.58 (0.34-0.99), p=0.04
Corail Cemented	1378	3	5.33	0.56 (0.12-1.65)	0.61 (0.20-1.91), p=0.40
Omnifit Cemented	1043	11	10.68	1.03 (0.51-1.84)	0.67 (0.35-1.29), p=0.23
Stanmore Modular	5784	35	49.57	0.71 (0.49-0.98)	0.67 (0.48-0.94), p=0.02
Spectron	1014	7	7.39	0.95 (0.38-1.95)	0.70 (0.33-1.46), p=0.34
Charnley Cemented	13287	101	131.84	0.77 (0.62-0.93)	0.76 (0.61-0.95), p=0.02
Excia Cemented	2124	7	10.53	0.66 (0.27-1.37)	0.79 (0.38-1.67), p=0.54
Anthology	3668	8	25.19	0.32 (0.14-0.63)	0.80 (0.39-1.62), p=0.53
miniHip	1189	2	8.82	0.23 (0.03-0.82)	0.80 (0.20-3.21), p=0.75
Synergy Cementless	4265	17	36.72	0.46 (0.27-0.74)	0.81 (0.49-1.34), p=0.41
Taperloc Complete Cementless	6523	8	28.46	0.28 (0.12-0.55)	0.81 (0.40-1.65), p=0.57
Corail collared	90070	217	535.23	0.41 (0.35-0.46)	0.82 (0.68-0.99), p=0.03
CPT, stainless steel	2164	24	21.71	1.10 (0.71-1.65)	0.91 (0.60-1.36), p=0.63
Exeter No.1 125mm	2241	4	8.97	0.45 (0.12-1.14)	0.96 (0.36-2.57), p=0.94
Accolade II	10775	13	39.50	0.33 (0.17-0.56)	0.98 (0.54-1.76), p=0.94
Exeter V40 standard	293356	1767	1986.48	0.89 (0.85-0.93)	***Reference***
CPS Plus	1569	18	16.47	1.09 (0.65-1.73)	1.03 (0.64-1.66), p=0.89
Taperloc Cemented	1935	10	10.16	0.98 (0.47-1.81)	1.04 (0.56-1.94), p=0.91
Taperfit Cemented	5055	16	22.72	0.70 (0.40-1.14)	1.05 (0.63-1.75), p=0.85
MS-30	4329	29	30.54	0.95 (0.64-1.36)	1.08 (0.74-1.58), p=0.69
Summit Cementless	1724	5	10.36	0.48 (0.16-1.13)	1.08 (0.45-2.61), p=0.86
C-Stem Cemented	21110	151	169.62	0.89 (0.75-1.04)	1.11 (0.93-1.33), p=0.25
Olympia	1255	10	8.93	1.12 (0.54-2.06)	1.15 (0.60-2.22), p=0.68
Furlong Evolution collared	3007	6	15.93	0.38 (0.14-0.82)	1.19 (0.53-2.70), p=0.68
Taperloc Cementless	22461	88	160.10	0.55 (0.44-0.68)	1.22 (0.94-1.58), p=0.13
Furlong HAC	32496	228	287.88	0.79 (0.69-0.90)	1.28 (1.04-1.57), p=0.02
C-Stem AMT Cemented	37689	202	195.40	1.03 (0.90-1.19)	1.29 (1.11-1.50), p<0.01
Excia Cementless, single taper	2757	12	19.29	0.62 (0.32-1.09)	1.32 (0.73-2.37), p=0.36
Profemur L Modular	2399	15	22.46	0.67 (0.37-1.10)	1.38 (0.82-2.34), p=0.23
Accolade	20472	132	175.77	0.75 (0.63-0.89)	1.41 (1.12-1.77), p<0.01
SL-Plus, grit-blasted finish	4383	35	42.23	0.83 (0.58-1.15)	1.42 (0.98-2.04), p=0.06
Metafix collarless	3757	12	22.11	0.54 (0.28-0.95)	1.54 (0.86-2.76), p=0.15
Polarstem collarless	11213	31	49.73	0.62 (0.42-0.88)	1.56 (1.06-2.29), p=0.03
Bimetric collarless	1922	17	17.37	0.98 (0.57-1.57)	1.65 (0.99-2.76), p=0.05
Corail collarless	64855	469	535.54	0.88 (0.80-0.96)	1.66 (1.41-1.96), p<0.01
Exeter V40 long	1335	21	4.80	4.38 (2.71-6.69)	1.72 (1.10-2.67), p=0.02
CLS Spotorno, grit-blasted	2456	24	23.19	1.03 (0.66-1.54)	1.80 (1.17-2.76), p=0.01

M/L Taper Cementless	10847	52	67.97	0.76 (0.57-1.00)	1.89 (1.39-2.59), p<0.01
C-Stem AMT Line Extension	1012	4	3.94	1.01 (0.28-2.60)	2.02 (0.76-5.40), p=0.16
CPCS, cobalt chrome	7436	74	40.83	1.81 (1.42-2.28)	2.12 (1.68-2.69), p<0.01
Omnifit Cementless	1099	24	12.68	1.89 (1.21-2.82)	2.62 (1.71-4.02), p<0.01
CPT, cobalt chrome long	1074	21	6.51	3.23 (2.00-4.93)	2.77 (1.80-4.28), p<0.01
CPT, cobalt chrome	62348	894	365.57	2.44 (2.29-2.61)	2.83 (2.60-3.08), p<0.01
ABG II Monolithic Cementless	1631	61	20.09	3.04 (2.32-3.90)	5.23 (3.88-7.05), p<0.01

Table 3. incidence of POPFF for patients over the age of 70, for stems implanted more than 1000 times, ordered by hazard ratio of POPFF. Dark grey indicates polished taper slip stem, light grey indicates composite beam stem and white indicates cementless stem. PTIR indicates patient time incidence rate (events per 1000 patient years), HR indicates hazard ratio, p indicates result of Wald test comparing HR to reference value (Exeter stem).

Stem brand	n	Events	Patient time (/1000yr)	PTIR (95%CI)	HR (95%CI)
Avanteon Cemented	1021	1	4.99	0.20 (0-1.12)	0.34 (0.05-2.40), p=0.28
Muller-Biomet	1816	9	15.99	0.56 (0.26-1.07)	0.43 (0.22-0.82), p=0.01
SP II Cemented	1083	7	9.34	0.75 (0.30-1.54)	0.45 (0.20-1.01), p=0.05
Muller Straight	2584	12	17.14	0.70 (0.36-1.22)	0.59 (0.34-1.05), p=0.07
Stanmore Modular	4281	26	34.89	0.74 (0.49-1.09)	0.60 (0.41-0.89), p=0.01
CCA SS Cemented	1217	6	9.22	0.65 (0.24-1.42)	0.65 (0.29-1.44), p=0.29
Charnley Cemented	8673	63	77.75	0.81 (0.62-1.04)	0.69 (0.52-0.91), p=0.01
Taperloc Complete Cementless	1808	3	7.73	0.39 (0.08-1.13)	0.69 (0.22-2.17), p=0.52
Corail Cemented	1172	3	4.48	0.67 (0.14-1.96)	0.72 (0.23-2.24), p=0.57
Exeter No.1 125mm	1085	2	4.13	0.48 (0.06-1.75)	0.72 (0.18-2.89), p=0.64
Synergy Cementless	1219	6	9.43	0.64 (0.23-1.38)	0.77 (0.34-1.76), p=0.54
CPT, stainless steel	1485	18	13.54	1.33 (0.79-2.10)	0.89 (0.56-1.42), p=0.63
Taperloc Cemented	1411	7	7.18	0.98 (0.39-2.01)	0.89 (0.42-1.87), p=0.75
Taperfit Cemented	2885	10	12.92	0.77 (0.37-1.42)	0.91 (0.49-1.70), p=0.77
Exeter V40 standard	174123	1300	1113.59	1.17 (1.10-1.23)	***Reference***
CPS Plus	1038	12	10.12	1.19 (0.61-2.07)	0.92 (0.52-1.64), p=0.78
Excia Cemented	1642	7	8.00	0.88 (0.35-1.80)	0.92 (0.44-1.94), p=0.83
Corail collared	36377	146	210.07	0.70 (0.59-0.82)	1.01 (0.81-1.26), p=0.90
C-Stem Cemented	10007	87	72.91	1.19 (0.96-1.47)	1.03 (0.82-1.30), p=0.79
MS-30	2869	24	18.62	1.29 (0.83-1.92)	1.08 (0.71-1.63), p=0.73
Olympia	1053	9	7.37	1.22 (0.56-2.32)	1.29 (0.67-2.50), p=0.45
Taperloc Cementless	7531	45	49.03	0.92 (0.67-1.23)	1.32 (0.94-1.86), p=0.11
Accolade II	3204	7	11.69	0.60 (0.24-1.23)	1.34 (0.62-2.88), p=0.46
C-Stem AMT Cemented	25217	167	126.84	1.32 (1.12-1.53)	1.35 (1.14-1.60), p<0.01
SL-Plus, grit-blasted finish	1581	19	13.19	1.44 (0.87-2.25)	1.56 (0.95-2.56), p=0.08
Furlong HAC	13282	146	108.26	1.35 (1.14-1.59)	1.60 (1.24-2.06), p<0.01
Accolade	6426	75	52.65	1.43 (1.12-1.79)	1.74 (1.29-2.34), p<0.01
Corail collarless	21086	233	162.59	1.43 (1.25-1.63)	1.84 (1.49-2.26), p<0.01
CPCS, cobalt chrome	5237	55	27.66	1.99 (1.50-2.59)	1.98 (1.50-2.60), p<0.01
Polarstem collarless	3447	18	15.44	1.17 (0.69-1.84)	2.00 (1.21-3.30), p=0.01
M /L Taper Cementless	2644	23	15.89	1.45 (0.92-2.17)	2.19 (1.40-3.44), p<0.01
CPT, cobalt chrome	38719	658	217.35	3.03 (2.80-3.27)	2.69 (2.43-2.97), p<0.01

Table 4. incidence of POPFF for patients with non-osteoarthritic hip disease and for stems implanted more than 1000 times, ordered by hazard ratio of POPFF. Dark grey indicates polished taper slip stem, light grey indicates composite beam stem and white indicates cementless stem. PTIR indicates patient time incidence rate (events per 1000 patient years), HR indicates hazard ratio, p indicates result of Wald test comparing HR to reference value (Exeter stem).

Stem brand	**n**	**Events**	**Patient time (/1000yr)**	**PTIR (95%CI)**	**HR (95%CI)**
Charnley Cemented	1106	16	9.71	1.65 (0.94-2.67)	0.69 (0.52-0.91), p=0.01
Exeter V40 standard	38023	316	219.36	1.44 (1.29-1.61)	***Reference***
Corail collared	7868	34	45.56	0.75 (0.52-1.04)	1.01 (0.81-1.26), p=0.90
C-Stem Cemented	2532	19	19.81	0.96 (0.58-1.50)	1.03 (0.82-1.30), p=0.79
Taperloc Cementless	2023	10	14.49	0.69 (0.33-1.27)	1.32 (0.94-1.86), p=0.11
C-Stem AMT Cemented	4980	42	21.90	1.92 (1.38-2.59)	1.35 (1.14-1.60), p<0.01
Furlong HAC	2645	28	22.28	1.26 (0.84-1.82)	1.60 (1.24-2.06), p<0.01
Accolade	1722	16	13.71	1.17 (0.67-1.90)	1.74 (1.29-2.34), p<0.01
Corail collarless	5741	36	46.32	0.78 (0.54-1.08)	1.84 (1.49-2.26), p<0.01
Polarstem collarless	1197	6	5.16	1.16 (0.43-2.53)	2.00 (1.21-3.30), p=0.01
M/L Taper Cementless	1015	5	6.42	0.78 (0.25-1.82)	2.19 (1.40-3.44), p<0.01
CPT, cobalt chrome	9180	129	45.24	2.85 (2.38-3.39)	2.69 (2.43-2.97), p<0.01

Table 5. incidence of POPFF for patients with neck of femur fracture and for stems implanted more than 1000 times, ordered by hazard ratio of POPFF. Dark grey indicates polished taper slip stem and white indicates cementless stem. PTIR indicates patient time incidence rate (events per 1000 patient years), HR indicates hazard ratio, p indicates result of Wald test comparing HR to reference value (Exeter stem).

Stem brand	**n**	**Events**	**Patient time (/1000yr)**	**PTIR (95% CI)**	**HR (95% CI)**
Corail collared	2661	17	13.75	1.24 (0.72-1.98)	0.68 (0.32-1.45), p=0.32
Corail collarless	1027	15	7.17	2.09 (1.17-3.45)	0.92 (0.40-2.11), p=0.84
Exeter V40 standard	16895	154	84.10	1.83 (1.55-2.14)	Reference
C-Stem AMT Cemented	2760	32	11.23	2.85 (1.95-4.02)	1.55 (1.03-2.32), p=0.03
CPT, cobalt chrome	4584	79	19.61	4.03 (3.19-5.02)	2.15 (1.61-2.88), p<0.01