**Article:**

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# Systematic Review and Meta-Analysis of Studies Comparing the Rate of Post Operative Periprosthetic Fracture Following Hip Arthroplasty with a Polished Taper Slip Versus Composite Beam Stem.

Abstract:

**Background:**

We compare the incidence of post-operative periprosthetic femoral fractures (POPFF) following hip replacement with either a cemented polished taper stem (PTS) or cemented composite beam stem (CB) in comparative studies.

**Materials and Methods:**

A systematic review of comparative studies, written in English, and published in peer-reviewed journals since the year 2000 to 2021 was conducted using Ovid MEDLINE, EMBASE, Web of Science, and Scopus. The methodology followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. Study quality was assessed using the Newcastle-Ottawa scale. Cohorts were classified as high or low risk of POPFF based on patient risk factors. Metanalysis was performed using a random effects model and the relative incidence with 95% confidence intervals was reported.

**Results:**

The overall study quality was good. 913,021 patients from 18 cohorts were included in the meta-analysis. 294,540 patients received a CB stem and 618,481 received a PTS stem. For patients at low risk of POPFF the incidence rate ratio (IRR) was 3.14 (CI: 2.48, 3.98) for the PTS group versus the CB group. For patients at high risk of POPFF the IRR of 9.87 (CI: 3.63, 26.80) for the PTS group versus the CB group.

**Conclusions:**

The risk of POPFF is lower when hip arthroplasty was performed using a composite beam stem versus a polished taper slip stem. This protective effect was greatest in patients with a higher risk of POPFF. Surgeons should consider the effect of cemented stem choice on the risk of subsequent periprosthetic femur fracture, particularly in frail or elderly patients who are at a higher risk of postoperative periprosthetic femoral fracture.

## Introduction

Post-operative periprosthetic femoral fractures (POPFF) are associated with high mortality equivalent to native hip fractures and even significantly higher short-term morbidity[1]. POPFF is associated with a high percentage of complications and a high reoperation rate[2,3]. Management of periprosthetic hip fractures is challenging due to both the medical comorbidities and bone fragility of the population where these fractures commonly occur[4]. There is data to suggest that the risk of POPFF following hip arthroplasty is higher with polished taper slip (PTS) stems over composite beam (CB) implants5–10. Additionally, more frequent and earlier reoperation following arthroplasty with a PTS stem has been reported due to POPFF[7].

However, in the United Kingdom (UK), the most frequently used cemented femoral stems adhere to the PTS design philosophy[11]. Recent UK guidance has highlighted the potential benefit to patients and care providers of cemented hip arthroplasty in patients over the age of 70 years [12]. This may increase the use of cemented PTS implants in an older frail population and a potentially possible increase in the risk of subsequent POPFF.

It is important to understand which implants might infer the lowest risk of POPFF so that surgeons and health providers are aware of the potential effects of implant choice on patients requiring hip arthroplasty. Current data collection methods in national arthroplasty registers is largely limited to revision operations and will miss POPFF treated with fixation 13–15. Combining the incidence of POPFF from cohort studies that have captured both fixation and revision events may be the most accurate method. The study aimed to objectively quantify the difference in the risk of POPFF in patients having primary hip arthroplasty (either total or hemi) with a cemented PTS versus a cemented CB stem by pooling the results of all available comparative studies.

## Materials and Methods

*Data source:*

An initial scoping search revealed a lack of randomized controlled trials on the incidence of POPFF after hip arthroplasty. Therefore, our data was limited to the peer-reviewed cohort studies, all of them were found to be published in the last decade.

Eligibility criteria:

Studies that directly compared cohorts of patients with a PTS and a CB stem as part of a hemi or total hip arthroplasty and which were written in English language, available in full text, were of level three or above (Based on Oxford center of evidence-based medicine: levels of evidence, 2009), and published in peer-reviewed journals since the year 2000 onwards, were included.

Studies were excluded if they were conference abstracts, manuscripts that reported on the same cohort twice, and systematic reviews to prevent duplication of observation.

*Systematic review and meta-analysis of cohort studies*:

The study methodology was registered on the PROSPERO (id: CRD42021237555). Reporting followed established Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines [16]. The literature search was conducted using Ovid MEDLINE (MEDLINE and Embase), Web of Science, and Scopus. Articles were identified using a combination of keyword searches describing periprosthetic fracture of the femur, hip replacement, polished taper, and composite beam (Appendix 1).

Citation searching was performed for all full-text manuscripts to identify manuscripts that were not found in initial searches.

Abstracts and the full texts were screened by two authors (AM and JF) independently and disagreements at each stage were settled by consensus. The risk of bias/quality of studies was assessed using the Newcastle-Ottawa Tool by two authors (AM and JF) . Study quality was summarized using the Agency for Healthcare Research and Quality (AHRQ) scale [17].

Where available, extracted data included: Title, authors, year of publication, number in the cohort, the average age of the cohort, average co-morbidity score of cohorts, average follow-up, follow-up range, the number lost to follow-up, femoral implant used, femoral implant design (PTS or CB), replacement construct (hemiarthroplasty or total hip arthroplasty), indication for surgery, number of patients with POPFF, number of reoperations and time of reoperations. Where data did not exist in the manuscript, authors were contacted and asked to supply the relevant information. Data were extracted by three authors (ON, AA, and JL).

*Statistical analysis:*

The primary exposure was primary hip arthroplasty (Total hip replacement or hip hemiarthroplasty) with a PTS stem, and the primary outcome measure was POPFF. Incidence was calculated as the number of POPFF occurring per 100 years of patient time observed in the study. Study and patient-level statistics were estimated using mean values weighted by the number of cases. The suitability of metanalysis based on the similarity of patient groups and study design was assessed using reported patient demographics and methods. To better enable a practical understanding of how stem choice may affect the incidence of POPFF, Studies were then grouped into those studies on high-risk groups and lower-risk groups according to published risk factors around cemented stems [18].

The low-risk group included patients where the cohort was representative of a typical orthopaedic practice; with the predominant indication being osteoarthritis. Whereas, the lower risk group included studies with a selective cohort made up of a majority with non-osteoarthritic indications for arthroplasty. This stratification on high versus low risk was mainly undertaken to reduce heterogeneity between the studies so that a valid metanalysis could be performed. Additionally, the Random effects model was chosen because of increased heterogeneity between studies.

Incidence rate ratios for each study with 95% confidence intervals were estimated using a random effects model (Mantel-Haenszel method). The included studies were assessed for heterogeneity $I^2$ values. All data analysis was completed using R (R version 4.1.3, Vienna, Austria). Meta-analysis was conducted using the `meta ()` package (version 5.5-0) [19].

## Results

*Search results:*

Our search resulted in 1246 unique references from database and citation searches. After title and abstract screening, 1215 records were excluded, and 31 manuscripts underwent full-text review (Figure 1). After a full-text review, nine studies (18 cohorts of patients) were included in the meta-analysis.

*Data quality assessment*:

The overall quality of the studies included was good in all studies. Most studies lacked tight control of group characteristics beyond ensuring indications for surgery and demographics in each group were similar. Every study achieved maximum ratings for selection and moderate ratings for comparability and outcome (Table 1). Of the 9 included studies, two were from multi-center cohort studies, five cohort studies used national arthroplasty registry data and two were single-center cohort studies (Table 2).

*Included studies:*

18 cohorts from nine comparative studies were included. One study was excluded to prevent the same cohorts from being included twice (figure 1).

The included studies observed a total of 913021 patients who underwent primary hip arthroplasty. The included studies contained 294,540 patients with a CB stem and 618,481 patients with a PTS stem.

*Study characteristics:*

Five studies observed patients at higher risk of POPFF who were comprised of large proportions of patients above the age of 80 years old, with an indication of surgery that was not osteoarthritis. Four studies observed patients who were more representative of the general population undergoing hip replacement.

Since the incidence of POPFF is dependent on the population risk factors, patients within each study were grouped into a ‘low’ risk and a ‘higher’ risk of POPFF to improve the validity of metanalysis. The criteria of low risk versus high risk are demonstrated in Table 3.

The demographics of patients in both treatment groups are shown in Table 4 and 5.

*Metanalysis*

Metanalysis demonstrated that for patients with a normal POPFF risk the pooled relative incidence rate ratio of POPFF was 3.1 (95% CI 2.5 to 4.0, p< 0.0001, Figure 2), and for patients with a higher risk of POPFF the pooled relative incidence rate ratio of POPFF was 9.9 (95% CI 3.6 to 26.8, p< 0.0001, Figure 3.

## Discussion

Multiple studies have demonstrated a higher incidence of POPFF following polished taper stems (PTS) in comparison with composite beam stems (CB)[5–9,20–23]. This is the first study to estimate the overall pooled effect of cemented stem choice on the incidence of subsequent POPFF. This study estimates that in low-risk patients who underwent a total hip replacement, where the indication was mostly osteoarthritis, the incidence of POPFF was three times greater for PTS stems versus CB stems. Whereas, in higher-risk patients, where the predominant indication for surgery was not osteoarthritis, the incidence of POPFF was ten times greater for PTS stems versus CB stems. This demonstrates that the excess risk of POPFF associated with PTS versus CB stems is likely to be dependent on indication for surgery and patient features such as age and gender, which is similar to observations of POPFF risk in other cohorts (REF)

The underlying mechanism responsible for the difference in risk of POPFF between CB and PTS stems is unknown. PTS stems are designed to gradually subside inside the surrounding cement mantle, generating hoop stresses in the femoral cortex and increasing stem stability over time. It is possible that during a traumatic event that the PTS stem is able to move within the cement mantle, creating very large hoop stresses which increase the chance of fracture. This may in part explain the existence of log-split type fractures which have been reported around PTS stems but not CB stems 24.

After hip replacement with CB stems, 20-year revision-free survival rates for aseptic loosening and radiological stem loosening were 95.9% and 97.1% have been reported 25. Other studies reported significantly higher overall revision rates for CB stems in comparison with PTS stems [11]. This increased risk of revision has been attributed to a higher risk of aseptic femoral loosening in the composite beam versus taper slip [26]. Polyethylene wear particle-induced osteolysis is one of the most common causes of aseptic loosening and revision total hip arthroplasty [27–29]. Partly in response to concerns regarding aseptic loosening the use of PTS stems has increased in the last two decades in the UK [15]. Wear reduction has been observed since the introduction of highly cross-linked polyethylene in

1998 [30], which coincided with the decline in the use of CB stems in favor of PTS stems in the UK[15]. These events ensured that CB stems were never implanted with highly cross-linked polyethylene in sufficient numbers to allow observation of the subsequent revision results.

This study demonstrates that there is a large difference in risk associated with cemented stem design philosophy and risk of POPFF. It is widely believed that cement is protective against POPFF, however much of this evidence is based on studies from American cohorts, where the predominant cemented stem usage has been of CB design philosophy [31]. Recent comparison has demonstrated unadjusted incidence rates of revision for POPFF in cemented PTS stems similar to that seen following THR with a cementless stem [18].

In general, cemented stems are more durable and exhibit lower revision rates rate in patients who are 70 years of age and older [32,33]. In the last decade, this evidence has formed the basis of English guidance, which encourages surgeons to use cemented stems in older patients, which is likely to increase the use of PTS stems in patients most at risk of POPFF in the UK [12]. This review demonstrated that the reduced incidence of POPFF associated with CB stems appears to be related to the underlying risk of POPFF in the cohort observed. A risk-based approach to implant choice could significantly reduce reoperation by reducing the risk of POPFF [10], which is likely to reduce the burden of poor outcomes on patients [4,34] and health service providers alike [35,36]. The current evidence relating to risk-factor identification in patients with THR suggests that older patients with the non-osteoarthritic hip disease may be most at risk [37], but a validated tool to identify patients most at risk of POPFF is yet to be developed. Such a tool could identify patients for whom this approach would be most beneficial.

The strength of recommendations from this study is limited by inherent bias contained in observational studies. Assignment of PTS or CB stems was prone to bias and studies did not control for other factors which are known to affect POPFF risk. These limitations increase the chance that the observed differences in POPFF incidence were the result of bias and or confounding rather than the treatment effect. Given the large differences in the incidence of POPFF, it is likely that stem choice plays a significant role in the future risk of POPFF. The risk of POPFF may be time dependent and this may have lead to more or less observed POPFF in each study group. Future work should seek to establish evidence from prospective trials if feasible. Further work should focus on the effects of stem choice in non-European populations. Whilst we are confident that our included evidence represents a current state of the art, future studies should assess whether the inclusion of registry data may improve the body of evidence. Whilst we have identified a large relative difference in the risk of POPFF for patients with a PTS versus a CB stem, surgeons should weigh up the overall benefit and risk profile of each case to judge whether patients might benefit from the use of CB stems. Further work should seek to compare overall outcomes following each approach and seek to evaluate socioeconomic cost differences.

**Conclusion:**

The risk of POPFF is lower when hip arthroplasty was performed using a composite beam stem versus a polished taper slip stem. This protective effect was greatest in patients with a higher risk of POPFF. Surgeons should consider the effect of cemented stem choice on the risk of subsequent periprosthetic femur fracture, particularly in frail or elderly patients who are at a higher risk of postoperative periprosthetic femoral fracture.

**Highlights**

- This study has demonstrated that there is a low incidence of POPFF for patients undergoing hip arthroplasty, either hemiarthroplasty or total hip arthroplasty, with a composite beam stem versus a polished taper-slip stem.
- This study supports the use of composite beam stems in patients where there is a high risk of failure due to POPFF.
- Further work is required to develop validated risk-scoring systems to identify patients who would most benefit from hip arthroplasty using a CB stem.

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**ICMJE COI statement**

All authors have no conflict of interest to declare

This systematic review has been registered with PROSPERO (id: CRD42021237555)

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## *Appendix*

**Table 1**. Study quality assessment using the Newcastle-Ottawa scale and Agency for Healthcare Research and Quality grade.

The Newcastle-Ottawa scale is a tool for evaluation of the quality of non-randomized studies included in a systematic review and/or meta-analyses. Assessment involves evaluating each study against 8 items grouped under 3 major categories; the selection of the study group; the comparability of the groups; and the ascertainment of either the exposure or outcome of interest for case-control or cohort studies, respectively. And the AHRQ grades and levels a research into 5 categories. With grade A being strongly recommended with good evidence, and grade E being evidence is insufficient, lacking or of poor quality. Similarly level I is the highest level which is metanalysis of multiple studies and level V for case reports and clinical examples.

| **Study** | **Newcastle-Ottawa Scale** | | | **AHRQ** |
|---|---|---|---|---|
| | **Selection** | **Comparability** | **Outcome** | |
| Chatziagorou et al. 2019 | 3 | 2 | 2 | Good |
| Joanroy et al. 2021 | 3 | 2 | 2 | Good |
| Kazi et al. 2019 | 3 | 1 | 2 | Good |
| Kristensen et al. 2018 | 3 | 2 | 2 | Good |
| Mellner et al. 2021 | 3 | 1 | 2 | Good |
| Mohammed et al. 2019 | 3 | 2 | 2 | Good |
| Mukka et al. 2016 | 3 | 2 | 2 | Good |
| Palan et al. 2016 | 3 | 1 | 2 | Good |
| Thien et al. 2014 | 3 | 1 | 2 | Good |

**Table 2.** Study characteristics of included studies and cohorts.

| Author | Year | n | POP FF Sample Size (n) | Group | Follow up (years) | Age (years) | Female (n) | ASA 1 | ASA 2 | ASA 3 | ASA 4 | OA | NOFF | Inflammatory | THR | HA | Stem (Implant, manufacturer) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Comorbidities | | | | | | Indications | | | Arthroplasty | | |
| Mellner et al. 2021 | 2021 | 1202 | 9 | CB | 3.9 | 81 | 823 | ASA 1 - 2: 456 | | ASA 3 - 4: 600 | | 0 | 1202 | 0 | 208 | 994 | SP II, Waldemar LINK, Hamburg, Germany |
| Mellner et al. 2021 | 2021 | 1326 | 30 | PTS | 3.9 | 82 | 909 | ASA 1 - 2: 416 | | ASA 3 - 4: 905 | | 0 | 1326 | 0 | 216 | 1110.00 | Exeter V40, Stryker, New Jersey, USA |
| Mukka et al. 2016 | 2016 | 555 | 1 | CB | 1.7 | 86 | 297 | ASA 1 - 2: 169 | | ASA 3 - 4: 249 | | 0 | 424 | 0 | 23 | 415.0 | SP II, Waldemar LINK, Hamburg, Germany |
| Mukka et al. 2016 | 2016 | 424 | 21 | PTS | 1.7 | 86 | 398 | ASA 1 - 2: 128 | | ASA 3 - 4: 424 | | 0 | 555 | 0 | 58 | 512.0 | CPT, ZimmerBiomet, Indiana, USA |
| Chatziagorou et al. 2019 | 2019 | 27188 | 298 | PTS | 5.6 | 72.1 | 16866 | | | | | 22280 | 2794 | 1816 | 27188 | 0 | Exeter V40, Stryker, New Jersey, USA |
| Chatziagorou et al. 2019 | 2019 | 52625 | 167 | CB | 5.6 | 72.2 | 31755 | | | | | 43648 | 6181 | 1816 | 52625 | 0 | SP II, Waldemar LINK, Hamburg, Germany |
| Kazi et al. 2019 | 2019 | 47586 | 30 | CB | 4.2 | 73.6 | 31717 | 7170 | 31902 | 8513 | 379 | 43692 | 825 | 722 | 47586 | 0 | Multiple stems* |
| Kazi et al. 2019 | 2019 | 245401 | 407 | PTS | 4.2 | 71.9 | 159915 | 33680 | 169083 | 41074 | 1509 | 221068 | 6068 | 3594 | 245401 | 0 | Multiple stems* |
| Kristensen et al. 2018 | 2018 | 7400 | 4 | CB | 1.3 | 83.9 | 5424 | 266 | 2295 | 4262 | 577 | 0 | 7400 | 0 | 0 | 7400.00 | Charnley, Depuy Synthese. Massachusetts, USA; Charnley Modular, Depuy Synthese. Massachusetts, USA; Spectron, Smith & Nephew, Tennessee, USA; SP II, Waldemar LINK, Hamburg, Germany |
| Kristensen et al. 2018 | 2018 | 1323 | 44 | PTS | 2.7 | 83.9 | 825 | 16 | 391 | 829 | 87 | 0 | 1323 | 0 | 0 | 1323.00 | Exeter V40, Stryker, New Jersey, USA; CPT, ZimmerBiomet, Indiana, USA |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Palan et al. 2016 | 2016 | 20182 | 15 | CB | 3.8 | 73 | 12916 | | | 20182 | 0 | 0 | 12916 | 0 | Charnley, Depuy Synthese. Massachusetts, USA |
| Palan et al. 2016 | 2016 | 237020 | 375 | PTS | 3.8 | 72 | 154063 | | | 237020 | 0 | 0 | 154063 | 0 | Exeter V40, Stryker, New Jersey, USA CPT, ZimmerBiomet, Indiana, USA; C-Stem, Depuy Synthese. Massachusetts, USA |
| Thien et al. 2014 | 2014 | 94917 | 32 | CB | 2.0 | | | | | | | | 94917 | 0 | SP II, Waldemar LINK, Hamburg, Germany |
| Thien et al. 2014 | 2014 | 85336 | 120 | PTS | 2.0 | | | | | | | | 85336 | 0 | Exeter V40, Stryker, New Jersey, USA |
| Joanroy et al. 2021 | 2021 | 300 | 7 | PTS | 1.0 | 82 | 222 | | | 0 | 300 | 0 | 0 | 300 | CPT, ZimmerBiomet, Indiana, USA |
| Joanroy et al. 2021 | 2021 | 284 | 1 | CB | 1.0 | 82 | 214 | | | 0 | 284 | 0 | 0 | 284 | SP II, Waldemar LINK, Hamburg, Germany |
| Mohammed et al. 2019 | 2019 | 534 | 2 | CB | 1.7 | 82 | 399 | ASA 1 - 2: 185 | ASA 3-4: 138 | 124 | 383 | 17 | 248 | 286 | SP II, Waldemar LINK. Hamburg, Germany |
| Mohammed et al. 2019 | 2019 | 543 | 18 | PTS | 1.7 | 82 | 387 | ASA 1 - 2: 349 | ASA 3-4: 405 | 94 | 421 | 16 | 211 | 332 | CPT, ZimmerBiomet, Indiana, USA |

*Note:* n indicates number of patients, POPFF indicates post-operative periprosthetic femoral fracture, ASA indicates American Society of Anesthesiology grade, OA indicates osteoarthritis, NOFF indicates neck of femur fracture, THR indicates total hip arthroplasty, HA indicates hemiarthroplasty. * Multiple stems can be seen in original references.

**Table 3:** Criteria of the "high risk" versus "low risk" for sustaining postoperative periprosethetic femur fracture following hip arthroplasty

| **High Risk Group Criteria** | **Low Risk Group Criteria** |
|---|---|
| Advancing age; majority of patient older than typical hip arthritis patient (median 70 years). | Age similar to standard arthritis patients (median age 70). |
| Non Osteoarthritis indications for surgery | Groups where predominant indication for hip replacement was osteoarthritis. |

**Table 4**. Comparison of the number of POPFF based on the type of cemented stem fixation in the low risk group of patients.

| | **CB** | **PTS** |
|---|---|---|
| POPFF Fractures (n) | 215310 | 594945 |
| Year (range) | 2014-2019 | 2014-2019 |
| Age (mean) | 72.9 | 72.0 |
| Female (%) | 63.4 | 64.9 |
| Total hip replacement (n) | 208044 | 511988 |
| Hemiarthroplasty (n) | - | - |
| Follow-up (mean) | 3.5 | 3.8 |
| Follow-up (range) | 2.0-5.6 | 2.0-5.6 |

*Note*: n indicates number, mean indicates weighted mean value

**Table 5**. Comparison of the number of POPFF based on the type of cemented stem fixation in the higher risk group of patients.

| | **CB** | **PTS** |
|---|---|---|
| POPPF (n) | 9975 | 3916 |
| Year (range) | 2016-2021 | 2016-2021 |
| Age (mean) | 83.5 | 83.1 |
| Female (%) | 71.7 | 70.0 |
| Total hip replacement (n) | 479 | 485 |
| Hemiarthroplasty (n) | 9379 | 3577 |

| | | |
|---|---|---|
| Follow-up (mean) | 1.6 | 2.7 |
| Follow-up (range) | 1.0-3.9 | 1.0-3.9 |

*Note*: n indicates number, mean indicates weighted mean value