Outcomes of modular stem for the treatment of periprosthetic femoral fracture: a systematic review of the literature

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Background: Periprosthetic femoral fractures (PFFs) are a frequent complication after total hip arthroplasty (THA). Both modular and non-modular tapered fluted titanium (TFT) stems could be used in total hip revisions (THRs). Nevertheless, the most appropriate femoral stem type is still under debate. The current systematic review aims to analyze the survival rate and all causes of stem revision, the overall complication rate and reason for reoperation, and patient reported outcome measures (PROMs) in THR for PFF using the modular tapered titanium stems (MTTS).

Methods: A comprehensive search in four databases, PubMed, Scopus, Embase, and the Cochrane Database of Systematic Reviews databases, was performed, and following the PRISMA guidelines, a systematic review was conducted. Strict inclusion and exclusion criteria were applied, starting from 1,259 studies. The risk of bias was analyzed according to the MINORS tool system. Descriptive statistical analysis was performed for all data extracted.

Results: Eighteen clinical studies were included in the qualitative analysis for a total of 775 patients enrolled. A mean MINORS criteria score of 9.8 [8–12] was reported. The overall survival of MTTS for PFF treatment was 95.4%, with an overall reintervention rate of 10.3% at an average follow-up of 4.5 years. Despite the use of modular components, postoperative hip instability remains the most frequent complication and cause of reintervention in these patients. In addition, a mean postoperative Harris Hip Score (HHS) of 78.1 was reported, which was considered acceptable given the high mean age of 74.1 years at the time of the revision.

Conclusions: Several therapeutic approaches and a wide variety of implants have been described in the literature for PFF management; however, no one solution has proven superior to others in the PFF treatment. MTTS has become a commonly used treatment option for Vancouver B2 and B3 fractures because they provide good clinical and radiological results with a reasonable survival rate. However, the complication rate of MTTS is still high.

Keywords: Total hip arthroplasty (THA); periprosthetic femoral fractures (PFFs); modular tapered titanium stem (MTTS); vancouver classification

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Introduction

The number of primary total hip arthroplasties (THAs) performed yearly in the United States is expected to increase by 174%, from 208,600 in 2005 to 572,000 in 2030. Similarly, total hip revisions (THRs) are estimated to rise by 137% between 2005 and 2030 (1,2). Among the leading causes of THR, periprosthetic femoral fractures (PFFs) are a frequent complication with a cumulative incidence of 3.5% after THA (2). Based on results from large U.S. databases and the Australian Orthopaedic Association National Joint Replacement Registry (AONJRR) (3,4), PFF is the fifth THR most frequent cause, with a prevalence of 6.2%, after hip instability/dislocation (22.5%), mechanical loosening (19.7%), infection (14.8%), and implant failure (9.9%). Simultaneously, the Swedish registry describes PFF as the third most frequent THR cause after hip instability and aseptic loosening (5). Several risk factors contribute to PFF occurrences, and numerous variables, such as bone quality, patient age, and surgeon experience, should be considered during treatment (6). Among the various PFF risk factors, prostheses loosening with cortical bone loss and stress risers within the cortex, such as those produced by screw holes, plate edges, or loose stem impingement on the lateral femoral cortex, should be considered. In addition, it was demonstrated that PFF is related to localized osteolysis (6,7).

Several classifications have been proposed for PFF; nevertheless, the Vancouver classification remains the most widely used because it could orient the treatment procedure focusing on three crucial points: site, implant stability and bone stock (8). In the "Vancouver A" PFF, fractures are in the trochanteric region; they are further subdivided into "G" and "L" depending on the involvement of the greater or lesser trochanter, respectively. The PFF around the femoral stem is classified as "Vancouver B". These fractures are additionally graded, according to stem stability, into "B1", which is characterized by a stable stem, "B2", which presents an unstable stem, and "B3", characterized by both an unstable stem and inadequate bone stock. Finally, PFF below the femoral stem is classified as "Vancouver C" (8,9). Femoral stem stability and bone loss guide treatment, which may range from non-surgical, in minimal cases of composed fractures or patients inadequate for surgical treatment, to open reduction and internal fixation (ORIF) in stable stem cases or femoral component revision, alone or in association with ORIF, in the presence of unstable stem (8-10).

Both modular and non-modular tapered fluted titanium (TFT) stems could be used in THRs. Nevertheless, the most appropriate femoral stem type is still under debate. Modular tapered titanium stems (MTTS), from the literature evidence, are usually easier to implant due to the possibility of adjusting lower limb length, forward inclination, and the femoral offset. On the other hand, MTTSs increase the intraoperative fracture risk, adverse reaction to metal debris (ARMD), and modular component failure at the neck-stem junction (9-11). Non-modular stems do not exhibit the above specific complications but, based on data reported in the literature, are characterized by a higher postoperative dislocation risk and femoral stem subsidence (12,13). Modular and monoblock TFT stems have become increasingly popular, especially when bone stock is limited. Due to the simplicity of adjusting offset and leg length, some surgeons prefer MTTS to monoblock ones (11).

The purpose of the current systematic review is to analyze (I) the survival rate and all causes of stem revision;

Highlight box

Key findings

- Modular tapered titanium stems (MTTS) are an excellent solution for treating Vancouver B2 and B3 periprosthetic femoral fracture (PFF).

What is known and what is new?

- The management of PFF remains complex in orthopedics, with multiple therapeutic approaches and implant options. However, surgical solutions have not yet shown superiority in treating PFF. In recent years, MTTS has become a commonly used treatment option for Vancouver B2 and B3 PFFs, with good clinical and radiological results at a mid-term follow-up. However, the complication rate of MTTS is still high.

What is the implication, and what should change now?

- In situations with major femoral bone defects, an MTTS is a functional and efficiently designed element in total hip arthroplasty (THA), as it strengthens fixation, allowing anteversion and offset adjustment. Aseptic loosening, stress shielding, and dislocation are reduced, and MTTSs have been seen to provide an even more accurate leg length measurement.

(II) the overall complication rate and reason for reoperation; (III) and PROMs in THR for PFF using the MTTS. We present this article in accordance with the PRISMA reporting checklist (available at https://aoj.amegroups.com/article/view/10.21037/aoj-23-27/rc).

Methods

Research strategy

This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria (14-16). A literature search was conducted in PubMed, Scopus, Embase, and the Cochrane Database of Systematic Reviews databases to identify studies investigating the THR due to PFF using a MTTS. The search included all studies available until December 2022, using the following key terms in association with the Boolean operators "AND", and "OR": "periprosthetic femoral fracture", "PFF", "Vancouver B2", "Vancouver B3", "revision modular stem", and "revision arthroplasty".

Inclusion and exclusion criteria

Clinical studies reporting the patient clinical outcomes, complications, survival rate, and Harris Hip Score (HHS) of patients undergoing THR due to PFFs using a MTTS were included. Review articles, biomechanical reports, and case series with fewer than ten patients or less than one year of follow-up were excluded. In addition, studies written in non-English languages were excluded.

Study screening

Two authors performed the research separately (GC and LB). A third author (GS) was consulted in case of disagreement. The initial search produced a result of 1,275 articles. All duplicates were removed. The full text was reviewed for the 49 studies included based on the title and abstract. After evaluating the inclusion and exclusion criteria, eighteen clinical studies (17-34) were included in the final analysis (*Figure 1*). Specifically, fifteen retrospective case series (17-20,22,23,25,27-34), two prospective case series (21,24), and one retrospective comparative study (26) were analyzed. Additional relevant articles were searched through analysis of the bibliography of included studies.

Qualitative assessment

The Methodological Index for Non-Randomized Studies (MINORS) criteria score (35-37) was used to assess the quality of the included studies. The MINORS criteria score helps assess the relevance of non-randomized surgical research and have been frequently used in the literature regarding systematic reviews on hip and knee studies (38-40).

Data extraction

One author (LB) collected the data in a Microsoft Excel worksheet, which was then verified by a second author (GC). In case of disagreement, the senior author (GS) was consulted. The following characteristics were collected: study design, level of evidence, implant brand, patient demographic characteristics, mean duration of follow-up and fracture classification according to Vancouver criteria. Furthermore, details of revision rate, causes of stem revision and stem survival, HHS, and complications that required reoperation were collected.

Statistical analysis

Descriptive statistical analysis was performed for all data extracted from the included studies. Absolute numbers and frequency distribution were used to analyze categorical variables. For continuous variables, mean values were calculated with a measure of variability as standard deviation (SD) or range (minimum–maximum). A P value <0.05 was considered statistically significant.

Results

Study characteristics

A total of 758 patients were initially enrolled: 330 (44.8%) and 406 women (55.2%), while one study did not report gender distribution (30); after excluding patients who died or were lost to follow-up, 664 patients were included in the final analysis. The mean age at the time of surgery was 74.1 (65.7–78.1) years. The mean duration of follow-up was 4.5 [1–14] years. The overall mean quality of the included studies was low. A mean MINORS criteria score of 9.8 [8–12] was reported. Six studies were classified as "excellent" (21,22,24,29-31), while the quality of the remaining studies was classified as "moderate" (17-20,23,25-27,31-34). No studies were classified as "very

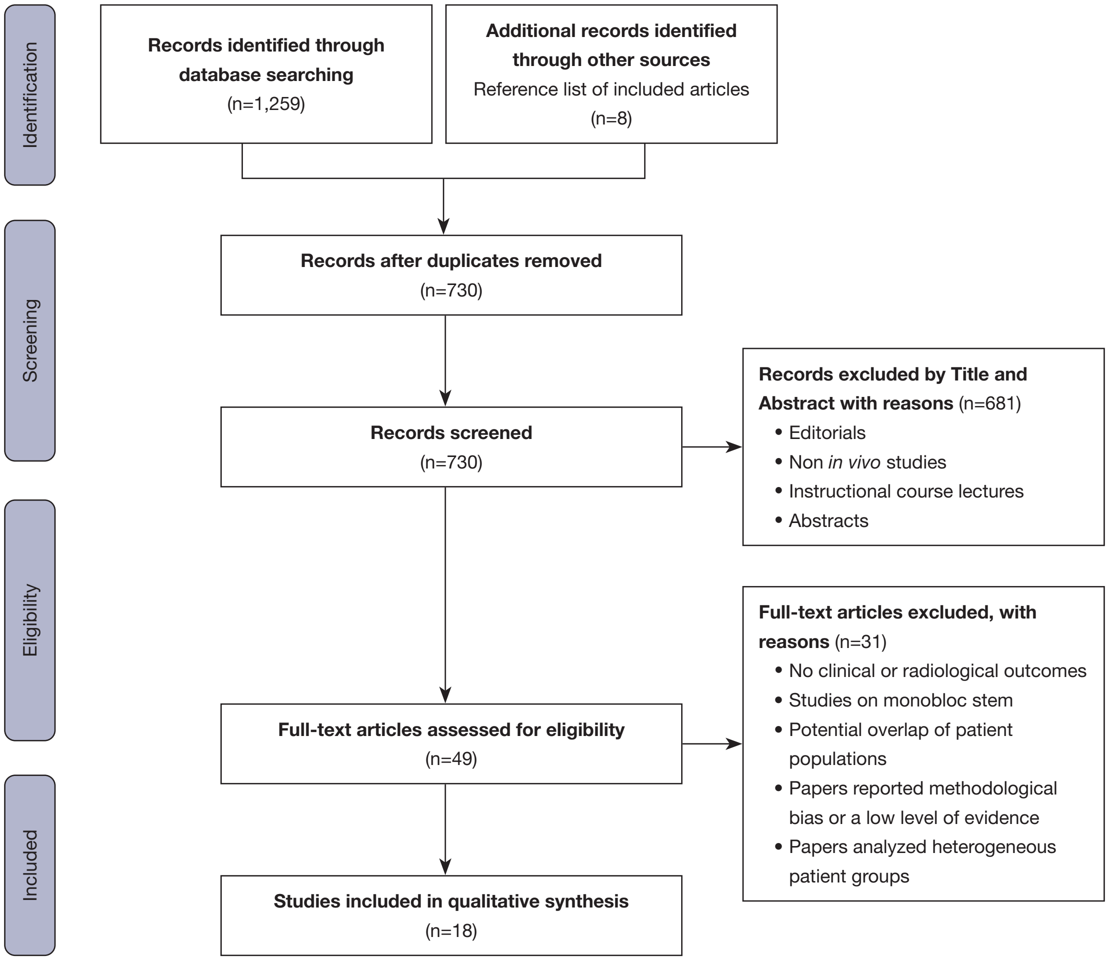

Figure 1 PRISMA flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

bad". Study demographics, design, and quality are summarized in *Table 1*.

Reintervention, stem revision and stem survival

Stem survival according to the duration of follow-up was analyzed and reported in *Table 2*. The overall reintervention rate was 10.4% (74 of 710 hips). Conversely, the rate of patients who required stem revision was 4.7% (33 of 710 hips); of the 33 revised stems, 9 were replaced due to deep infection with two-stage revision, 7 due to aseptic loosening, 6 due to hip instability, 6 due to PFF, and 5 due to stem failure with the development of tension pain.

HHS

Among the 18 studies included, only 2 reported the preoperative HHS (18,19), while 12 mentioned only the postoperative HHS (20-22,25-27,29,30,31-34), and 4 did not report the HHS (23,24,28,31). The postoperative HHS had an average value of 78.1 [20–100]. In the two studies (18,19) that reported both preoperative and postoperative HHS, improvements in HHS were observed from an average of 37.5 [5–60] points before surgery to an average of 81.4 [46–94] points at final follow-up.

Complications

Complications were reported in all 18 included articles (*Table 3*) (17-34).

Dislocation

The most frequent complication was a hip dislocation. Of 45 dislocations, 23 (or 51%) required reoperation. In seven

Table 1 Study characteristic and demographic data of the included studies

Study	MINORS	Study type (LoE)	Implant type	Hips initially/ finally included	Gender distribution (M/F)	Mean age in years	Mean follow-up in months	Vancouver type, B2/ B3	Mean operation time in minutes	Type of revision, stem only/all
Mulay [2005] (17)	9	Retrospective case series (IV)	MP stem (Link)	24/22	NA	74 [36–95]	12	10/14	179.7	NA
Zaki [2007] (18)	9	Retrospective case series (IV)	Charnley-like stem (DePuy)	37/37	22/14	70 [66–79]	168 [96–216]	0/37	NA	NA
Park [2023] (19)	8	Retrospective case series (IV)	MP stem (Link) + Revision stem (Lima)	27/27	19/8	65.7 [41–91]	57 [36–122]	16/11	102.8	26/1
Rodriguez [2017] (20)	9	Retrospective case series (IV)	NA	14/14	NA	NA	40 [5–84]	12/2	194 [160–248]	NA
Fink [2012] (21)	11	Prospective case series (IV)	Revitan stem (Zimmer)	32/32	12/20	67.4 [39–90]	32.2 [24–60]	22/10	NA	30/2
Abdel [2014] (22)	11	Retrospective case series (IV)	MP stem (Link) + Restoration stem (Stryker)	44/44	20/24	72 [34–92]	54 [24–96]	25/19	251 [113–426]	26/18
Amenabar [2015] (23)	10	Retrospective case series (IV)	ZMR stem, (Zimmer)	81/76	28/48	75.7 [41–97]	74.4 [24–167]	66/10	NA	52/24
da Assunção [2015] (24)	12	Prospective case series (IV)	Restoration strem (Stryker)	38/37	17/20	77 [47–96]	35 [4–66]	31/6	175 [95–260]	15/22
Hernandez-Vaquero [2015] (25)	8	Retrospective case series (IV)	NA	17/12	NA	67 [51–92]	43 [12–168]	7/5	NA	12/0
Moreta [2019] (26)	10	Retrospective comparative study (III)	Modular-Plus stem (Smith & Nephew)	24/24	NA	78 [71–85]	60 [24–144]	17/7	199 [120–360]	NA
Parry [2018] (27)	10	Retrospective case series (IV)	MP stem (Link) + restoration stem (Stryker) + reclaim stem (Depuy)	61/61	26/35	72 [43–88]	54 [24–120]	57/6	NA	NA
Lizaur-Utrilla [2019] (28)	10	Retrospective case series (IV)	MGS revision stem (Samo)	87/77	21/56	75.5 (67–82)	42.8 [24–60]	42/35	90.3	NA
Munegato [2020] (29)	11	Retrospective case series (IV)	Revision stem (Lima)	25/23	NA	74 [47–92]	29 [8–104]	19/4	128 [80–235]	20/3
Schreiner [2022] (30)	11	Retrospective case series (IV)	Prevision stem (B. Braun)	22/18	06/12	75.5 [60–89]	18.5 [3–43]	12/6	182.5 [112–260]	16/2
Klasan [2022] (31)	11	Retrospective case series (IV)	Restoration stem (Stryker)	70/70	49/21	77.6 [69–87]	42 [10–196]	70/0	230 [167–293]	69/1
Santiago [2021] (32)	9	Retrospective case series (IV)	NA	36/35	NA	68 [22–85]	42 [12–96]	16/19	NA	9/26
Schöfl [2022] (33)	8	Retrospective case series (IV)	Revitan stem (Zimmer)	80/34	15/19	78.1 [34–96]	63 [12–102]	NA	145 [82–279]	NA

Table 1 (*continued*)

Table 1 (*continued*)

Study	MINORS	Study type (LoE)	Implant type	Hips initially/ finally included	Gender distribution (M/F)	Mean age in years	Mean follow-up in months	Vancouver type, B2/B3	Mean operation time in minutes	Type of revision, stem only/all
Zampieri [2023] (34)	10	Retrospective case series (IV)	Femoral stem (PRIUS, Evolutis)	39/21	NA	76.1 [52–96]	36.5 [15–71]	NA	NA	NA
Overall	9.8	–	–	758/664	235/277	74.1 [65.7–78.1]	53.9 [12–168]	422/191	154.5	275/99

Data are shows as mean values (with standard deviation or range) or percentages. MINORS, Methodological Index for Non-Randomized Studies; LoE, level of evidence; M, male; F, female; NA, not available.

patients, switching from standard to constrained inserts was used to avoid further hip dislocations; another six patients received cup revision for hip dislocation, and no further revision was required. In three patients, the femoral head diameter was adjusted without requiring further revision, while another six patients underwent stem revision for multiple episodes of hip dislocation and subsequent hip instability. Finally, 21 patients with dislocation episodes underwent closed reduction treatment under general anesthesia. One study did not specify how dislocations were treated (32).

Clinically significant stem subsidence (>5 mm)

Stem subsidence was the second most common complication reported. Only 5 of the 21 people who experienced this condition underwent revision stem surgery. Stems that had previously subsided more than 5 mm were stable in the other 16 patients at the time of the last follow-up, and no intervention was required. In the 16 patients who experienced subsidence but did not require revision surgery due to stable stem fixation, the discrepancy in lower limb length was effectively managed with shoe lifts, and they did not report any significant sensations of imbalance or difference in lower limb length.

PJI

PJI was the third leading cause of complications. Fourteen hips out of 710 (1.97%) had a deep infection. All patients with PJI required further intervention. In five cases, a debridement, antibiotics, and implant retention (DAIR) was performed, preserving the implant components; however, in nine cases, the stem was replaced, and a two-stage revision was performed, resulting in the implantation of a new modular stem.

PFF

PFF ranked fourth in terms of complications, with an incidence of 1.83% (13 of 710 hips). Seven patients with Vancouver B1 fracture underwent ORIF (open reduction, internal fixation) with wires, cables, and plates. The remaining six patients required stem revision because they developed a Vancouver B2-B3 fracture.

Stem nonunion

Given the stability of the stem, conservative treatment was used in all cases of nonunion (10 of 710 hips).

Wound healing problems

With an average rate of 1.8% (13 of 710 hips) and 1.4% (10 of 710 hips), respectively, wound infection and postoperative hematoma were two common complications. Washing, local debridement, and antibiotics were used to treat most patients (8 of 710 hips) who developed a superficial infection. The remaining five patients were given intravenous suppressive antibiotic therapy without a second procedure. On the other hand, only one study (33) documented reoperation in cases of wound hematoma (2 of 710 also). Conservative treatment was applied to the other hematoma episodes.

Discussion

The PFF incidence has been increasing in recent years, and several factors are involved in this phenomenon. First, it should be underlined that the excellent THA outcomes have led to a widening of the age range of patients eligible for this procedure with increasing involvement of both young and elderly patients (41,42). In young patients, PFF is associated with high-energy trauma, while in the elderly, the

Table 2 Survivorship and reason for stem revision

Study	Sample size	Stem survivorship	Reason for stem revision	Stem subsidence, n (%)	Deep infection, n (%)	PFF, n (%)	Aseptic loosening, n (%)	Hip instability, n (%)
Mulay [2005] (17)	22	100% at the last follow-up	None	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Zaki [2007] (18)	37	100% at 14 years	None	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Park [2023] (19)	27	93% at 5 years	One significant subsidence, one PJI	1 (3.7)	1 (3.7)	0 (0.0)	0 (0.0)	0 (0.0)
Rodriguez [2017] (20)	14	93% at 3.5 years	One hip instability	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)
Fink [2012] (21)	32	100% at 2.7 years	None	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Abdel [2014] (22)	44	86% at 4.5 years	Two PJI, one aseptic loosening	0 (0.0)	2 (4.5)	0 (0.0)	1 (2.3)	0 (0.0)
Amenabar [2015] (23)	76	91% at 6.2 years	Five aseptic loosening, one PFF, one PJI	0 (0.0)	1 (1.3)	1 (1.3)	5 (6.6)	0 (0.0)
da Assunção [2015] (24)	37	100% at 2.9 years	None	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Hernandez-Vaquero [2015] (25)	12	100% at 3.6 years	None	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Moreta [2019] (26)	24	96% at 5 years	One hip instability	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (4.1)
Parry [2018] (27)	61	93% at 5.4 years	Two hip instability	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.3)
Lizaur-Utrilla [2019] (28)	77	100% at 3.6 years	None	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Munegato [2020] (29)	23	92% at 2.4 years	Two hip instability	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (8.7)
Schreiner [2022] (30)	18	89% at the last follow-up	Two PJI	0 (0.0)	2 (11.0)	0 (0.0)	0 (0.0)	0 (0.0)
Klasan [2022] (31)	70	96% at 3.5 years	Two stem subsidence, one PFF	2 (2.8)	0 (0.0)	1 (1.4)	0 (0.0)	0 (0.0)
Santiago [2021] (32)	35	97% at 3.5 years	One PJI	0 (0.0)	1 (2.8)	0 (0.0)	0 (0.0)	0 (0.0)
Schöfl [2022] (33)	80	92% at 1 year	Three PFF, one PJI, two stem subsidence	2 (2.5)	1 (1.3)	3 (3.7)	0 (0.0)	0 (0.0)
Zampieri [2023] (34)	21	86% at 3 years	One aseptical loosening, one deep infection, one PFF	0 (0.0)	1 (4.7)	1 (4.7)	1 (4.7)	0 (0.0)
Overall	710	95.35%	33 (4.65%)	5 (0.7)	9 (1.3)	6 (0.8)	7 (1.0)	6 (0.8)

PFF, periprosthetic femoral fracture; PJI, periprosthetic joint infection.

PFF incidence is higher due to an increased risk of falls and worse bone quality (43). The main goal of PFF treatment is to restore limb alignment with a stable stem allowing early mobilization and return to pre-injury function (44,45). In these situations, involving femoral bone defects, an MTTS is a useful and efficiently designed element in THR as it strengthens fixation and soft tissue, allowing anteversion and offset adjustment (44,46,47). Aseptic loosening, stress shielding, and dislocation are reduced, and it is expected that MTTS will provide an even more precise leg length measure (44-46). The most significant finding of this systematic review is that the overall survival of MTTS for

Table 3 Complications

Study	No. patients	Stem subsidence	DI	PFF	NU/AL	Hip instability	WI	DVT	WH	NP	PE	OTH	Ov. complication	Ov. reoperation	Ov. stem revision
Mulay [2005] (17)	22	2 (9.0)	1 (4.5)	1 (4.5)	2 (9.0)	5 (22.7)	0 (0.0)	1 (4.5)	0 (0.0)	1 (4.5)	1 (4.5)	0 (0.0)	14 (63.6)	4 (18.0)	0 (0.0)
Zaki [2007] (18)	37	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (5.4)	2 (5.4)	3 (8.1)	3 (8.1)	0 (0.0)	1 (2.7)	0 (0.0)	11 (30.0)	0 (0.0)	0 (0.0)
Park [2023] (19)	27	2 (7.4)	1 (3.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (3.7)	0 (0.0)	1 (3.7)	0 (0.0)	0 (0.0)	5 (18.5)	2 (7.0)	2 (7.4)
Rodriguez [2017] (20)	14	1 (7.1)	0 (0.0)	0 (0.0)	0 (0.0)	2 (14.3)	2 (14.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	5 (35.7)	3 (21.4)	1 (7.1)
Fink [2012] (21)	32	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (3.1)	0 (0.0)	1 (3.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (6.3)	0 (0.0)	0 (0.0)
Abdel [2014] (22)	44	1 (2.3)	2 (4.5)	0 (0.0)	1 (2.3)	5 (11.4)	1 (2.3)	1 (2.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	11 (25.0)	8 (18.1)	3 (6.8)
Amenabar [2015] (23)	76	NA	1 (1.3)	3 (3.9)	5 (6.6)	4 (5.2)	2 (2.6)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	15 (19.7)	10 (13.2)	7 (9.2)
da Assunção [2015] (24)	37	1 (2.7)	1 (2.7)	1 (2.7)	0 (0.0)	4 (10.8)	1 (2.7)	1 (2.7)	0 (0.0)	0 (0.0)	0 (0.0)	2 (5.4)	11 (29.7)	3 (8.1)	0 (0.0)
Hernandez-Vaquero [2015] (25)	12	NA	0 (0.0)	1 (8.3)	0 (0.0)	2 (16.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3 (25.0)	3 (25.0)	0 (0.0)
Moreta [2019] (26)	24	0 (0.0)	0 (0.0)	0 (0.0)	3 (12.5)	4 (16.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7 (29.1)	1 (4.1)	1 (4.0)
Parry [2018] (27)	61	NA	0 (0.0)	0 (0.0)	4 (6.5)	4 (6.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	8 (13.1)	5 (8.2)	2 (3.3)
Lizaur-Utrilla [2019] (28)	77	3 (3.9)	0 (0.0)	0 (0.0)	1 (1.3)	3 (3.9)	3 (3.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	10 (13.0)	1 (1.3)	0 (0.0)
Munegato [2020] (29)	23	2 (8.7)	1 (4.3)	0 (0.0)	0 (0.0)	4 (17.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7 (30.4)	2 (8.7)	2 (8.7)
Schreiner [2022] (30)	18	0 (0.0)	2 (11.0)	0 (0.0)	0 (0.0)	1 (5.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.5)	0 (0.0)	4 (22.2)	5 (27.8)	2 (11.1)
Klasan [2022] (31)	70	2 (2.8)	2 (2.8)	3 (4.3)	0 (0.0)	0 (0.0)	2 (2.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	9 (12.8)	9 (12.8)	3 (4.3)
Santiago [2021] (32)	35	4 (11.4)	1 (2.8)	0 (0.0)	0 (0.0)	2 (5.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7 (20.0)	1 (2.8)	1 (2.8)
Schöfl [2022] (33)	80	2 (2.5)	1 (1.3)	3 (3.7)	0 (0.0)	2 (2.5)	0 (0.0)	0 (0.0)	2 (2.5)	0 (0.0)	2 (2.5)	1 (1.3)	11 (13.8)	11 (13.8)	6 (7.5)
Zampieri [2023] (34)	21	1 (4.7)	1 (4.7)	1 (4.7)	1 (4.7)	0 (0.0)	0 (0.0)	0 (0.0)	5 (23.8)	0 (0.0)	0 (0.0)	0 (0.0)	9 (42.8)	5 (23.8)	3 (14.3)
Overall	710	21 (3.0)	14 (2.0)	13 (1.8)	17 (2.4)	45 (6.3)	13 (1.8)	8 (1.1)	10 (1.4)	2 (0.3)	5 (0.7)	3 (0.42)	151 (21.3)	73 (10.3)	33 (4.7)

Data are shown as n (%). DI, deep infection; PFF, periprosthetic femoral fracture; NU, nonunion; AL, aseptic loosening; WI, wound infection; DVT, deep vein thrombosis; WH, wound hematoma; NP, nerve palsy; PE, pulmonary embolism; OTH, other; Ov., overall; NA, not available.

PFF treatment was 95.4%, with an overall reintervention rate of 10.3% at an average follow-up of 4.5 years. Despite the use of modular components, postoperative hip instability remains the most frequent complication and cause of reintervention in these patients. Therefore, more consideration should be given to assessing a proper stem version, femoral head diameter size, and careful use of constrained inserts to avoid a subsequent risk of dislocation and, consequently, a high reintervention rate. In addition, a mean postoperative HHS of 78.1 was reported, which was considered acceptable given the high mean age of 74.1 years at the time of the revision.

The overall MTTS survivorship rate in THR for PFF was 95.4%. Among all included studies, six papers reported 100% overall survival; specifically, three papers considered an average follow-up between 1 and 3 years (17,21,24), two studies between 3 and 5 years of follow-up (25,28), and the last one included patients with more than 5 years of follow-up (18). To better evaluate overall survival over time, stem survivorship was analyzed according to follow-up period: stem survival was 97% in studies with an average follow-up of fewer than 3 years, 95.8% in papers with a mean follow-up between 3 and 5 years, and 93.6% in studies with an average follow-up longer than 5 years. The overall survival rate reported in this systematic review is slightly higher than that evidenced in recent case series where modularity is generally used for THR (48,49). Riesgo *et al.*, in their paper, performed THR using Stryker Restoration® modular stem and reported an overall revision rate of 14.9% at a 6-year follow-up (48). Smith *et al.* observed a similar revision rate of 18% at a 6-year follow-up in a group of patients who underwent THR with the same Stryker Restoration® modular stem (49). Several case series in which a monoblock stem was implanted in THR described outcomes similar to those in this systematic review (49-53).

Dislocation, observed in 45 THRs, was the most frequent complication in this systematic review, with a prevalence of 6.3%. In 23 patients, reoperation was required. Due to the stem component modularity, a total stem revision was necessary in only 6 cases (0.8%); in the remaining 17 patients, the exchange of a modular component was performed, and no further dislocation occurred. Modular stems allow surgeons to stabilize the hip distally with good precision and then implant the proximal component, correcting leg length and improving offset and anteversion, restoring the hip biomechanics. Modularity, separating fixation from hip biomechanics restoration, allows for a more straightforward and predictable procedure (54). These systematic review results align with the current literature, where MTTS are used for THR (12,19,55,56). Koutalos *et al.* reported a reoperation rate of 5.4% and 6.8%, respectively, in a recent systematic review that analyzed MTTS and monoblock stems in THR (12). Mahomed *et al.* described an 8.4% reoperation rate due to dislocation in THR performed with monoblock stems (57). Despite modular stem implantation, a high dislocation rate still seems challenging for patients undergoing THR; Koutalos *et al.* reported that modularity did not reduce the dislocation and re-revision rates (12). The same dislocation rate between modular and monoblock stem may be caused by the combined effects of extra scar tissue on the femur medial side and weakness or absence of abductor muscles due to previous surgeries (17). However, no data are available in the literature on the dislocation rate in THR for PFF with a monoblock stem. Further studies will be needed to better estimate the dislocation rate in this patient cohort (58).

A 3% prevalence of clinically relevant stem subsidence, defined as a movement greater than 5 mm, was described in this systematic review. Only six studies reported overall stem subsidence, including both relevant (≥5 mm) and non-relevant (<5 mm), while relevant stem subsidence was analyzed in 15 of the 18 included studies (17-22,24,26,28-34). Twenty-one stems had subsided more than 5 mm, but only five underwent surgical revision; the others were radiographically well-fixed since the last follow-up. Generally, and in line with the studies reviewed, subsidence developed in the first 6 months and then stabilized (17-22,24,26,28-34). The reason for early subsidence is presumably related to the lack of an adequate initial press fit to withstand patient loading. Critical points for stem migration prevention include firm canal filling, solid osteotomy site anchorage, sufficient stem length choice, and appropriate implant designs properties. According to Tangsataporn *et al.*, to prevent stem subsidence, adequate reaming is essential to ensure proper cortical stem contact and fixation in the femoral diaphysis (59). Koutalos *et al.* observed that MTTS in THR had a lower stem subsidence incidence than monoblock stem in THR (12).

Lastly, bone grafting should be considered for patients with poor bone stock or major femoral bone defects. Some authors have addressed the need to use cortical fibula onlay autografts in cases of poor bone stock, reporting clinical and radiological results comparable to allografts (60,61). Autograft incorporation would be more rapid, costeffective, and easy to achieve without severe morbidity at the donor site than the allograft (60).

This systematic review has several limitations. First, it was limited by the original studies' quality, the inclusion criteria variability, the methodologies for reporting the variables evaluated, and the patients' volume included. Second, the analysis may be limited by potential publication bias. Third, all these studies were case series, and different MTTS were used for THR in PFF; this does not allow for a precise analysis of the overall survival of the different modular stems (60,62). However, the causes of THR were the same in all the included studies, and this systematic review provides the strongest available evidence in the literature to date. Randomized controlled trials with an adequate number of cases and sufficient follow-up will provide more robust evidence.

Conclusions

PFF management is still a complex topic. Several therapeutic approaches and a wide variety of implants have been described in the literature; however, nowadays, no one solution has proven superior to others in the PFF treatment. In recent years, MTTS has become a commonly used treatment option for Vancouver B2 and B3 fractures because they provide good clinical and radiological results with a reasonable survival rate at an average follow-up of 4.5 years. However, the complication rate of MTTSs is still high, particularly the dislocation rate, and deserves further attention, especially for prolonged periods.

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