Review Article

Last generation fluted modular titanium stem in revision hip arthroplasty: a narrative review of mid- and long-term outcomes

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Background and Objective: Tapered fluted titanium stems (TFTS), were introduced to overcome proximal femur bone defects. They obtain stable fixation even in catastrophic proximal bone loss. Modular ones have the advantage to adjust length, rotation, off-set independently from the distal module. Short-term publications have been showing favorable outcomes burdened by an unacceptably high rate of stem failure. Still, there is a paucity of mid- and long-term reports. This narrative review aims at analyzing recent literature on modular TFTS with at least 5 years of minimum follow-up to gain a better understanding of implant survival, performance, and complications.

Methods: A search of the PubMed database was performed with selected key terms. Results were screened after the application of strict inclusion and exclusion criteria. Extracted data were subsequently evaluated to obtain an up-to-date overview of the results and complications of TFTS.

Key Content and Findings: Modular TFTS showed a consistent increase in patient reported outcomes that persists at 10 years and above. Femoral fractures were the most common intraoperative complication. Despite modularity, dislocation still occurs at a variable rate (1.2–12%). With revision for any cause as an endpoint, overall survival approaches 83% after 10 years of follow-up. If femoral revision only is evaluated, excellent survival rates (>95%) have been published. Stem subsidence over 5 mm was reported in less than 5% of patients, only 1 requiring femoral revision. The mean incidence of stem mechanical failure was 3.39%, although most breakages occurred in stems eventually retired from the market.

Conclusions: Satisfactory survival rates were observed, with an acceptable rate of complications. Stem mechanical failure, excluding those stems eventually retired from the market, remains a marginal event. Therefore, the use of modular TFTS in revision surgery is safe and effective even in the long term.

Keywords: Modular stem; revision stem; revision total hip arthroplasty (revision THA); stem survival; stem fracture

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Introduction

Given the increasing number of total hip arthroplasties (THA) performed in the last decades and the aging population, it's not surprising that the number of revision THA surgeries are increasing as well. Indeed, a 70% increment in performed procedures is expected by 2030 (1).

Revision surgery remains a difficult challenge with several difficulties to overcome. From the femoral side aseptic loosening and periprosthetic fractures are second only to periprosthetic joint infection as a cause of revision (2).

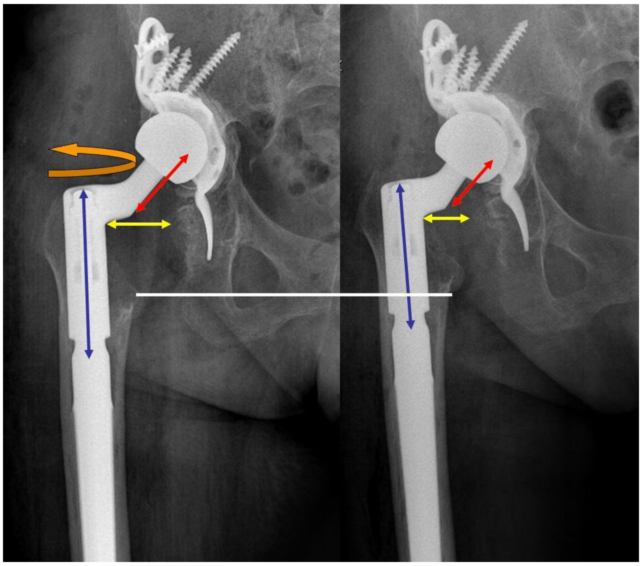

Figure 1 Comparison of pre- (right) and postoperative (left) re-revision for stem instability shows the great advantage of modularity: the distal diaphyseal tapered stem module has been maintained while the proximal body replaced with a new one to increase length, vertical and lateral offsets and antetorsion, thus sparing the patient a much more invasive surgery. Orange arrow: increased antetorsion; red and yellow arrows: increased offset; blue arrow: increased proximal body length; white line: increased leg length.

Monoblock tapered fluted titanium stems (TFTS) were first introduced in the late 1980's by Wagner (3) to overcome the main challenge in femoral revision. The loss of bone proximal support. It was a kind of revolution and cases until then inoperable could be treated. Unfortunately, undersizing with stem subsidence, a valgus neck and difficulty in judging the appropriate ante-torsion produced a high rate of subsidence and dislocation (4).

Modular TFTS were designed and introduced in the market around 20 years ago to partially solve such problems. They are composed of a proximal porous body and a fluted distal stem. The fluted distal stem is inserted first. It is shaped to obtain immediate axial and rotational stability due to the tapered design. It usually comes in different lengths and can be either straight or bowed. The proximal porous body is available in different forms and sizes and with multiple lengths and/or offsets. Often, the proximal body surface is plasma sprayed, microporous or hydroxyapatite-coated, to stimulate osteointegration. The two pieces are finally joined on the field by a taper lock and a bolt.

Thanks to a modified fluted geometry, modular TFTS can optimally engage even in diaphyseal segments shorter than 4 cm (5), guaranteeing optimal resistance to axial and rotational forces, lowering the incidence of clinically significant subsidence with respect to monoblock stems (6). The same design also reduces the incidence of thigh pain and fractures (7). The possibility of inserting the proximal body on a well-fixed distal component allows for the independent correction of version, offset, and length, thus maximizing stability while minimizing leg length discrepancies. This can be achieved even in a second stage surgery, as in case of recurrent dislocation (*Figure 1*). Finally, (FMT) stems have shown less proximal stress shielding compared to older stems, probably because of the lower elasticity modulus of titanium and the increased proximal body-bone contact granted by modularity (8).

Therefore, it is not surprising that modular TFTS are used most successfully in cases of severe diaphyseal bone loss (*Figure 2*), particularly in defects categorized as type III and IV according to Paprosky (9). Similarly, they can be effectively used in cases of peri-prosthetic fractures B2 and B3 (10), where the proximal cortical support has been lost (11).

Unfortunately, a modular design is not free of complications. Mainly mechanical. Modular stems are at risk of failure at the taper junction (12). Fink (13) described a typical failure pattern where integration can be observed distally while the proximal cortical support is missing. The bending forces where the two components join may lead to failure, particularly in the case of high body mass index (BMI). Stem fractures have also been linked to older designs and small stem sizes (14). Finally, there have been reports of stem failures in cases where an extended trochanteric osteotomy (ETO) has been utilized, although reports in the literature are conflicting (15). Even if modular stems are the most used device today in common practice for complex stem revision cases, there is still a lack of medium and long-term results in a wide cohort of patients, in literature (14). The following narrative review aims to collect and analyze the more recent literature on modular TFTS with a minimum of 5 years of follow-up and to provide an overview of the performances and complications of these implants. We present this article in accordance with the Narrative Review reporting checklist (available at https://aoj.amegroups.com/article/view/10.21037/aoj-23-35/rc).

Methods

Extensive research of the PubMed database was executed between January 2nd to February 16th using the following

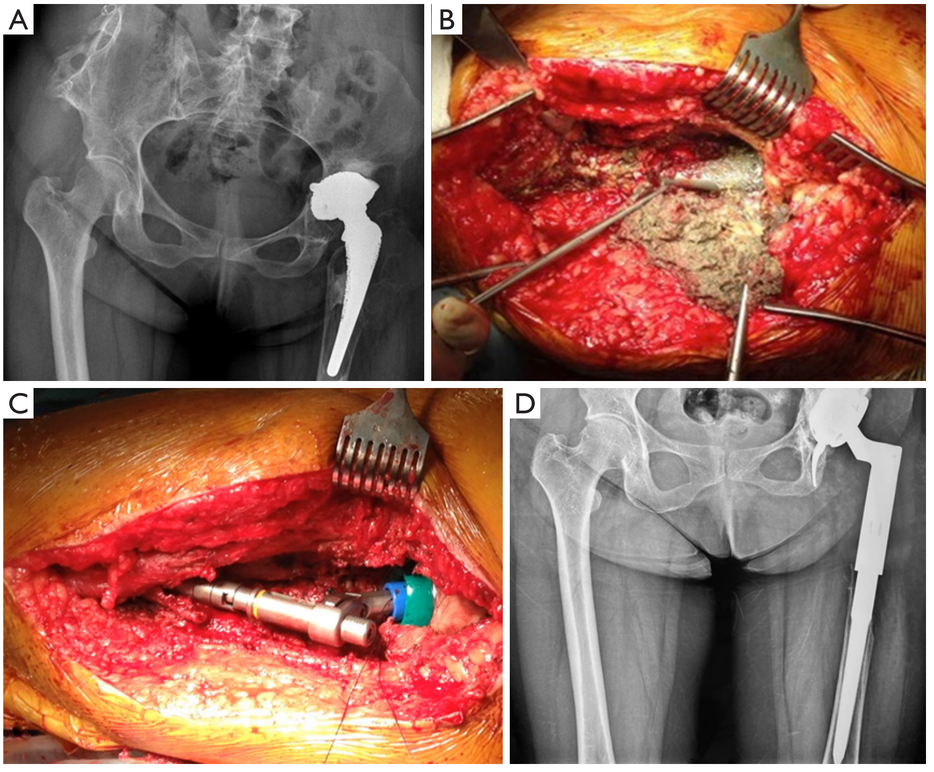

Figure 2 Successful total hip revision with a tapered fluted modular titanium stem in presence of massive proximal femoral bone loss. (A) Periprosthetic fracture of the greater trochanter in the context of massive proximal femoral osteolysis (Paprosky type 3B). (B) Revision through an extended lateral approach was performed and complete proximal femoral reabsorption with abundant metallosis was found. (C) a Reclaim modular tapered stem (Depuy, Warsaw, IN, USA) was implanted allowing to bridge the extensive bone loss, here shown with the trial components. (D) Follow-up X-ray at 7 years from surgery shows good implant integration.

terms: "tapered stem"[Title/Abstract] OR "revision femoral component"[Title/Abstract] OR "modular stem"[Title/Abstract] OR "tapered fluted stem"[Title/Abstract] AND "revision total hip"[Title/Abstract] OR "revision femoral"[Title/Abstract] OR "femoral revision"[Title/Abstract] OR "revision arthroplasty"[Title/Abstract].

Date restriction was applied, including only studies published in the last 10 years [2013–2023]. The search did not include studies published in non-English language abstracts from congresses and gray literature. When more than one study was available on the same cohort of patients, the one with the longer follow-up was included. After articles were found, additional manual screening of the references of the selected articles was performed to include papers that had been missed out.

Two authors (M.V. and G.B.) independently screened the titles, abstracts, and whole texts to evaluate for relevant papers according to the selection criteria. Chosen studies reported on the outcome of fluted, modular, titanium stems after total hip revision for either aseptic loosening or periprosthetic fracture. Exclusion criteria were the following: minimum follow-up inferior to 5 years, non-aseptic revision, case reports and reviews, non-human studies, and studies reported in languages other than English.

The search strategy is summarized in *Table 1*.

Results

A first screen of the PubMed database yielded 108 papers (*Figure 3*). After abstract revision, 38 were selected for their relevance. Additional four papers were included after carefully revising the selected articles' references. After the application of the exclusion criteria, a total of 15 papers were left for review (*Table 2*).

Overall, modular TFTS guarantee an appreciable and clinically relevant improvement of patients' function. Most

Table 1 The search strategy summary

Items	Specification
Date of search	2/1/2023–16/2/2023
Databases and other sources searched	PubMed
Search terms used	"tapered stem"[Title/Abstract] OR "revision femoral component"[Title/Abstract] OR "modular stem"[Title/Abstract] OR "tapered fluted stem"[Title/Abstract] AND "revision total hip"[Title/Abstract] OR "revision femoral"[Title/Abstract] OR "femoral revision"[Title/Abstract] OR "revision arthroplasty"[Title/Abstract]
Timeframe	2013–2023
Inclusion and exclusion criteria	Inclusion criteria: outcome of fluted, modular, titanium stems after total hip revision for either aseptic loosening or periprosthetic fracture
	Exclusion criteria: minimum follow-up inferior to 5 years, non-aseptic revision, case reports and reviews, non-human studies, and studies reported in languages other than English
Selection process	Two authors (M.V. and G.B.) independently screened the titles, abstracts, and whole texts to evaluate for relevant papers according to the selection criteria. When more than one study was available on the same cohort of patients, the one with the longer follow-up was included. After articles were found, additional manual screening of the references of the selected articles was performed to include papers that had been missed out

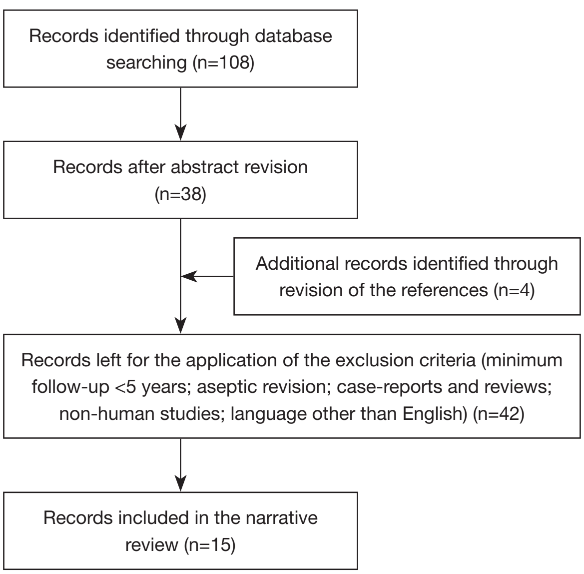

Figure 3 Flowchart of the literature search is shown. PubMed was the explored database.

of the included studies evaluated (PROMs) through the application of the HHS. When evaluated with a minimum follow-up of 5 years, the mean improvement in HHS score was 35.6 [standard deviation (SD), ±9.33]. If only studies with >5 years of follow-up are considered, the pooled improvement in HHS was 34.2 (SD, ±9.98); while over 10 years, the mean improvement from baseline scores remained 29.38 (SD ±11.5). These data show how modular TFTS guarantee durable and reliable good outcomes even after many years, as demonstrated by Valtanen (16) and Domoulin (17), reporting two case series with a minimum of 14- and 12-year follow-up, respectively.

Intraoperative fractures remain a significant concern utilizing modular TFTS. While they seem less aggressive than fully coated metadiaphyseal long stems (18), some studies have noticed a higher risk than monoblock tapered ones (19). Cortical perforations, longitudinal cracks and fractures of the greater trochanter are the most commonly described (*Figure 4*). The incidence varies significantly in literature. Feng and Park reported intraoperative fracture rates as high as 16.7% and 11.8% (19,20), while others described none (7). Some authors attribute this difference to an individual tendency toward a more aggressive search for the "fit and fill" (21). Clearly, osteoporosis and amount of bone loss have been recognized as risk factors for this complication (22). Other predisposing conditions include excessive anterior femoral bowing and the use of stem with a diameter superior to 18 mm or longer than 200 mm (23). In patients with increased risk, it may be beneficial to adopt strategies such as prophylactic cable wiring, bowed distal module, flexible reamers, and a transversal distal osteotomy.

Dislocation remains a major complication of hip revision surgery (24). The possibility of modular stem to adjust the proximal component length and version should reduce this complication. Nevertheless, dislocation still occurs

Table 2 Mid- to long-term follow-up of modular fluted titanium stems in revision hip arthroplasty

Study	Description		Postoperative outcomes		
	No. of hips	Mean follow-up (years)	Mean improvement in Harris Hip Score (points)	Overall survivorship* (%)	Stem survival for stem related revisions only (%)
Valtanen *et al.* [2023]	21	14–18.5	22	86	96.3
Park *et al.* [2022]	72	16	42	91	NA
Willems *et al.* [2022]	30	5	–	87	NA
McInnes *et al.* [2021]	78	11.1	30	88	NA
Perticarini *et al.* [2021]	62	8.5	35	92	NA
Zheng *et al.* [2021]	34	9.1	43	95	NA
Feng *et al.* [2020]	108	8.5	46	95	NA
Schwarze *et al.* [2020]	53	6	47	87	NA
Kang *et al.* [2018]	48	7.9	32	98	NA
Dumoulin *et al.* [2018]**	24	14.5	28	75	NA
Sivananthan *et al.* [2017]	68	11	42	90	NA
Wirtz *et al.* [2014]	163	10	42	97	NA
Fink *et al.* [2014]	121	7.5	42	91	95.7
Rodrieguez *et al.* [2014]	71	10	37	89	95.6
Van Houweling *et al.* [2013]	49	7	–	84	NA

*, overall survivorship was calculated with re-revision (cup and/or stem) for any reasons at the endpoint; **, Dumoulin *et al.* reports only fracture-free survival. NA, not available.

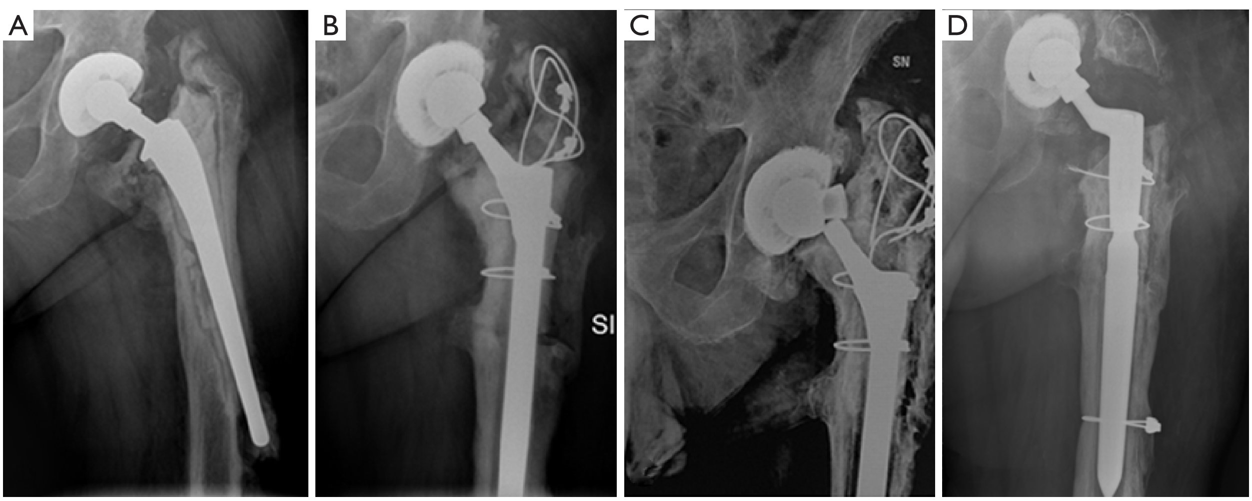

Figure 4 Given the complexity of the surgery and the scarce bone stock, intraoperative fracture may occur with tapered modular titanium stems. (A) Failure of a cemented revision stem with perforation of the lateral cortex. (B) Re-revision with a Wagner SL Revision Stem (Zimmer-Biomet, USA). (C) 10 years after, subsidence and an excessive bone deposition led to disassembling of the head from the stem neck. (D) Re-re-revision was performed with a Reclaim stem (Depuy, Warsaw, IN, USA).

Table 3 Reasons for re-revision across the studies analyzed

Study	Aseptic loosening	Instability	Periprosthetic fracture	Infection	Dislocation	Mechanical failure	Subsidence	Acetabular failure	Trunnionosis	Total (n)
Valtanen *et al.* [2023]	–	1 (12.5)	–	1 (12.5)	1 (12.5)	–	–	5 (62.5)	–	8/21
Park *et al.* [2022]	1 (16.7)	–	–	3 (50.0)	–	2 (33.3)	–	–	–	6/72
Willems *et al.* [2022]	–	–	–	–	1 (20.0)	2 (40.0)	2 (40.0)	–	–	5/30
McInnes *et al.* [2021]	9 (47.4)	–	1 (5.3)	5 (26.3)	–	2 (10.5)	1 (5.3)	–	1 (5.3)	19/78
Perticarini *et al.* [2021]	–	–	2 (40.0)	–	–	–	–	3 (60.0)	–	5/62
Zheng *et al.* [2021]	1 (33.3)	–	–	1 (33.3)	1 (33.3)	–	–	–	–	3/34
Feng *et al.* [2020]	–	–	2 (40.0)	1 (20.0)	–	2 (40.0)	–	–	–	5/108
Schwarze *et al.* [2020]	3 (50.0)	–	–	2 (33.3)	–	1 (16.7)	–	–	–	6/53
Kang *et al.* [2018]	–	–	–	1 (100.0)	–	–	–	–	–	1/48
Dumoulin *et al.* [2018]	–	–	–	4 (50.0)	–	2 (25.0)	–	2 (25.0)	–	8/24
Sivananthan *et al.* [2017]	1 (14.3)	–	1 (14.3)	2 (28.6)	–	1 (14.3)	–	2 (28.6)	–	7/68
Wirtz *et al.* [2014]	–	–	1 (50.0)	1 (50.0)	–	–	–	–	–	2/163
Fink *et al.* [2014]	–	–	–	4 (44.4)	2 (22.2)	–	–	3 (33.3)	–	9/121
Rodrieguez *et al.* [2014]	–	3 (37.5)	2 (25.0)	1 (12.5)	–	1 (12.5)	–	1 (12.5)	–	8/71
Van Houweling *et al.* [2013]	–	–	–	–	–	5 (100.0)	–	–	–	5/49

Data are presented as n (%).

at a variable rate. This could be ascribed to the fact that modular stems are preferentially chosen in severe bone and soft tissue defects, a recognized risk factor for dislocation. The overall reported incidence in the analyzed studies was 5.6% (SD, ±6.14%). Interestingly, the highest number of dislocations has been reported by Wirtz (n=20, 12%), who reported being in line with the published literature at that time (25). Considering only studies produced in the last 5 years (19,20,22,26,27), the overall dislocation rate drops to 2.6% (SD, ±2.7%). This difference can be hypothetically attributed to surgical techniques and tribology improvements, like the introduction of 36 mm heads and dual mobility couplings.

In this narrative review, few studies reported long-term survival of the stem only having, instead, any re-revision as an endpoint. Reasons for re-revisions differ across various investigations. The most commonly reported ones include acetabular revision, periprosthetic joint infections, periprosthetic fracture, mechanical stem failure and aseptic loosening (*Table 3*). A mean overall re-revision rate, meaning cup and/or stem, of 82.18% (SD, ±7.4%) at more than 10 years (range, 10.2–23 years), have been deducted (16-18,20). The few studies who focused on the survival of the only stem reported very good results. Fink *et al.* noticed a 95.7% stem survival rate at a mean of 7.5 years of follow-up, increasing to 100% if the endpoint was set to only aseptic loosening (7). A similar result was found by Rodriguez: 95.6% survival rate for stem re-revision with a mean follow-up of 10 years, and a 98.4% survival rate if mechanical stem failure were excluded (28). More recently, Park described a stem survival rate of 94.6% for aseptic loosening at a mean follow-up of 16 years, while Valtanen and its group reported a 96.3% stem survival rate up to 18 years of follow-up (16,20).

Historically among the concerns regarding these implants, stem subsidence is one of the more feared (*Figure 5*). Across the literature, this complication has been reported with a frequency varying wildly from 0.64 to 16 mm (29). Indeed, Parry *et al.* tried to evaluate the possible reasons for stem subsidence. Among the various parameters considered, the only association that could be established was with Dorr type C femurs and the use of structural grafts, both related to bone loss severity (30). In this review, 7 out of 15 studies reported a subsidence (19,20,22,26-28,31), with an average of 4.2 mm (SD, ±4.05 mm). Stem subsidence greater than 5 mm was reported only in 34/648 of cases, 5% of the total. Interestingly, only one subsided stem required a revision (17). So, a clinically relevant stem subsidence seems quite rare and

Figure 5 On the left a Reclaim stem (Depuy, Warsaw, IN, USA) on the post-operative X-ray. On the right the same stem at 3 months post-surgery. The white arrows quantify stem subsidence.

usually not significant for stem survival.

Mechanical stem failure in modular TFTS is the main argument from detractors when advocating for monoblock stems. Biomechanical studies have recognized junctional areas as weak spots (32). Indeed, 8/15 of this review studies reported at least one stem fracture (7,17-20,27,28,31). The incidence was 3.40% (22/648). However, 12 out of 22 stem fractures have been reported in just two studies. Van Houwelingen noted this complication in 7.7% (5/65) of patients implanted with a standard ZMR stem (Zimmer, Warsaw, IN, USA) (31). This stem has been removed from the market and replaced by the ZMR-XL (Zimmer, Warsaw, IN, USA), provided with a reinforced junction. Fractured stems were more likely to be implanted in obese patients (BMI >30 kg/m^2), to have a smaller diameter, and through an ETO. Conversely, Dumoulin did not have any aforementioned patient-related risk factors in their 7 stem fractures over 48 implanted PFMR modular stems (Protek, Sulzer Orthopaedics, Sulzer Orthopaedics, Austin, TX, USA) at a mean of 14.5 years of follow-up (17). Interestingly, also this stem has been removed from the market. The other published studies were related to more modern stems, with consistently lower incidences of mechanical failure.

Anyway, the intrinsic weakness of modular stems has led to a renewed interest in monoblock tapered stems, less prone to this complication. Some surgeons propose that monoblock stems should be preferred in "simpler" revision surgeries, where the size of bone defect is contained (33). A multicenter study from Huddelston *et al.* evaluated over 416 femoral revisions, classified as Paprosky type 1 to 3A, performed at three different centers, failed to recognize any difference in outcomes between modular and non-modular tapered stems (34). In line with these results, a recent systematic review of the literature comparing modular and monoblock stems reported similar rates of re-revision, dislocation, periprosthetic fracture, and infection (6). Nonetheless, modular stems showed a higher frequency of intraoperative fractures, while monoblock stems were more likely to subside (6,19).

The strength of this narrative review lies in the fact that it represents a comprehensive overview on the most recent available literature on the medium and long-term outcomes of modular TFTS. It summarizes in relatively few words the current state of the art on the topic and it outlines its future trends. Furthermore, its rather flexible inclusion criteria and scope of the review give the opportunity to diversify the sources and answer several, different questions in regard to modular TFTS. In turn, this may prompt readers toward generating new ideas, further driving the expansion of the field.

On the other side, lack of a rigorous systematization typical of systematic reviews makes this study more prone to bias. Indeed, selection of articles and evaluation of quality did not follow a structured process as requested for systematization. The interpretation of the literature and the synthesis of findings cannot therefore be objective and its dependent on the author's perspective, potentially introducing bias. Thus, this limits the generalizability of the present work, as it is based on diverse types of studies with different methodologies.

Conclusions

Modular TFTS have gained popularity in recent years and now represent the most favored implant solution in femoral revision surgery complicated by extensive bone loss and proximal bone remodeling. The possibility of obtaining immediate axial and rotational stability of the distal component while independently adjusting for version and soft tissue tension with the proximal segment allows for a reduction in dislocation and leg length discrepancy. Short-term publications have been showing favorable outcomes with a relatively low rate of complications, although a few studies reported an unacceptably high rate of mechanical stem failure. Data from our narrative review revealed an overall, cup and stem, survival of 91.26% at 10 years and 82.18% at more than 10 years, when revision for any cause was taken as the endpoint. All studies evaluating only femoral stem re-revision showed survival of almost 100% in midterm and >95% above 10 years of follow-up. Stem mechanical failure, excluding studies reporting on stems that have been eventually removed from the market, remains a marginal complication. Therefore, modular TFTS in revision arthroplasty surgery are safe and effective even in the long term.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://aoj.amegroups.com/article/view/10.21037/aoj-23-35/coif). The series "Modular Implants for Revision Arthroplasty in Orthopedics" was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All clinical procedures described in this study were performed in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for the publication of this article and accompanying images.

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