The Journal of Arthroplasty 28 (2013) 690–694

Contents lists available at SciVerse ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Results of Revision Total Hip Arthroplasty with Modular, Titanium-Tapered Femoral Stems in Severe Proximal Metaphyseal and Diaphyseal Bone Loss

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ARTICLE INFO

Article history:
Received 18 April 2012
Accepted 15 August 2012

Keywords:
total hip arthroplasty
revision
tapered femoral stems

ABSTRACT

Evidence supporting modular, tapered stems for severe proximal metaphyseal and diaphyseal bone loss is limited. We report our clinical experience with its use for severely deficient femurs. Of 211 revision total hip arthroplasties (THAs), 18 tapered, modular titanium stems were implanted in Paprosky type III and IV femurs. Clinical data were reviewed for function, stability, structural failure and revision surgery at a mean follow-up of 4.5 years. The overall survival rate was 94%. One required revision due to infection and subsidence. The mean subsidence was 3.5 mm and the mean pre- and post-operative Harris Hip score was 56 and 79, respectively. In surviving cases, patients achieved satisfactory function and there were no mechanical failures. Modular, tapered stems demonstrated acceptable outcomes for management of severe proximal metaphyseal and diaphyseal defects.

Revision total hip arthroplasty (THA) for severe proximal metaphyseal and diaphyseal bone loss include long cemented stems, monoblock cementless cobalt–chrome porous stems [1–3], monoblock-tapered fluted titanium stems (e.g. Wagner SL stems (Sulzer Orthopaedics, Barr, Switzerland)) [4–6], impaction grafting techniques [7,8] and modular stems which are fixed distally then mated with a variety of proximal bodies. A precipitous rise in revision THAs is anticipated over upcoming decades [9] and will require implant constructs and techniques that can address severe proximal femoral bone loss.

Cementation relies on interdigitation into cancellous bone for initial and long-term stability. Proximal bone and cancellous bed loss combined with endosteal sclerosis compromises fixation of cemented femoral revision [10,11]. Extensively porous-coated cylindrical monolithic stems rely on diaphyseal interference fit for initial fixation and subsequent biologic ingrowth for long-term stability. These constructs are an excellent option in many revision scenarios [1–3] specifically for Paprosky type I, II and IIIA-deficient femurs. However when proximal bone deficiency extends to the diaphysis (Paprosky type IIIB and IV femurs) fixation is compromised, intraoperative fractures are prevalent and axial instability and subsidence diminish their utility. Additionally, with only head neck modularity, monolithic stems have limited ability to adjust anteversion, leg length and offset. The stiff modulus of cobalt–chrome stems are associated with thigh pain and proximal stress shielding (particularly with larger-diameter stems) [12]. Titanium monoblock-tapered fluted stems, such as the Wagner SL (a predecessor to current modular designs) are viable options for severe proximal bone loss [4–6,12]. The tapered geometry wedges itself into the diaphyseal endosteum and flutes provide rotational stability. Reduced thigh pain and restoration of proximal femoral bone stock [4–6,13] has been reported with their use. However, implant subsidence in cases of severe metaphyseal and diaphyseal bone loss, such as Paprosky type IIIB and IV femurs, remains a problematic issue [14].

Modular–tapered fluted designs increase stem versatility, by achieving distal fixation into diaphyseal bone and independent adjustment of anteversion, length and neck offset with modular proximal body components. The short and midterm results are promising yet outcome data regarding their use for severe proximal metaphyseal and diaphyseal bone loss (Paprosky IIIB and IV) are limited [15–17]. Implant fracture at the modular junction with structurally unsupportive proximal bone has been reported and is a source of concern [18–22]. In this report we examine clinical and radiographic results of modular, tapered, fluted titanium stems for management of severe proximal and diaphyseal bone loss. Technical factors impacting implant stability and clinical outcome are discussed.

The Conflict of Interest statement associated with this article can be found at http://dx.doi.org/10.1016/j.arth.2012.08.019.

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0883-5403/2804-0030$36.00/0 – see front matter
http://dx.doi.org/10.1016/j.arth.2012.08.019

Materials and Methods

Implant

The Restoration (Stryker; Mahwah, New Jersey) modular stem (Fig. 1B) consists of three components; a cobalt chromium (CoCr Va40) or ceramic femoral head, titanium alloy (Ti-6Al-4V) proximal cylindrical body and diaphyseal engaging fluted conical stem. The body is textured with a titanium plasma-sprayed surface and a hydroxyapatite (HA) coating with four possible body lengths ranging from 70 to 100 mm at 10-mm increments. Offset is defined by four body diameters: 19-mm-diameter body with a 34-mm offset, 21-mm body with a 36-mm offset, 23-mm body with a 40-mm offset and a 25-mm body with a 44-mm offset. Anteversion, leg length and offset can all be adjusted independently of the distal stem by proximal body selection and orientation. In our series one 19-mm-diameter body and two 21-mm, six 23-mm and nine 25-mm bodies were implanted. The conical, diaphyseal engaging stem is fluted to provide immediate axial and rotational fixation. Straight or "kinked" geometries are available to accommodate the diaphyseal contour. It has a grit-blasted titanium surface with three stem lengths: 155, 195 and 235 mm. In this series the mean stem diameter was 20 mm (range, 16–26 mm) and lengths were one 155-mm, five 195-mm, and twelve 235-mm. Two were straight and 16 were "kinked."

Patients and Surgical Procedure

From January 2005 to July 2008, 211 revision THAs were performed by two surgeons at one institution. Of these, 22 cases in 21 patients were identified as Paprosky type IIIB or IV femurs using radiographs and intraoperative observation and were treated with Restoration modular stems. Patients consisted of 11 (50%) females and 10 (45%) males with a mean age of 71 years (range, 40–82 years) (Fig. 2). The mean body mass index (BMI) was 28 (range, 20–44 kg/m^2). The primary outcome measures were re-operation due to clinical or implant mechanical failure. Prospectively collected clinical data were reviewed retrospectively including Harris Hip scores (HSS) and telephone surveys were performed to rate post-operative satisfaction as unsatisfied, partially or

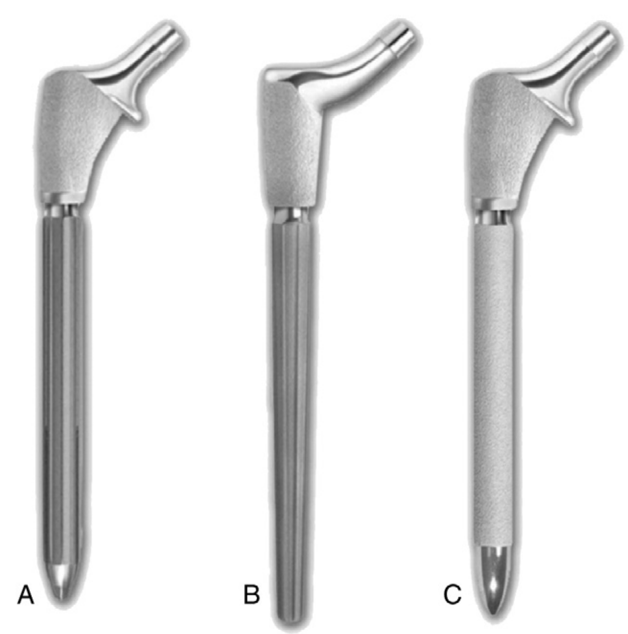

Fig. 1. Restoration modular revision stem system courtesy of Stryker Orthopaedics (Mahwah, New Jersey). Cylindrical fluted (A), tapered fluted (B—implant used in this series) and fully coated cylindrical stems (C).

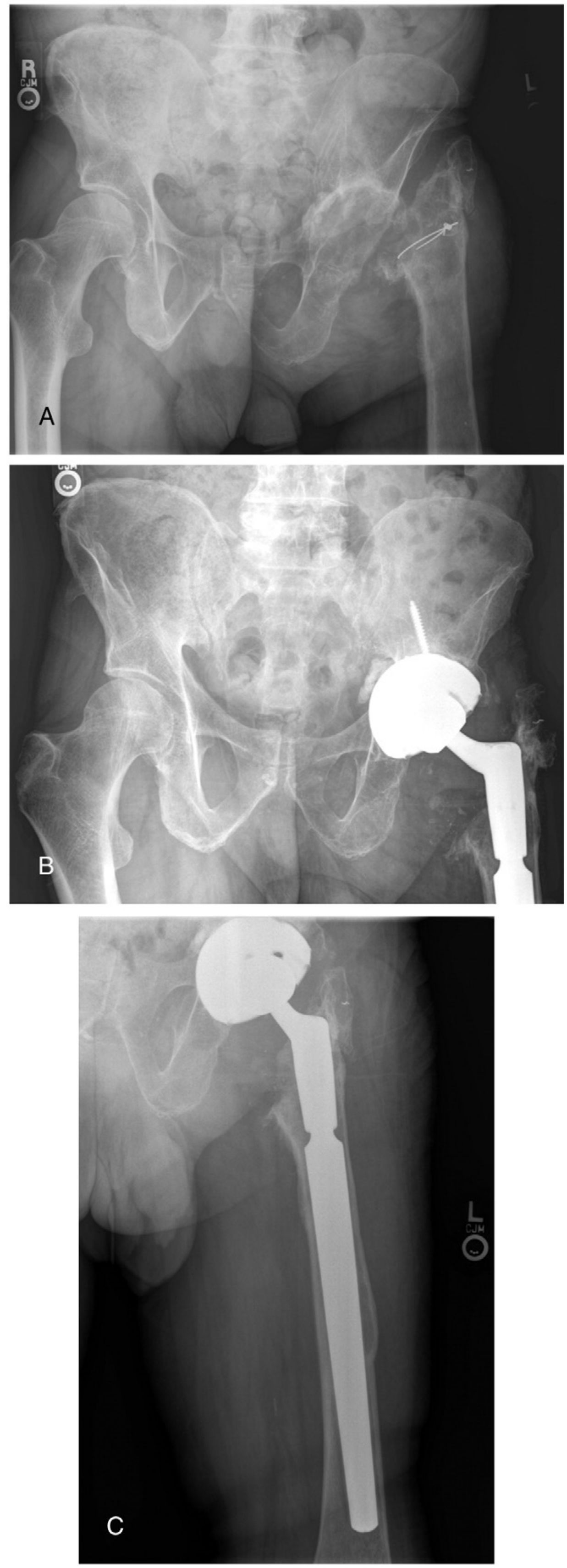

Fig. 2. (A) Pre-operative radiograph of a 73-year-old female with Paprosky type IV femur. Post-operative radiographs of the pelvis (B) and left femur (C) after revision THA with a Restoration modular stem.

completely satisfied. Inclusion criteria included a minimum follow-up of 2 years, which excluded four patients due to inadequate follow-up, leaving 18 cases for final analysis.

Revision indications were as follows: aseptic loosening in 10 (56%) patients, second-stage reimplantation for periprosthetic infection in 6 (33%) and periprosthetic fracture in 2 (11%) patients. Pre-revision stem fixation was polymethyl methacrylate (PMMA) cement in 10 hips (56%) and proximal porous-coated stems in 8 (44%) hips. At revision, osteotomies were performed in 66% of cases for component explantation. This included extended trochanteric osteotomy (ETO) in 5 (28%), transfemoral diaphyseal osteotomy in 3 (17%) and exposure through a greater trochanter fracture in 2 (11%) cases. Transverse femoral osteotomies were performed to preserve the proximal femoral tube in circumstances where cement was easily removed proximally but was fixed distally. It consists of a diaphyseal osteotomy in the transverse plane at the level of the fixed cement [23,24]. In two cases, a greater trochanter fracture was encountered during the surgical exposure. The fracture was exploited in a manner similar to a trochanteric osteotomy or ETO and was completed by fracture fragment fixation with cables or a trochanteric claw plate with the addition of allograft when deemed appropriate. Cerclage cables were used in 14 (78%) cases for either osteotomy repair or for fracture prophylaxis during reaming and stem implantation. Femoral stem size was chosen intraoperatively based on the surgeon's tactile sense of canal fill during reaming.

Radiographic Analysis

Post-operative radiographs were performed in the recovery room, at 2-3 weeks, 6 weeks, 3 months, 6 months and then annually. Two independent reviewers evaluated x-rays for mechanical failure, radiographic loosening and subsidence. All measurements were performed using MedView imaging software (MedImage, Ann Arbor, MI). Component subsidence was assessed by measuring the distance from the center of the femoral head (COH) to the tip of the greater trochanter (Fig. 3). The measurement difference between immediate post-operative radiographs and radiographs at final follow-up represented the measured subsidence. All measurements were corrected for magnification (reference: actual head size compared to radiographic head size) to determine the true subsidence.

Statistical Analysis

Two-tailed Student's *t*-test was performed to evaluate the association of the grade of femoral deficiency (Paprosky types IIIB and IV) and the use of cerclage cables on component subsidence. The same test was used to evaluate the statistical significance of pre- and post-operative HHS improvements.

Results

A total of 18 cases were included in the final analysis. Eleven (61%) were classified as IIIB and 7 (39%) as type 4 femurs. The mean follow-up was 4.5 years (range, 2–6 years) (Table).

The mean pre-operative and post-operative Harris Hip scores improved from 56 (range, 30–79) to 79 (range, 43–100) ($p = 0.0006$). Four (22%) patients achieved an excellent HHS (>90), 7 (39%) good HHS (80–89), 3 (17%) fair HHS and 4 (22%) poor HHS. Telephone questionnaires demonstrated all but one patient to be completely satisfied with their outcome. The one unsatisfied patient underwent a resection arthroplasty for a chronic periprosthetic infection and symptomatic subsidence 5 years post-operatively. The overall implant survival rate at final follow-up was 94%.

The mean radiographic subsidence of patients with Paprosky type IIIB and IV deficiencies was 3.6 mm (range, 1–9.8 mm) and 3.8 mm (range, 3–4 mm), respectively ($p = 0.843$). In one case subsidence measured 8 mm post-operatively yet she remained asymptomatic and was satisfied with her result with a HSS score of 100 at final follow-up. The single clinical failure had 1 cm of subsidence, a post-operative HHS of 40 and a clinical work-up consistent for a chronic periprosthetic infection. Intraoperatively she had severe femoral bone loss and reconstruction necessitated a total femoral replacement. She elected not to proceed with reimplantation. Prior to explantation the femoral stem (17-mm diameter) was radiographically deemed undersized diametrically due to lack of implant–diaphysis endosteal contact. This finding was supported intraoperatively when the stem was easily extracted with little osseous ingrowth after 5 years.

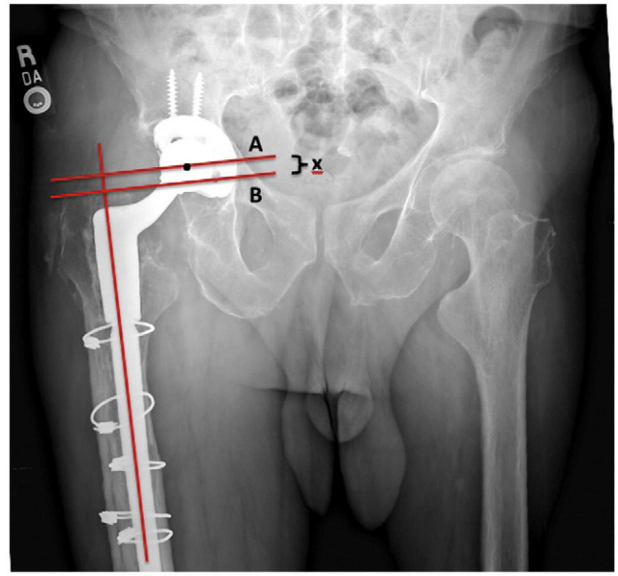

Fig. 3. Subsidence was determined by measuring the distance from the center of the femoral head (A) to the tip of the trochanter (B) immediately post-operatively and at final follow-up. Magnification was corrected by comparing the actual and radiographically determined femoral head sizes.

Cerclage cables were used in 78% of cases. The mean subsidence with cerclage cables was 3.6 mm (range, 1–9.8 mm) and 3.2 mm (range, 1.6–4.8 mm) without cables ($p = 0.642$). No clinical or radiographic evidence of implant, more specifically, modular junction structural failure was observed in our series.

Discussion

This series is the largest to date that specifically evaluates modular, tapered fluted stems for major proximal metaphyseal and diaphyseal bone loss categorized as Paprosky type IIIB and IV femoral deficiencies [25,26]. Successful functional outcomes were observed as indicated by a mean increase of 23 points in the HHS. The overall implant survival was 94% at a mean follow-up of 4.5 years. These results compare favorably to other reports of similar implants for treatment of high-grade femoral deficiencies [15,27]. Mcinnis et al. [27] reported a series of 130 femoral revisions treated with modular tapered stems. Subsidence was common occurring in 84% of cases however subcategorical analysis of subsidence based on the degree of bone loss was not performed.

Clinical outcomes and implant survival in the setting of severe femoral bone loss are intimately related to component design and technical considerations. Extensively porous-coated cylindrical stems achieve axial and rotational fixation through interference fit with endosteal bone, which is strictly dependent on surface roughness, fit and contact. In the case of IIIB femurs, only 5 cm of bone is available for interference fixation prior to isthmal divergence and in type IV femurs the diaphysis is ectatic with little area for interference fixation. Axial instability and subsidence of cylindrical stems is

Table
Clinical and Demographic Data Including Patients Treated with Modular Tapered Fluted Titanium Stems.

Patient	Gender	Age (years)	Paprosky Class.	Follow-Up (years)	Indication for Revision	Initial Fixation Mode	Osteotomy	Cerclage Cable	Subsidence (mm)	Body Diameter (mm)	Stem Diameter (mm)	Stem Length (mm)	Failure or Revision	Pre-op HHS	Post-op HHS
1	M	56	3b	5.6	Infection	Prox. ingrowth	N/A	No	1.6	23	23	195	No	*	77
2	F	57	3b	4.6	AL	Cement	N/A	Yes	1.7	23	19	235	No	59	89
3	M	82	3b	5.6	PF	Cement	TFD	Yes	1.9	25	17	235	No	42	59
4	M	74	3b	4.8	AL	Cement	N/A	No	2.3	25	20	195	No	73	100
5	F	71	3b	4.4	AL	Prox. ingrowth	Troch fracture	Yes	9.8	25	17	235	Infection/ Subsidence	*	43
6	F	84	3b	6.2	Infection	Prox. ingrowth	TFD	Yes	2.9	21	18	195	No	73	81
7	M	80	3b	2.2	AL	Cement	ETO	Yes	7.5	21	18	235	No	*	100
8	M	66	4	5.4	AL	Prox. ingrowth	N/A	Yes	3.0	19	23	155	No	46	82
9	F	71	4	5.5	Infection	Prox. ingrowth	ETO	Yes	3.3	23	20	235	No	*	77
10	M	84	4	4.1	AL	Cement	TFD	Yes	4.1	23	17	235	No	44	86
11	F	67	4	2.3	PF	Cement	N/A	Yes	3.9	25	22	235	No	*	63
12	F	70	3b	3.3	AL	Cement	N/A	Yes	2.4	23	16	195	No	79	92
13	F	43	3b	3.3	Infection	Prox. ingrowth	ETO	Yes	4.1	25	18	235	No	*	75
14	M	65	4	3.3	Infection	Prox. ingrowth	N/A	No	4.8	23	23	235	No	60	88
15	F	73	3b	5.1	Infection	Cement	Troch fracture	Yes	0.7	25	17	195	No	30	85
16	F	67	3b	2.3	AL	Prox. ingrowth	N/A	No	4.1	25	22	235	No	*	60
17	M	71	4	6.6	AL	Cement	ETO	Yes	3.9	25	26	235	No	54	85
18	M	63	4	4.5	AL	Cement	ETO	Yes	1.6	23	20	235	No	68	93

AL, aseptic loosening; PF, periprosthetic fracture; ETO, extended trochanteric osteotomy; TFD, transfemoral diaphyseal osteotomy.
* Indicates that data were not available.

inevitable in these circumstances where proximal femoral-stem engagement can not be achieved. Conversely, tapered, distally fitting stems rely on implant wedging into the remaining diaphysis to obtain circumferential contact with the endosteal bone. Axial loading of these stems results in further endosteal engagement, greater stem-diaphyseal diametric mismatch and resultant increase in circumferential compression of the implant. This provides the initial axial and rotational stability needed to achieve long-term osseous integration. Appropriately over-sizing the implant helps to achieve initial femoral endosteal-stem diametric mismatch and is crucial for initial implant axial stability. Cerclage cables were used in the majority of cases in this series for fracture prophylaxis to resist hoop stresses and/or osteotomy fixation. Cerclage augmentation permitted more vigorous reaming and impaction of the implants allowing for greater diametrical mismatch to protect against subsidence. However, a significant difference in subsidence was not observed in cases without cerclage cables, therefore their role in resisting diaphyseal hoop stresses remains hypothetical. Additional studies with greater statistical power are needed to determine their effect in preventing subsidence.

Although literature supporting modular tapered stems for management of high-grade femoral deficiencies remains limited, our series demonstrates promising results compared to reported outcomes of Wagner style stems used in similar clinical settings. Della Valle and Paprosky [28] reported osteointegration in only 50% of revised IIIB femurs and clinical failure necessitating revision in all Type IV femurs treated with extensively porous-coated stems. Additionally, Bohm and Bischel [4] reported a 93% survivorship at 8 years using Wagner SL stems however symptomatic subsidence was common. The high incidence of failed osteointegration and subsidence in these reports reflects the difficulties encountered with the lack of modularity. Adjustment of femoral neck length, anteversion and offset is difficult with the Wagner SL stem and can result in sizing mismatch and insufficient diaphyseal engagement leading to subsidence.

There were no occurrences of mechanical failure in our series despite the lack of a structurally supportive proximal bone in all 18 cases. Diaphyseal fixation with modular devices without proximal support has been a concern due to reports of implant fracture at the modular junctions [18–20,22]. An 82% rise in femoral stem strain has been reported in the setting of severe proximal metaphyseal deficiencies [21]. Use of larger-diameter components and protected weightbearing post-operatively are proposed methods to decrease implant peak strain and risk of mechanical failure. Additionally, a potential attribute adding to the lack of mechanical failure in our series relates to implant design and, more specifically, the mechanical hardening process of this design's taper junction. The Modular Restoration taper undergoes shot peening, which consists of a bombardment of the taper surface by small spheres made of ceramic, steel or other materials less than 0.5 mm in diameter. Molecular compression occurs at the surface resulting in a work hardening of the taper. A 33% increase in resistance to fatigue failure has been demonstrated by Stryker during biomechanical analysis of this process [29].

There are some limitations to the current study. The number of cases included in this analysis was small because we focused on the relatively uncommon high-grade deficiencies. Despite this, it remains one of the largest studies to date evaluating outcomes of modular, tapered fluted stems for Paprosky IIIB and IV-deficient femurs. Lastly, proximally unsupported Wagner modular implants have been reported to fracture; yet in this series there were no mechanical failures. Although these results are promising, larger studies with longer follow-up may better define adverse issues with modular stem design.

Conclusion

Modular, tapered femoral components for management of Paprosky type IIIB and IV deficiencies provided predictable clinical outcomes and excellent intermediate survivorship. Initial fixation is dependent on geometrical mismatch of the diaphysis and stem to achieve initial axial and rotational interference. Despite previous reports of mechanical failure of similar devices in proximally unsupported femurs, this was not our experience. Our results are promising and represent a satisfactory intermediate solution for these challenging defects.

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