The Rationale for Short Uncemented Stems in Total Hip Arthroplasty

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2 authors:

Ronak M Patel
Hinsdale Orthopaedic Associates

Samuel David Stulberg
Northwestern University

The Rationale for Short Uncemented Stems in Total Hip Arthroplasty

Ronak M. Patel, MD, S. David Stulberg, MD*

KEYWORDS

• Short stem implants • Metaphyseal-engaging implants • Uncemented total hip arthroplasty

KEY POINTS

- Metaphyseal fit and ingrowth can provide both rotational and axial stability without distal diaphyseal support.
- Bone remodeling on radiographic analysis of short stems of various designs show endosteal condensation and cortical hypertrophy in the proximal metaphyseal region of the femur.
- Functional Harris Hip Scores (HHS) and Western Ontario and McMaster Universities Arthritis Index (WOMAC) pain scores are equivalent in patients with metaphyseal-engaging short stems compared with stems of conventional length.
- Short stem metaphyseal-engaging implants enhance the preservation of proximal femoral bone stock as well as provide an adaptive alternative in minimally invasive anterior approaches.
- Metaphyseal-engaging short stems provide an alternative to bone preservation procedures with reproducible and reliable radiographic and clinical outcomes while maintaining a short learning curve.

INTRODUCTION

Total hip arthroplasty (THA) has proved clinically and functionally successful in the treatment of end-stage degenerative joint disease of the hip.[1–8] Porous-coated, uncemented femoral stems were introduced for use in THA in the early 1980s. Uncemented implants rely on diaphyseal or metaphyseal contact and, ultimately, bone fixation to ingrowth or ongrowth surfaces to provide long-term stability and dependable clinical results.[3,9–19] Uncemented, porous femoral implants are now routinely used in virtually all patients undergoing primary THA. Uncemented femoral components with a variety of shapes, metallurgy, and surface treatment have been developed to address the broad spectrum of proximal femoral morphology.[12,17,20–24]

Despite the documented success of these implants, current uncemented stems are used in patients whose size, age, level of physical activity, and bone quality present particular challenges for uncemented fixation technologies. These

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Department of Orthopaedic Surgery, Feinberg School of Medicine, Northwestern University, 676 N. St. Clair, Suite #1350, Chicago, IL 60611, USA
* Corresponding author. Northwestern Orthopaedic Institute, LLC, 680 North Lakeshore Drive, Suite 924.
E-mail address: jointsurg@northwestern.edu

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challenges include (1) the preservation of proximal femoral bone stock; (2) the potential need for effective, femoral component revision; (3) proximal-distal mismatch; and (4) the ability to insert implants safely, securely, and reproducibly with specific surgical approaches (eg, the direct anterior) that are currently being evaluated and promoted.

Short stem uncemented femoral implants have been developed to address some of these challenges while maintaining the current level of success achieved by uncemented implants of conventional length (Fig. 1). Short stem implants have been defined as 120 mm in length or less, which approximately correlates to the metadiaphyseal junction of the proximal femur.[25]

The purposes of this article are to (1) explain the evolution to short stem design, (2) describe the rationale and types of short stem implants, (3) provide the benefits of short stem implants, and (4) summarize the clinical results with these implants.

EVOLUTION TO SHORT STEM DESIGN

To understand the evolution of uncemented THA to short stem implants, femoral implant design and stability must first be reviewed. Successful THA relies on initial and long-term rotational and axial stability. The diaphyseal portion (cylindrical or tapered) of the femoral implant contributes to the initial stability. Cylindrical, extensively porous-coated implants (eg, AML) achieve durable fixation but can be associated with stress shielding and thigh pain. Cylindrical implants without porous-coated stems achieve varying degrees of initial axial and rotational stability through contact points in the diaphysis but rely on metaphyseal bone contact to enhance their initial rotational stability. Furthermore, these implants seek long-term fixation and stability through bone ingrowth or ongrowth at the metaphysis. Long-term clinical results of these implants have been satisfactory and reliable with an overall lower incidence of thigh pain and proximal stress shielding relative to their extensively coated counterparts. Early concerns with a cylindrical diaphysis, however, inspired investigators to produce tapered stems.

Fig. 1. Young active man with Dorr type A bone.

Tapered uncemented implants achieve primary axial fixation through a 3-point contact mechanism with the creation, and ultimate relaxation, of hoop stresses between a tapered stem and cylindrical femur. Rotational stability is achieved in the proximal femur through surface treatment, various shape geometries, and overall fit and fill. Secondary fixation depends on the extent of contact between the ingrowth/ongrowth surfaces of the implant and metaphyseal bone. Many studies have established the long-term clinical and radiographic reliability and durability of tapered femoral implants. These stems have been associated with little thigh pain compared with cylindrical stems.

In these designs, the tapered or uncoated cylindrical diaphyseal portion provides primary axial stability but varying degrees of rotational stability. Rather, rotational stability is attained from metaphyseal bone-implant contact.

DESIGN RATIONALE AND TYPES OF UNCEMENTED SHORT STEM METAPHYSEAL-ENGAGING FEMORAL IMPLANTS

Short stem metaphyseal-engaging implants achieve secure initial fixation in the metaphysis, theoretically making the axial and rotational stability provided by the diaphyseal portion of the femoral implant negligible. Metaphyseal ingrowth or ongrowth secures long-term fixation, with the pattern of bone implant contact varying by implant design. A variety of implants have been introduced over the past few years, leading to the development of a classification system by McTighe and colleagues.[25] The 3 main types of short stem implants are

1. Metaphyseal stabilized (standard neck resection) (Fig. 2A)
2. Neck stabilized (femoral neck sparing) (see Fig. 2B)
3. Head stabilized (resurfacing-type procedures) (see Fig. 2C)

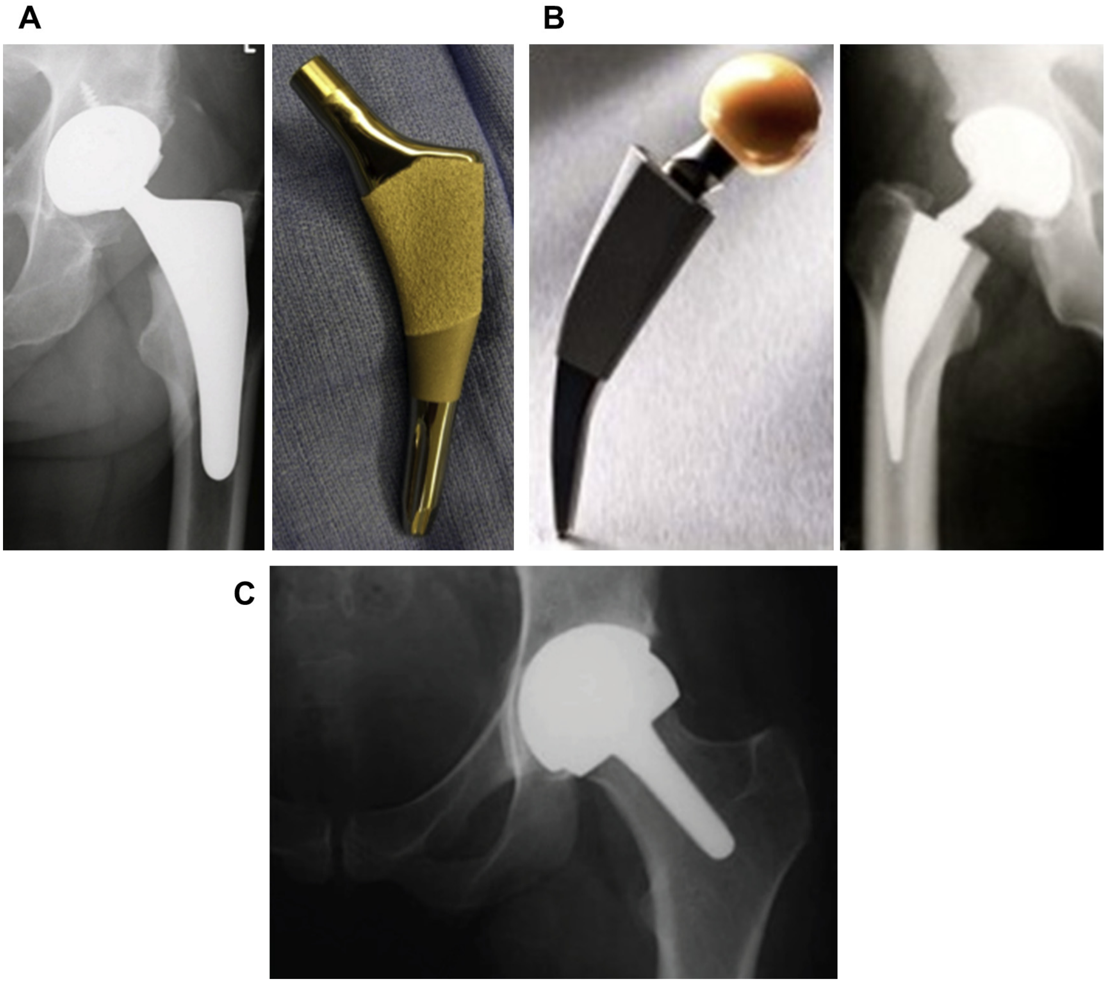

Fig. 2. (*A*) Metaphyseal-stabilized implant (standard neck resection). (*B*) Neck-stabilized implant (femoral neck sparing). (*C*) Head-stabilized implant.

Standard neck resection short stem implants can further be classified into (a) anatomic and (b) wedge fit implants. These implants also tend to be shortened versions of conventional uncemented implants. Femoral neck-sparing or neck-preserving implants instead have unique design features to accommodate the native anteversion of the femoral neck. Head-stabilized short stem implants commission a completely different surgical technique and necessitate specific clinical indications; thus, they are not discussed in this article.

Femoral neck-sparing or high femoral neck resection designs seek to optimize proximal load transfer by engaging solely the femoral neck and the metaphysis. A more proximal and horizontal femoral neck osteotomy produces an oval-shaped intramedullary opening compared with a standard cut, which offers a broad opening (Fig. 3). Studies have shown greater resistance to torsional stresses with these high-neck osteotomies.[26–28] The concept of femoral neck preservation in uncemented designs has been well described since the earliest days of arthroplasty.[29,30] Proponents of this concept have suggested improved bone and soft tissue preservation. Moreover, soft tissue preservation enhances implant fixation, reduces surgical morbidity, improves abductor function, and preserves bone stock for potential future surgery.

Santori and Santori[31] reported satisfactory midterm results in a high femoral neck resection short stem implant. They performed a complete clinical review at a mean interval of 8 years in their cohort of patients under the age of 60 who underwent THA. Despite other encouraging results reported by the developers of uncemented femoral components inserted with high femoral neck

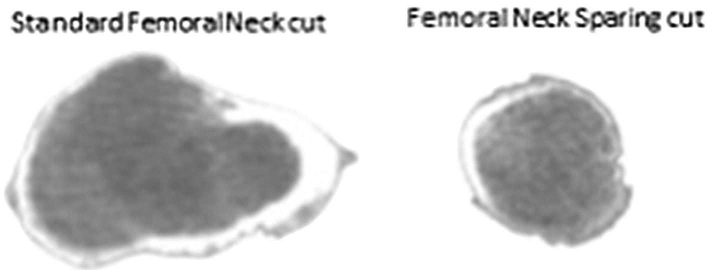

Fig. 3. Cross-sections of osteotomy levels for standard neck versus femoral neck-sparing implants designs.

resection, widespread use of these devices has not yet occurred.

Several reasons have been proposed for the slow adoption of this concept:

1. The surgical technique for inserting stems of this design is different from and potentially more difficult than more standard neck resection approaches. The long retained femoral neck can make exposure of the acetabulum difficult.
2. Accurate, reproducible alignment of the femoral stem within the diaphysis may be difficult to accomplish given the native anteversion of neck shaft.
3. The small surface area of bone at the proximal femoral neck makes restoration of accurate leg length and avoidance of lengthening of the extremity difficult to achieve.
4. The high-neck resection limits exposure of the metaphysis and may reduce the extent and reliability with which metaphyseal fit and contact can be achieved.
5. The combination of high-neck resection and short stems may be associated with an increased incidence of proximal femoral fractures.
6. A high femoral neck resection may result in increased bone-bone impingement and, subsequently, a reduction in range of motion.

Initial experimentation with femoral neck preservation short stem implants may have been considered a radical shift in paradigm at the time. Recent renewed interest in these stems is largely due to a natural progression of uncemented femoral components from cylindrical to tapered to shortened designs. Design teams continue to develop high-neck resection implants based on encouraging results from original designs and aim to address some of the design flaws (discussed previously) (**Fig. 4**). For example, the Fitmore stem (Zimmer, Warsaw, Indiana) has variability in its curve to allow for greater medial calcar contact for enhanced stability (**Fig. 5**). Development of these devices is spurred by a renewed interest in the use of the direct anterior approach for THA, the desire for surgical and implant approaches that minimize soft tissue and bone trauma, and a concern about proximal bone preservation and positive bone remodeling.

Standard neck resection metaphyseal-engaging short stem implants tend to be shortened versions of commercially available conventional-length uncemented femoral implants (**Fig. 6**). These stems have shortened tapered or cylindrical diaphyseal-reaching stems and a wide variety of metaphyseal shapes. The 2 main categories of metaphyseal shapes include 2-D or 3-D taper shapes that achieve 2-point wedge fixation in the metaphysis and anatomic shapes that seek to fit and fill the metaphysis. Theoretic studies have shown that the use of a lateral flare configuration reduces distal femoral stress transfer in conventional-length uncemented femoral components by engaging the proximal lateral, medial, and anterior cortices.[32,33] Use of this rationale has extended into short stem designs.

Proponents of these short stem designs state the proximal metaphyesal fixation achieved is adequate for initial and long-term stability. Various designs have been shown to have reliable fixation and successful clinical and radiographic outcomes up to 8 years postoperatively.[29,34–36] Two-point wedge designs attempt to achieve contact and fit at the metaphyseal-diaphyseal junction. Although these implants can be tapered in 2 or 3 dimensions, the wedge-fit is primarily 2-point at the medial and lateral cortices (**Fig. 7**). Anterior and/or posterior endosteal contact is variable on design. Similarly, anatomic implants attempt fit and fill the metaphysis—in the coronal or sagittal planes or in both.

Recently, a finite element analysis was completed in a composite bone model evaluating uncemented femoral stem length on primary stability.[37] No significant reduction in stability was observed from reducing stem length from 146 mm to 105 mm; furthermore, decreasing

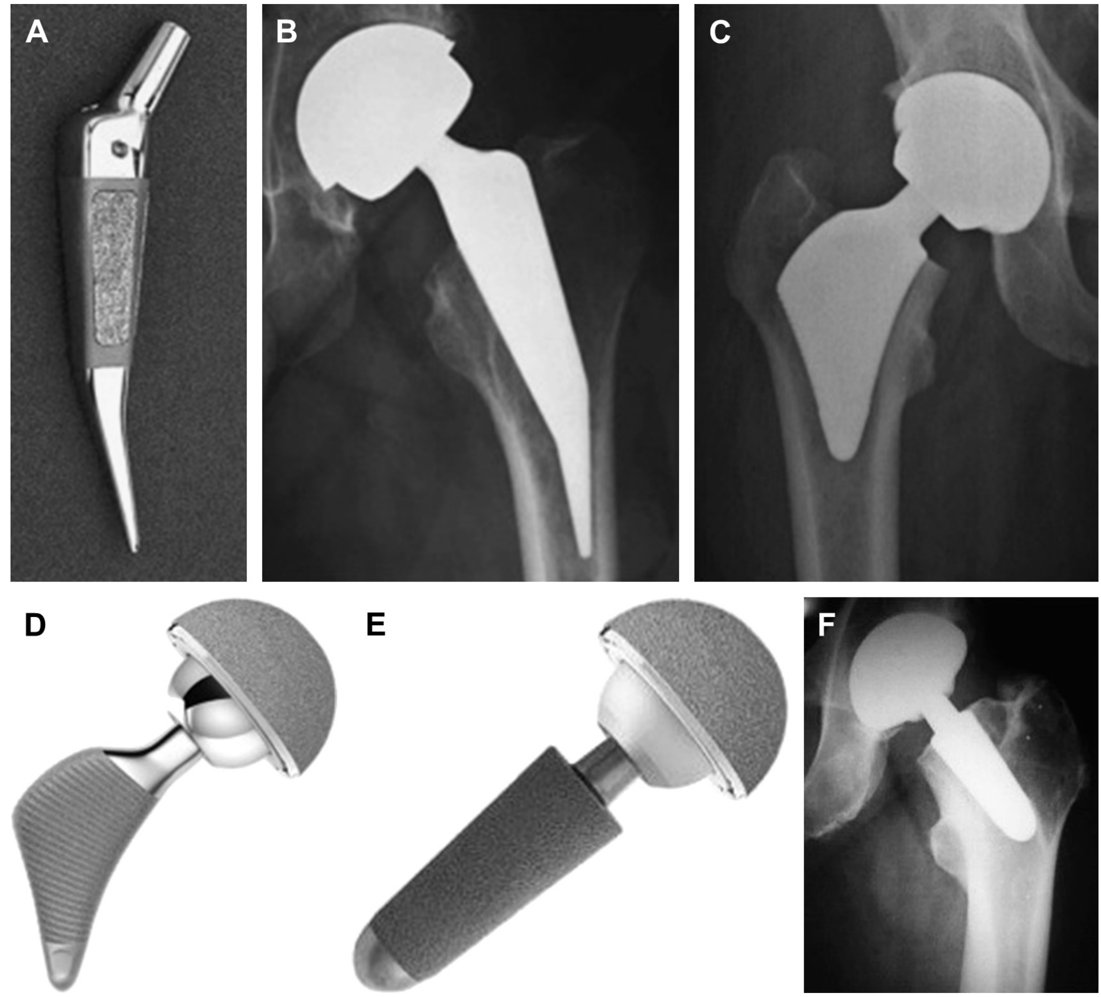

Fig. 4. (*A*) Mayo implant. (*B*) Radiograph of THA with Mayo Implant. (*C*) Proxima radiograph. (*D*) Proxima stem. (*E*) Silent implant and (*F*) radiograph.

stem length further did not lead to micromotion that would inhibit osteointegration.[38] Furthermore, 2-year migration analysis of a metaphyseal anchored short stem implant using Ein Bild Roentgen Analyse femoral component analysis showed subsidence rates and patterns of stability comparable to conventional-length uncemented implants.[39] Although long-term studies remain the gold standard in joint arthroplasty, migration analysis allows prediction of implant survival.

Preservation of proximal femoral bone stock is becoming increasingly important because THA is performed in younger, more active patients. Distal bone-implant fixation can lead to proximal femoral stress shielding and subsequent bone loss. Arno and colleagues[40] completed a cadaveric evaluation of femoral strain with the use of uncemented femoral components with 3 different stem lengths. As the stem length increased, there was a typical pattern of increased distal strain and decreased proximal femoral strain. This pattern can, theoretically, by Wolff's law, contribute to stress shielding in the proximal femur. These investigators concluded that although the stemless component best matched the strain pattern in a native femur, the ultrashort implant (one-third length of standard Revelation Lateral Flare, DJO Surgical, Austin, Texas) performed close to the stemless design. A proposed benefit of short stem femoral implants is optimal proximal bone remodeling. Although roentgen stereophotogrammetric and dual energy x-ray absorptiometry (DEXA) analysis are considered gold standards in accurate measurement of bone mass surrounding a prosthesis, many investigators report appreciable changes on radiographic analysis. In comparison with conventional-length uncemented femoral implants, short stem implants have less

Fig. 5. Zimmer Fitmore short stem implant.

bone resorption.[41] Chen and colleagues[41] found an average bone loss of 3.3% in DEXA analysis of the Mayo Conservative stem (Zimmer, Warsaw, Indiana). The average bone resorption found in the literature is 20%, with an autopsy retrieval study showing 42.1% loss proximally and a gradual decline distally.[42,43]

THEORETIC ADVANTAGES OF SHORT STEM FEMORAL IMPLANTS

Ease and Safety of Revision Surgery

The proximal bone resorption from stress shielding not only results in increased susceptibility to particle-induced osteolysis but also can complicate revision surgery.[41] The senior author has had a particular interest in short stem metaphyseal-engaging femoral implants. Recent use of a short stem modular femoral neck prosthesis (ABG II, Stryker, Mahwah, New Jersey) led to adverse local soft tissue reaction in a small percentage of patients from corrosion at the trunion of the femoral head-neck junction.[44] Similar soft tissue responses have been seen in modular femoral neck prostheses of conventional length (Rejuvenate, Stryker, Mahwah, New Jersey). Ultimately, revision surgery with component extraction and exchange to nonmodular prosthesis is recommended. The 2 case examples of these complications highlight potential benefits of revision surgery with a short stem femoral implant compared with a conventional-length implant.

Revision of a short stem implant

The posterolateral incision and exposure from the primary THA surgery was used and extended both

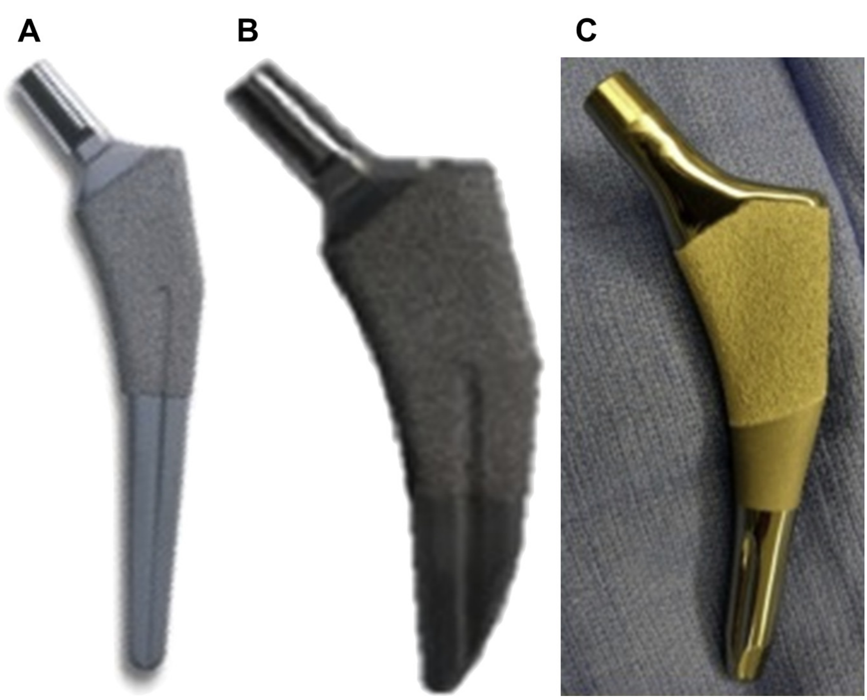

Fig. 6. (*A*) Taperloc. (*B*) Microplasty. (*C*) Citation short.

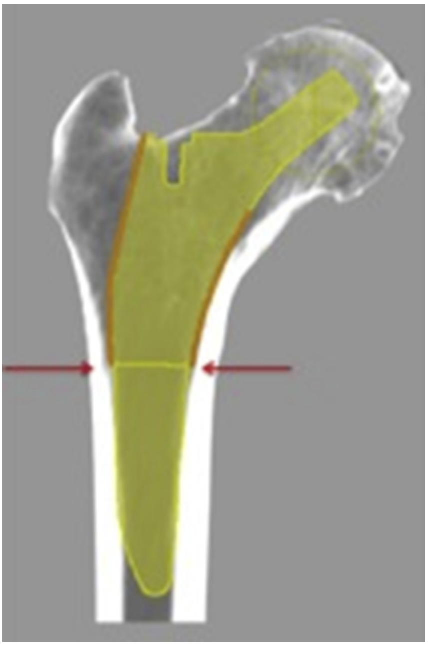

Fig. 7. Two-point wedge fit design. The implant is designed to contact the medial and lateral cortices at the metaphyseal-diaphyseal junction.

proximally and distally. The hip was dislocated and granulomatous tissue was excised. The head and modular tapered neck were removed without difficulty. The cobalt-chromium stem of the ABG implant appeared well aligned and well fixed. A pencil-tip burr created an opening along the shoulder of the femoral component, which allowed for a series of flexible osteotomes to be inserted. After circumferential wedging with the osteotomes, the implant extractor tool was used to remove the femoral component while preserving as much bone as possible. The quality of bone of the proximal femur was good. There was little bone loss. The decision was made to insert a nonmodular ABG implant. The femur was broached sequentially to 1 size up from the original modular ABG implant. After trial reduction and range of motion, the real implant was placed with solid circumferential fixation (Fig. 8).

Revision of a conventional-length implant

The posterolateral incision and exposure from the primary THA surgery was used and extended both proximally and distally. The hip was dislocated and granulomatous tissue was excised. The head and modular tapered neck were removed without difficulty. The titanium stem of the Rejuvenate implant was visualized and appeared well fixed. Initially, a 2.3-mm burr was used to open the proximal interface. A thin saw blade was then inserted into the

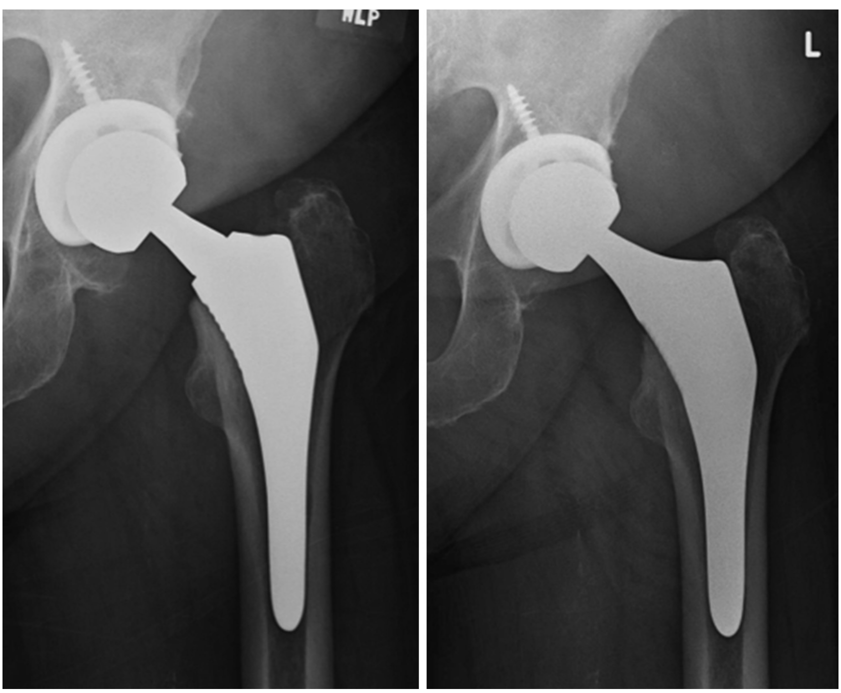

Fig. 8. Prerevision (*left*) and postrevision (*right*) radiographs with a short stem femoral implant (ABG modular and nonmodular designs, Stryker, Mahwah, New Jersey).

opening clearing a path for flexible osteotomes. Sequential insertion of the osteotomes met resistance at an area of firm bone at the base of the ingrowth zone of the femoral stem. Continued trial of various osteotomes was unsuccessful at extraction and aborted secondary to concern of fracture. An extended trochanteric osteotomy was then performed. Once the implant was extracted, the proximal bone stock was examined and confirmed to be thin, as seen on radiographs. At this point, diaphyseal fixation seemed necessary and a Wagner SL stem (Zimmer, Warsaw, Indiana) was selected. The appropriate reamers were used and good fixation was achieved a trial implant. After trial reduction and range of motion, the real implant was placed and the trochanter was reduced to the diaphysis. A standard 5-hole trochanteric grip plate (Accord, Smith & Nephew, Memphis, Tennessee) was placed laterally and secured first with 2 cables under the lesser trochanter and then 3 additional cables around the diaphysis providing secure, solid fixation and reconstruction (**Fig. 9**).

Well-fixed stable short stem implants afford the possibility of safe and effective revision surgery with greater preservation of femoral bone and less-invasive technique.

Proximal-Distal Mismatch

The lack of a long distal stem in short stem femoral components also lends flexibility and adaptability with the broad range of proximal femoral morphology that exists.[22] The presence of proximal metaphyseal-distal diaphyseal mismatch in young, vigorous patients with robust, thick diaphyseal cortices and large cancellous metaphyses presents particular challenges to conventional-length uncemented implants (**Fig. 10**). Furthermore, avoiding proximal-distal mismatch in osteoporotic bone with disproportionately widened and weakened cortices lessens the risk of femoral perforation. Although those scenarios are common, cases of proximal femoral deformity are less common but equally challenging. In patients with excessively bowed femurs, deformed bone as a

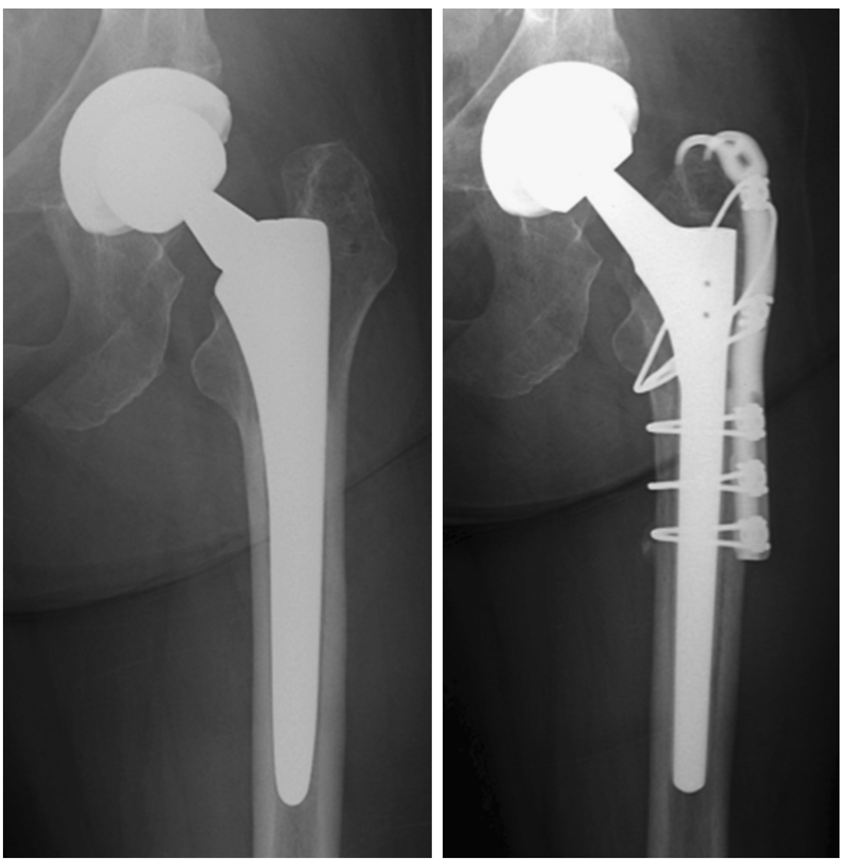

Fig. 9. (*Left*) Prerevision (Rejuvenate, Stryker, Mahwah, New Jersey) and (*right*) postrevision (Wagner SL, Zimmer, Warsaw, Indiana) radiographs of a conventional-length uncemented femoral implant.

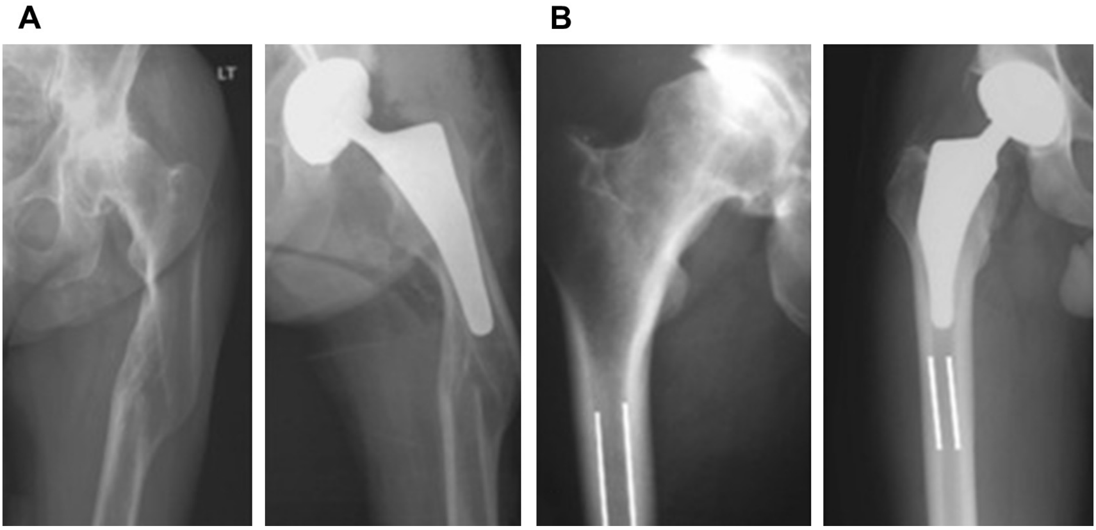

Fig. 10. Two types of proximal-distal mismatch treated with metaphyseal-engaging, short stem devices. (*A*) Proximal femoral fracture. (*B*) Wide metaphysis, narrow diaphysis in a young, robust male patient.

consequence of fracture or developmental abnormality short stem femoral implants may be able to provide adequate fixation while avoiding the area of deformity (see Fig. 10).

Use in Less-invasive Exposures

The smaller size of short stem implants lends itself to minimally invasive surgerical (MIS) approaches in THA. Molli and colleagues[34] found a lower complication rate with the use of short stem implants (0.4%) compared with conventional-length implants (3.1%) via a less-invasive direct lateral approach. In the short stem group, there was 1 femoral fracture. In the conventional-length stem group, there were 9 femoral fractures and 3 trochanteric avulsions. Lombardi and associates[45] found similar results with the use of the direct anterior approach for THA. Femoral fractures can be fixed intraoperatively with cerclage cables and lateral plates, but postoperative activity and function are impeded in the short term. MIS and less-invasive approaches can limit visualization of the subtrochanteric femoral shaft and may make safe insertion of longer stems more difficult than short stem implants.

CLINICAL AND RADIOGRAPHIC RESULTS OF SHORT STEM FEMORAL IMPLANTS

Short-term follow-up of anatomic uncemented short stem implants have been shown to provide pain relief, functional restoration, and stability similar to conventional uncemented designs (Table 1). The authors' center has recently published up to 7-year clinical and radiographic follow-up of a CT-based custom short stem femoral implant. The femoral stem was made of titanium alloy with a hydroxyapatite coating on a titanium plasma spray in the proximal one-third to one-half of the stem (Biomet, Warsaw, Indiana) with an average stem length of 90 mm (range, 70–105 mm) (Fig. 11). HHSs averaged 55 (20–90) preoperatively and 96 (55–100) postoperatively. WOMAC scores averaged 51 (13–80) preoperatively and 3 (0–35) postoperatively. No cases of subsidence were observed and no revision surgeries have been performed. Bone remodeling was typified by endosteal condensation and cortical hypertrophy in Gruen zones 2, 3, 5, and 6.

This custom implant inspired the use of an off-the-shelf metaphyesal implant with a similar design. The authors prospectively followed 148 hips in 139 consecutive patients treated with an uncemented metaphyseal-engaging short (91–105 mm) stem that fit closely against the endosteal metaphyseal bone along the anterior metaphysis, medial calcar, posterior femoral neck, and metaphyseal flare at the bottom of the greater trochanter (Citation, Stryker, Mahwah, New Jersey) (see Figs. 2A and 6C). At an average follow-up of 67 months, mean HHSs and WOMAC scores for the off-the-shelf cohort were 94 (range, 55–100) and 3.3 (range, 0–27), respectively. A subgroup of these patients was also evaluated to reveal stable fixation and comparable clinical outcomes in patients over the age of 70 years. Two-year follow-up of 60 patients (65 hips) 70 years and older (mean, 75 years; range, 70–86 years) with the Citation short stem revealed

Table 1
Summary of short uncemented femoral implants of various designs examined in cohorts of various ages

Study	Implant Design	Stem Fixation Type	N (Hips)	Average Postoperative HHS	Average Age (y)	Average Follow-up (y)	Stem Revisions for Aseptic Loosening
Patel et al,[49] 2012	Anatomic off-the-shelf short stem	Uncemented with hydroxyapatite	65	88	75	3	0 (0%)
Morrey et al,[29] 2000	Short stem with high valgus neck	Uncemented	20	98	N/A	2	1 (5%)
Pipino et al,[30] 2000	Anatomic femoral neck-sparing with collar	Uncemented	44	37% excellent, 45% good	62.5	13–17	0 (0%)
Santori & Santori,[31] 2010	Custom high-neck resection short stem	Uncemented with hydroxyapatite	129	95	51	8	0 (0%)
Morrey et al,[29] 2000	Double tapered short stem modular neck	Uncemented	159	90.4	51	6	3 (1.8%)
Morales de Cano et al,[35] 2013	Tapered short stem with elliptic-octagon cross-section	Uncemented with grit-blasted titanium	81	Merle d'Aubigné score: 16	65	1.3	0 (0%)
Molli et al,[34] 2012	Tapered flat-wedge short stem	Uncemented with porous plasma spray	269	83	63	2.3	0 (0%)
Ghera & Pavan,[46] 2009	Wedge femoral neck-sparing short stem	Uncemented with hydroxyapatite	50	91	70	1.7	0 (0%)
Lazovic & Zigan,[47] 2006	Modular femoral neck-sparing short stem	Uncemented with plasma Ca-P coating	55	92	48	0.5	0 (0%)
Rohrl et al,[48] 2006	Modular femoral neck-sparing short stem	Uncemented	26	93	54	2	0 (0%)
Patel et al,[36] 2013	Anatomic custom short stem	Uncemented with hydroxyapatite	69	96	56	5.5	0 (0%)

Fig. 11. Custom, CT-based, short stem femoral implant made of titanium alloy with a hydroxyapatite coating on a titanium plasma spray in the proximal one-third to one-half of the stem (Biomet, Warsaw, Indiana).

average HHSs of 88 (range, 70–100) and WOMAC scores of 6 (range, 0–43).

Another institution familiar with short stem femoral implants compared a large cohort of conventional-length femoral implants (Mallory-Head Porous, Biomet, Warsaw, Indiana) and short stem femoral implants (TaperLoc Microplasty, Biomet, Warsaw, Indiana). They found equivalent clinical and functional scores between 389 conventional-length stems and 269 short stems at average 29-month follow-up. Furthermore, they found a decreased complication rate (0.4%) in the short stem group compared with the conventional-length group (3.1%).

Santori and Santori reported reliable clinical and radiographic results in 129 custom-made uncemented high femoral neck resection short stem implants up to 8 years (Fig. 12). The indications for the use of this stem in this cohort were age of less than 60 years and good bone stock.

Although older generations of short stem femoral implants have longer follow-up (ie, Proxima [Depuy, Warsaw, IN] and Mayo Conservative Hip Prosthesis [Zimmer, Warsaw, IN]), newer generations lack long-term clinical and radiographic data.[29,30,41] One important difference in the 2 generations of implants is the surface coating. Initial

Fig. 12. Custom-made uncemented short stem femoral components (Stanmore Implants Worldwide, Elstree, United Kingdom, and Depuy International, Leeds, United Kingdom).

short stem implants were typically grit blasted with the extent and location varying significantly. Newer generations promote ingrowth with a porous coating and have osteoconductive stimulation via hydroxyapatite. This may explain the lower rate of subsidence in newer-generation short stem implants. Nevertheless, the success of older-generation implants and midterm success of newer-generation implants imply long-term clinical and functional success equivocal to conventional uncemented implants. Moreover, the benefits of soft tissue and bone preservation with short stem implants promote consideration of these implants. Increasing concerns regarding the use of metal-on-metal surface replacement arthroplasties are also stimulating interest in the development of reliable, safe, tissue-preserving short stem femoral implants as a possible alternative to surface replacements.

SUMMARY

In conclusion, uncemented femoral implants of various designs have proved to provide stable initial and long-term fixation in patients who undergo THA. Challenges in primary THA have led to the evolution of short stem designs. These challenges include proximal/metaphyseal and distal/diaphyseal mismatch; facilitation of less-invasive surgical exposures, especially the direct anterior approach; and bone preservation for potential revision surgery. The results of short stem implants with follow-up to 10 years strongly suggest that these implants will assume an increasingly important role in total hip arthroplasty.

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