Stable, Dependable Fixation of Short-stem Femoral Implants at 5 Years

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abstract

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Conventional uncemented femoral implants provide dependable long-term fixation in patients with a wide range of clinical function. However, challenges with proximal-distal femoral mismatch, preservation of bone stock, and minimally invasive approaches have led to exploration into various other implant designs. Short-stem designs focusing on a stable metaphyseal fit have emerged to address these challenges in total hip arthroplasty (THA). The purpose of this study was to present the 5-year clinical and radiographic results of a computed tomography–based, custom-made, metaphyseal-engaging short-stem femoral implant.

Sixty-one patients with an average age of 61 years (range, 22-75 years) and average body mass index of 28.9 kg/m^2 (range, 20.3-44.1 kg/m^2) at follow-up underwent 69 THAs with the metaphyseal-engaging short stem. Clinical performance was evaluated using the Harris Hip Score and Western Ontario and McMaster Universities Arthritis Index score, and radiographs were reviewed for stability and bony ingrowth. Harris Hip Score averaged 55 (range, 20-90) preoperatively and 96 (range, 55-100) postoperatively. Western Ontario and McMaster Universities Arthritis Index score averaged 51 (range, 13-80) preoperatively and 3 (range, 0-35) postoperatively. No cases of subsidence were observed, and no revision surgeries were performed. Bone remodeling was typified by endosteal condensation and cortical hypertrophy in Gruen zones 2, 3, 5, and 6. At 5-year follow-up, the uncemented, metaphyseal-engaging short stem was stable and exhibited proximal bone remodeling closer to the metaphysis than conventional stems. Short-stem, metaphyseal-engaging femoral implants can meet the goals of a successful THA.

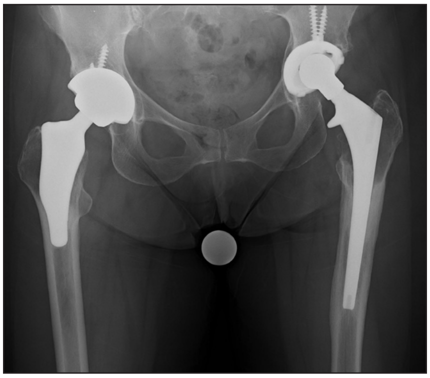

Figure: Anteroposterior pelvis radiograph of a 79-year-old woman who underwent a left total hip arthroplasty with an uncemented cylindrical extensively coated implant 14 years previously and a right total hip arthroplasty with the custom short-stem implant 6 years previously. With all patient factors controlled for, significantly less bone resorption is seen in the right metaphysis and diaphysis compared with the left.

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Conventional uncemented femoral implants provide dependable long-term fixation in patients with a wide range of clinical function.[1,2] Tapered designs have helped limit thigh pain and produced pain-free function in patients undergoing total hip arthroplasty (THA).[3] However, challenges with proximal-distal femoral mismatch, preservation of bone stock, and minimally invasive approaches have led to exploration into various implant designs. Recently, shorter stem designs focusing on a stable metaphyseal fit have emerged to address these challenges in THA.

Short-stem implants aim to achieve contact and fit in the metaphysis of the proximal femur, requirements in optimal proximal load transfer. By achieving an axially and rotationally stable proximal metaphyseal bind, the distal stem theoretically becomes redundant.[4] Many manufacturers have designed short-stem implants using different proximal geometries and design philosophies to test the aforementioned theoretical benefits. The current authors previously reported promising initial and short-term clinical and radiographic results of a computed tomography (CT)–based custom implant design.[5] Santori and Santori[4] reported satisfactory mid-term results in a high-femoral-neck resection (or neck-preserving) short-stem implant. They performed a complete clinical review at a mean interval of 8 years in their cohort of patients younger than 60 years who underwent THA.[4]

Standard femoral neck resection metaphyseal-engaging short-stem implants have been shown to have excellent clinical and radiographic results at 2 to 4 years follow-up.[5,6] Although subsidence and proximal stress-shielding are evident in the first postoperative year, longer follow-up allows for observation of bone remodeling and benefits from potential revision surgery. Little literature exists on the mid-term clinical and radiographic results of a standard-neck resection short-stem implant.

Therefore, the current authors investigated (1) hip function and pain scores at a minimum 5-year follow-up, (2) the stability and pattern of bony ingrowth of a custom short-stem femoral implant, and (3) the rate of aseptic loosening compared with published 2-year follow-up on the same implant and the mid-term follow-up on conventional-length uncemented femoral implants.

Materials and Methods

The Northwestern University Institutional Review Board approved the human protocol for this investigation, and all investigations were conducted in conformity with ethical principles of research.

A retrospective review was conducted of prospectively collected data for patients who underwent uncemented primary THA with a custom short-stem femoral implant by a single surgeon (S.D.S.). Eighty custom-made short stems were inserted in 72 patients between 2004 and 2005. All patients were younger than 70 years. No patient was excluded based on femoral bone quality, body mass index, sex, or etiology. Any patient younger than 70 years who needed a primary THA without metaphyseal femoral deformity that would make an anatomic stem impossible was a candidate for this stem. The indications for the short-stem implants were osteoarthritis, inflammatory (rheumatoid) arthritis, avascular necrosis, and traumatic arthritis. The contraindication for this stem was that of any anatomic implant: a femoral deformity that precluded fit and fill in the metaphysis (eg, dysplastic hips with high offset/severe valgus or metaphyseal deformity secondary to fracture).

Of the 72 patients, 5 died of causes unrelated to the THA and 6 were lost to follow-up (no patient declined follow-up). These 11 exclusions left 61 patients (69 THAs [86% follow-up]) with a minimum 5-year follow-up (average, 66 months; range, 60-81 months). Average patient age was 56 years (range, 16-69 years) at THA and 61 years (range, 22-75 years) at final follow-up. Thirty-eight THAs were performed in men and 31 in women. Average patient body mass index was 28.9 kg/m^2 (range, 20.3-44.1 kg/m^2).

Clinical data were obtained from preoperative, immediate postoperative, and minimum 5-year postoperative visit clinic notes and prospectively collected, patient-reported questionnaires. Harris Hip Scores (HHS) and Western Ontario and McMaster Universities Arthritis Index (WOMAC) pain scores were computed based on these standardized questionnaires[7-9] Mean preoperative HHS and WOMAC scores were 55 (range, 20-90) and 51 (range, 13-80), respectively. At minimum 2-year follow-up, mean HHS was 93.5. No WOMAC scores were computed at the time, although no patients reported thigh pain.

The metaphyseal-engaging femoral stems were customized for each patient based on preoperative axial CT scans (Figure 1). The implant was designed to 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 (Figure 2). The custom 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). Average stem length was 90 mm (range, 70-105 mm), and average stem diameter was 14 mm (range, 9-23 mm).

The CT scan also allowed determination of stem length by extending to the point at which the femoral metaphyseal cortices became parallel and merged with the diaphysis. The stem lengths in this design ranged from 70 to 105 mm, whereas 110 mm is generally accepted as the threshold for consideration as a short-stem implant. A porous-coated acetabular component was used in all cases. The bearing surface was metal-on-highly-cross-linked polyethylene. Femoral head size was 32 mm. The same surgeon (S.D.S.) performed all THAs with a standardized

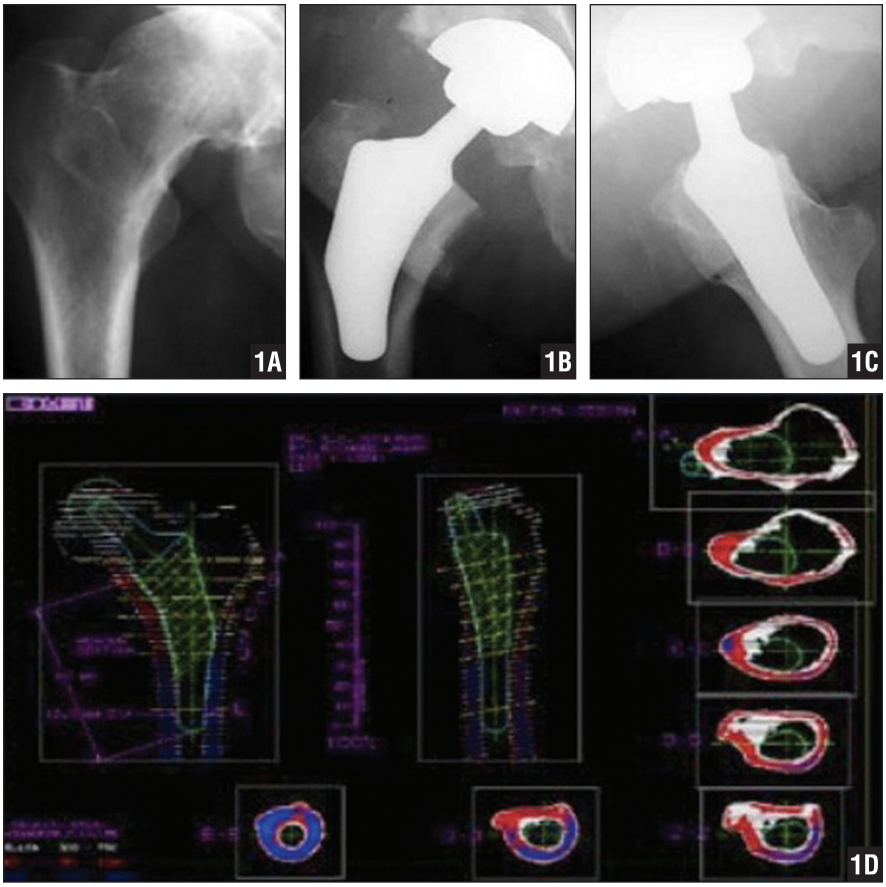

Figure 1: Preoperative anteroposterior (A) and postoperative anteroposterior (B) and lateral (C) radiographs showing the right hip that underwent THA with a computed tomography–based, short-stem implant.Three-dimensional analysis and sizing was used to produce an implant with optimal fit and fill in the metaphysis (D).

Figure 2: Photograph of the custom short-stem femoral implant.

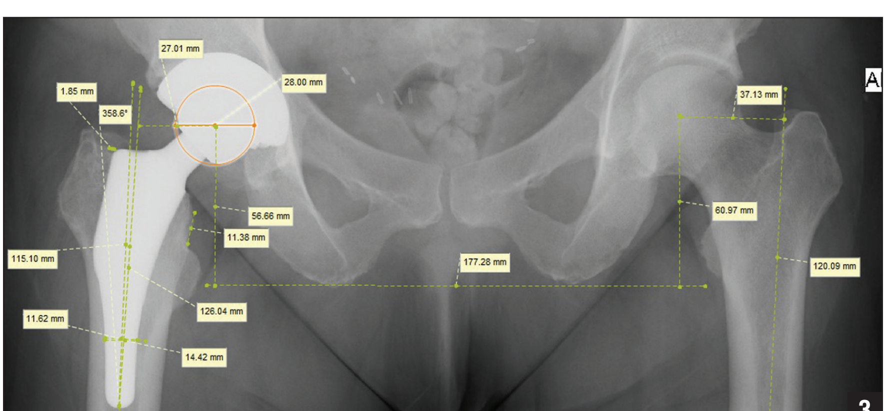

Figure 3: Anteroposterior pelvis radiograph a 62-year-old woman 6 years after a custom short-stem right total hip arthroplasty showing digital radiographic analysis.

surgical technique through a less invasive posterolateral approach.

All patients returned to a prescheduled outpatient clinic appointment 4 weeks postoperatively for clinical and radiographic examination, which included anteroposterior pelvis and frog lateral radiographs of the operative hip. Clinical examination performed by the primary surgeon included inspection of the wound, observation of gait, and evaluation of range of motion and strength in the operative extremity. Subsequent routine follow-up examinations occurred at 3, 6, and 12 months and then annually thereafter. Clinical data from preoperative, immediate postoperative, and minimum 5-year postoperative examinations were obtained from medical records.

All radiographs were digitized and imported into an online database that allowed digital calibration and subsequent analysis. Preoperative radiographs were analyzed for femoral bone quality based on the Dorr classification.[10] Using this classification, 19 (28%) femurs were type A, 39 (56%) femurs were type B, and 11 (16%) femurs were type C. Two independent examiners (R.M.P., S.D.S.) reviewed all postoperative radiographs for implant alignment and stability and were blinded to each other's interpretation.[11-14] Varus/valgus positioning (5° or more from neutral) of the implant was measured by direct measurement of angulation along the stem relative to the femoral shaft (Figure 3). To assess stability, length measurements from the superior tip of the greater trochanter to the distal tip of the implant were compared between immediate postoperative and long-term follow-up visits; differences of 2 mm or more were used to detect subsidence.[14,15] Bony ingrowth was assessed by noting bone bridging or endosteal condensation in the 7 adapted Gruen zones (Figure 4).[16] Canal fill at the proximal aspect of the stem (halfway

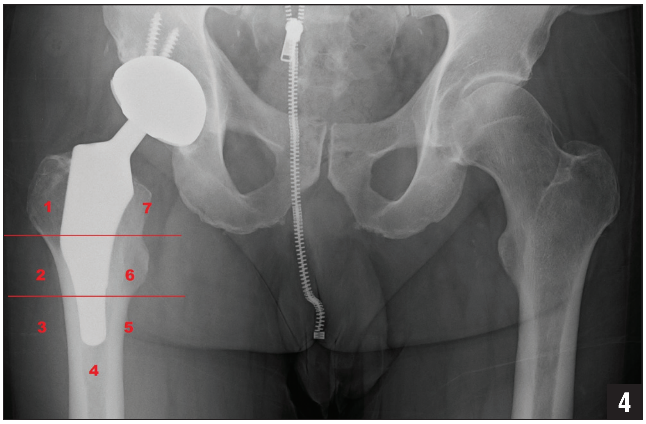

Figure 4: Anteroposterior pelvis radiograph of a 69-year-old man at 6-year follow-up showing Gruen zone assessment of a custom short-stem femoral implant.

Table 1

Mean 5-year HHS and WOMAC Scores in Patients With Dorr Type C Bone

	Mean Score		
Score	**Patients With Dorr Type C Bone**	**All Other Patients**	***P***
HHS	98	96	.25
WOMAC	3	4	.54

Abbreviations: HHS, Harris Hip Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

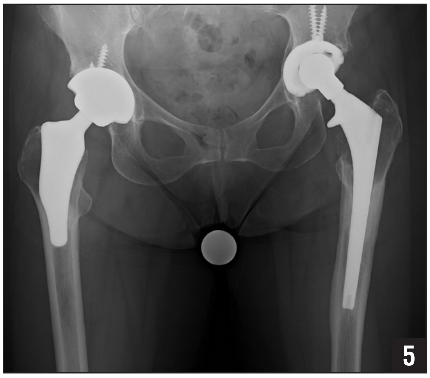

Figure 5: Anteroposterior pelvis radiograph of a 79-year-old woman who underwent a left total hip arthroplasty with an uncemented cylindrical extensively coated implant 14 years previously and a right total hip arthroplasty with the custom short-stem implant 6 years previously. With all patient factors controlled for, significantly less bone resorption is seen in the right metaphysis and diaphysis compared with the left.

between the shoulder and distal tip) was estimated by comparing the width of the stem with the width between both endosteal cortices. Loosening was evaluated by comparing valgus/varus alignment over time, as well as noting any lucent or reactive line greater than 2 mm around the stem. Other qualitative measures, including the presence of spot welds, bony pedestals, cortical hypertrophy, calcar rounding, and osteolysis, were documented.

The statistical significance of comparisons between sample means was determined using a 2-sided Welch's *t* statistic for independent samples or a paired *t* test where specified. For all comparisons, a statistical confidence level of 95% was selected; *P* values for HHS and WOMAC scores are reported throughout.

Results

At 5-year follow-up, mean HHS and WOMAC scores were 96 (range, 55-100) and 3 (range, 0-35), respectively. These scores were significantly improved compared with preoperative scores ($P<.001$ for both). No difference existed in 2- (93) and 5-year (96) follow-up HHS scores ($P=.43$). No patient reported thigh pain at either follow-up interval. No difference existed in HHS or WOMAC scores at more than 2 years postoperatively between Dorr type C femurs and the rest of the cohort (Table 1).

During radiographic analysis, subsidence was not evident in any implant (more than 2 mm of migration). Twenty femoral implants had thin zones of radiolucency (less than 2 mm) surrounding distal portions of the stem, along with a sclerotic line. No implant had an area of lucency more than 2 mm or osteolysis around the stem. Of the 59 hips with 5-year radiographic follow-up, no implants were found to be in varus (more than 5°) (Figure 5).

All implants had radiographic evidence of bony ingrowth, as seen by bone bridging and endosteal condensation. Adapted Gruen zones 2, 3, 5, and 6 in the metadiaphysis most consistently showed this pattern (Table 2). Using a conventional Gruen zone scale, the majority of the bony ingrowth and bone preservation would be confined to Gruen zones 1, 2, 6, and 7.

Observable calcar rounding was noted in 9 (15%) hips, and overall bone resorption in zone 1 was seen in 11 (19%) hips. A delineated spot weld was observed in 1 (2%) hip in zone 5, and distal bony pedestals were observed in 2 (3%) hips.

At minimum 5-year postoperative follow-up, no complications associated with the femoral component, including aseptic loosening, were noted. Two acetabular revisions were performed for recurrent dislocations within 2 years of initial surgery. No postoperative periprosthetic fractures or femoral revisions occurred. At initial surgery, no intraoperative fractures or complications were noted.

Furthermore, when measuring canal fill of the stem relative to the inner intramedullary width on anteroposterior radiographs, average canal fill was 84% (range, 63%-99%).

Discussion

Uncemented femoral implants of various designs have proven to provide stable initial and long-term fixation in patients undergoing THA.[17-21] Challenges in primary THA, including proximal/metaphyseal and distal/diaphyseal mismatch, facilitation of less invasive surgical exposures (especially the direct anterior approach), and bone preservation for potential revision surgery, have led to the evolution of short-stem designs. Studies with short-term follow-up of anatomic uncemented short-stem implants have shown them to provide pain relief, functional restoration, and stability similar to conventional uncemented designs.[5,6,22,23] Santori and Santori[4] reported reliable mid-term clinical and radiographic results in 129 custom-made uncemented, high femoral neck resection short-stem implants, but these implants represent a different design rationale. The purpose of the current study was to report the mid-term results of a standard femoral neck resection, metaphyseal-engaging, short-stem femoral implant. This implant was designed to optimize metaphyseal contact and stability with preoperative CT imaging.

No patient reported thigh pain in the current cohort, which could be attributed to the shorter stem of the design and less potential for distal micromotion.[24,25] Although tapered designs have reduced the incidence of thigh pain, it has not been eliminated.[17,26] Furthermore, average improvement of 48 points on the WOMAC scale and 41 points in HHS show pain relief and function restoration comparable with historical standards.[4,5,17,22,27-30] The current study's rate of aseptic loosening of the femoral component (0%) at 5 years is ideal and is at, or lower than, the level of other uncemented designs, including conventional implants (Table 3). This could be contributed to the optimization of the

Table 2

Bony Remodeling by Original Gruen Zones

	Gruen Zone, % of Hips With Bone Ingrowth or Resorption						
Bone Remodeling Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Endosteal condensation	28	79	81	2	74	75	14
Cortical hypertrophy	21	63	75	2	60	58	11
Bone resorption	19	3	0	0	0	2	15

Table 3

Literature Comparison of Clinical Results of Various Uncemented Femoral Implants at Short- to Long-term Follow-up

				Average			
Study	**Implant Design**	**Stem Fixation Type**	**No. of Hips**	**Postop HHS**	**Patient Age, y**	**Follow-up, y**	**Stem Revision for Aseptic Loosening, No. (%)**
Santori & Santori[4]	Custom high-neck resection short stem	Uncemented with HA	129	95	51	8	0 (0)
Stulberg & Dolan[5]	Anatomic custom short stem		65	93	56	2	0 (0)
Berend et al[17]	Conventional	Uncemented	49	84	79	5	0 (0)
Morrey[22]	Short stem with high valgus neck	Uncemented	20	98	n/a	2	1 (5)
Morrey et al[27]	Double-tapered short-stem modular neck	Uncemented	159	90	51	6	3 (1.8)
Pipino & Molfetta[28]	Anatomic femoral neck-sparing with collar	Uncemented	44	37% Excellent, 45% Good	62.5	13-17	0 (0)
Meding et al[29]	Conventional	Uncemented with HA	127	93	63	5	0 (0)
Kelly et al[30]	Conventional	Uncemented with HA	15	95	54	12	0 (0)
Current study	Anatomic custom short stem	Uncemented with HA	69	96	56	5.5	0 (0)

Abbreviations: HA, hydroxyapatite; HHS, Harris Hip Score.

proximal metaphyseal fit and subsequent bony ingrowth.

At up to 7-year follow-up, no femoral revisions of this implant were required to validate the theory of bone-conserving revision surgery. However, the necessity of bone preservation for potential revision surgery has been well documented, particularly given younger surgical candidates and the increasing longevity and activity of traditional patients.[31] Furthermore, this stem aims to optimize load transfer to the proximal femur and minimize bone resorption.[32-36] Radiographic analysis showed generalized bony ingrowth and preservation of bone stock in the proximal metadiaphysis of the femur. The infrequent (3%) observation of a distal bony pedestal also supports the proximal loading of this implant.[4]

The preservation of the calcar in the current study likely reflects the circumferential metaphyseal fit and the moderate, but not overbearing, lateral flare. The calcar is known to be most susceptible to bone loss postoperatively in general uncemented THA.[35] A lateral flare potentially provides compressive force in the proximal lateral column, preventing varus angulation.[37] However, this implant lacked an extensive lateral flare. Thus, the current authors felt that an appropriate insertion point and circumferential metaphyseal fit provided the stability, limiting the usefulness of the diaphyseal portion.[38] Nevertheless, not all short-stem implants provide the same fit, alignment, and ultimate bone remodeling.[39]

Although hip-resurfacing and femoral-neck-sparing THA have gained popularity, the surgical technique is considerably different from that of standard THA.[31,39] Standard neck resection short-stem femoral implants do not incur a steep learning curve.[23] Furthermore, recent concerns with metal-on-metal hip resurfacing may direct surgeons toward other bone-preservation techniques.[40] High neck resection or femoral neck sparing implants offer bone preservation, but concerns remain regarding bone impingement, adequate acetabular visualization, and potential increased incidence of proximal femoral fracture.[41] Short-stem implants with a standard neck cut that rely on the same surgical technique as conventional uncemented femoral designs avoid these potential complications. Molli et al[42] reported a decreased rate of intraoperative complications, including fractures, in a large series of patients who underwent THA with a short stem compared with a conventional length femoral implant (0.4% vs 3.1%, respectively).

The current study data demonstrate that short-stem implants can meet the goals of a successful THA, including being reproducibly inserted with a surgical technique associated with a minimal learning curve, providing secure enough initial fixation to allow immediate full weight bearing, allowing a high level of function without thigh pain, and providing durable fixation.

However, the study had some limitations. It represents a single surgeon's experience and approach. Also, customized implants are higher in cost and require more time preoperatively compared with standardized off-the-shelf implants. Preoperative CT scans may not be compatible with the growing scrutiny of health care costs and efficiency. Nevertheless, the implant served as a proof of principle and foundation for production of off-the-shelf designs. In addition, although the positive bone remodeling observed in this study is encouraging, radiographic analysis is inferior to roentgen stereophotogrammetric and dual-energy X-ray absorptiometry analysis in regard to accurate measurement of component migration and bone mass surrounding the prosthesis.[43,44] Engh et al[45] reported successful systematic methods of measuring bone remodeling on radiography by confirming radiographic results of stress shielding with histologic examination. Thus, a qualitative assessment of bone remodeling from radiographs acknowledges overall changes without the quantitative accuracy of advanced imaging.[45] Although the current study presents 5-year follow-up data, bone remodeling continues to undergo changes up to 8 years postoperatively.[34]

Conclusion

The short-stem implant seeks to provide a solution to the issues that remain in THA while maintaining the radiographic and clinical results of conventional implants. Long-term and dual-energy X-ray absorptiometry follow-up is needed to more definitively validate the theoretical benefits of the short-stem implant and to compare it with other bone-preserving THA procedures.

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