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Short Stem Metaphyseal-Engaging Femoral Implants: A Case-Controlled Radiographic and Clinical Evaluation with Eight Year Follow-Up

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ABSTRACT

A prospective comparison of 148 hips in 139 consecutive patients treated with an off-the-shelf uncemented metaphyseal engaging (91–105 mm) stem and 69 hips in 61 patients treated with a custom uncemented metaphyseal engaging short stem was conducted to evaluate the mid-term clinical and radiographic results of an off-the-shelf metaphyseal-engaging short stem implant. All implants were radiographically stable with proximal bony in-growth. There was no significant difference in post-operative HHS ($P <$. 001) or WOMAC scores ($P < .001$) between cohorts. An off-the-shelf short femoral stem designed to fit and fill the metaphysis provides reliable fixation up to eight years with equivalent clinical and radiographic results to a customized implant.

Total hip arthroplasty (THA) is a highly successful and cost-effective intervention for reducing pain, improving function, and enhancing quality of life in patients with moderate to severe degenerative hip disease [1–4]. Conventional length uncemented stems produce dependable long-term fixation and pain-free function in patients of all ages, bone quality and with a wide range of clinical function [5–10]. Despite the documented success of these implants, current uncemented stems are being used in patients whose size, age, level of physical activity, and bone quality present particular challenges for uncemented fixation technologies.

These challenges include: 1) The presence of proximal metaphyseal–distal diaphyseal mismatch in patients with excessively bowed femurs, deformed bone as a consequence of fracture or developmental abnormality, or in young, vigorous patients with robust, thick diaphyseal cortices and large cancellous metaphyses (Fig. 1) [11,12]; 2) the optimization of load transfer to the proximal femur, especially in younger, active patients [13,14]; 3) the ease of removal for revision surgery; and 4) the facilitation of minimally invasive approaches, such as the direct anterior approach [15–17].

Short stem uncemented femoral implants have gained popularity to address some of these challenges while maintaining the current level of success with uncemented implants of conventional length [18].

A pilot study conducted by the same surgeon and institution investigated custom-made metaphyseal engaging short stem implants based on pre-operative computed tomography (CT) imaging (Fig. 2). The custom implant was designed to maximize fit and fill in the metaphysis, providing both rotational and axial stability that conventionally comes in the diaphysis. The published results of the custom implants have had excellent radiographic and clinical outcomes at two-year follow-up [18,19]. The custom short stem implant served as a proof of principle model to demonstrate that implants without a long stem that had metaphyseal fit and fill had satisfactory clinical and radiographic outcomes. The results with the custom short stem implant spawned interest in an off-the-shelf implant with similar design characteristics without the need for pre-operative CT. For this reason, we found a shortened version of a currently available off-the-shelf femoral component with an established performance record [20].

While older generation short stem designs have reported good mid-term and long-term follow-up, current day short stem metaphyseal-engaging implants lack longer follow-up. Santori et al found clinical and radiographic success in femoral neck sparing implants at mean eight-year follow-up. They had five acetabular and/or polyethylene revisions, but no femoral component revisions during this time period. The survival rate of femoral components, along with the rate of aseptic loosening, remains pivotal in the adaption of implants in total joint reconstruction. Limited mid-term and long-term data exist on standard-neck resection short stem femoral components. The purpose of this study is to compare the radiographic and clinical outcomes of an off-the-shelf metaphyseal-engaging short stem femoral implant with those of the custom short stem implant at minimum of 4-year post-operative follow-up. Our hypothesis is that off-the-shelf short stem implants will do, clinically and radiographically, as well as the study control (custom short stems) and literature control (conventional length implants).

Furthermore, this study investigates whether 1) bone quality affected function and pain scores in the custom vs. off the shelf cohorts; 2) the frequency of varus positioning was similar and not

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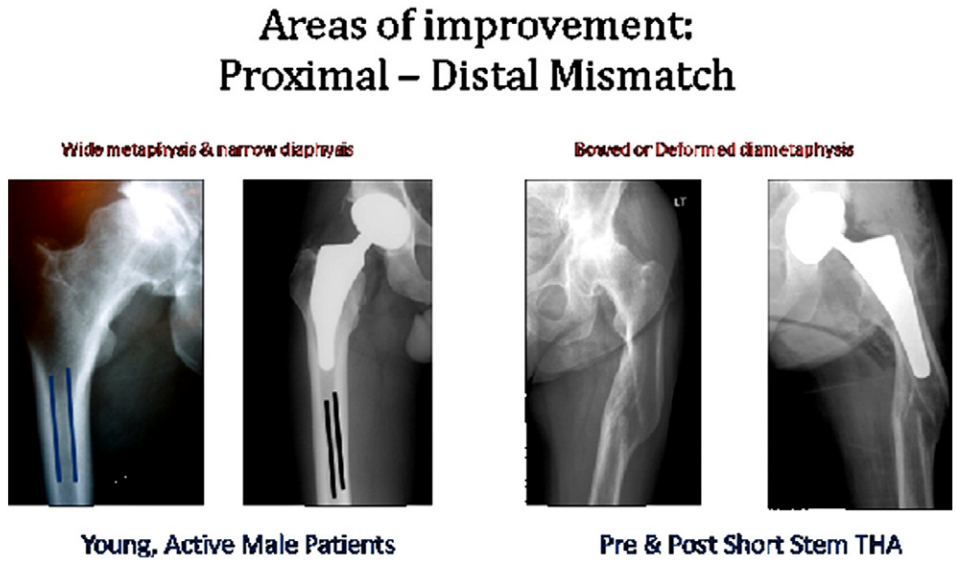


Fig. 1. Current issues in total hip arthroplasty: Proximal–distal femoral mismatch.

associated with negative outcomes; 3) age >70 had an effect on function and pain scores.

Materials and Methods

After obtaining Institutional Review Board (IRB) approval, a review was conducted of prospectively collected data of all patients who underwent uncemented primary THA with an off-the-shelf (Study) short stem implant (Citation, Stryker, Mahwah, NJ) or a custom short stem implant (Control) (Biomet, Warsaw, IN) by a single surgeon (SDS).

Patients undergoing primary THA between 2004 and 2006 were eligible for the study. In the off-the-shelf group, no exclusions were made based on age, gender, body mass index (BMI), bone quality or degenerative joint disease etiology. In the custom group, all patients were younger than 70 years. The indications for the short-stem implants included (1) osteoarthritis, (2) inflammatory arthritis (i.e., rheumatoid), (3) avascular necrosis, and (4) traumatic arthritis. The contraindication for this stem was that of any anatomic implant: a femoral deformity that precluded fit and fill in the metaphysis, for example: (1) dysplastic hips with high offset/severe valgus or (2) metaphyseal deformity secondary to fracture.

The study population consisted of 188 consecutive primary total hip arthroplasties in 177 patients (Fig. 3). A total of 15 patients (16 THAs) died in the process of follow-up secondary to causes unrelated to the THA. Eight patients (9 THAs) were contacted and declined to participate in follow-up for various reasons unrelated to the actual THA. Fifteen patients (15 THAs) were lost to follow-up. One hundred and forty-eight hip arthroplasties in 138 patients were available for this review (79% follow-up). The average age of patients in the study cohort at the time of surgery was 64 years (range, 30–86) and the average age at follow-up was 70 years (range, 36–92) with an average BMI of 28 (range, 19–67). Minimum follow-up was 4 years (mean, 67 months; range, 44–96 months).

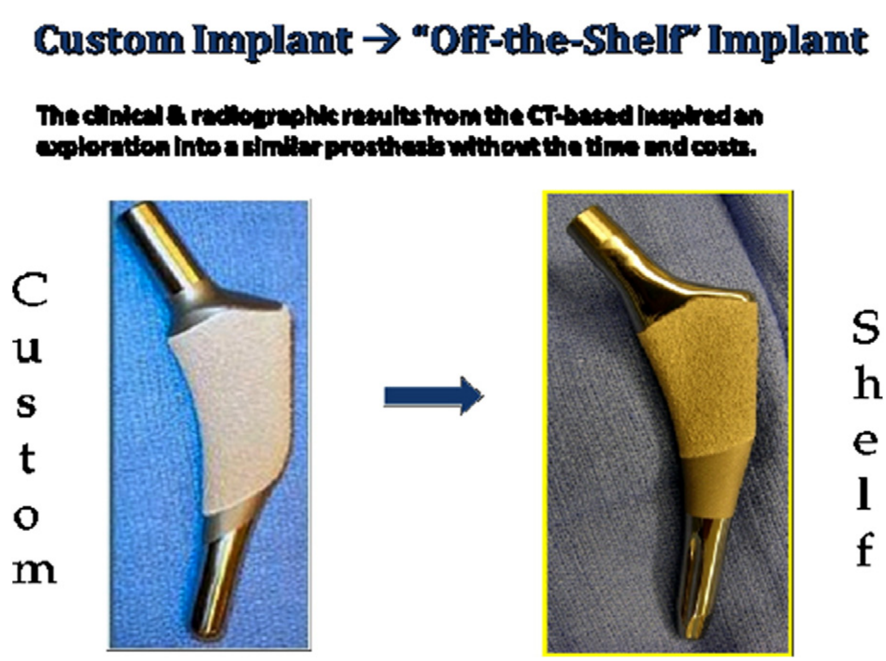


Fig. 2. Design of the off-the-shelf implant.

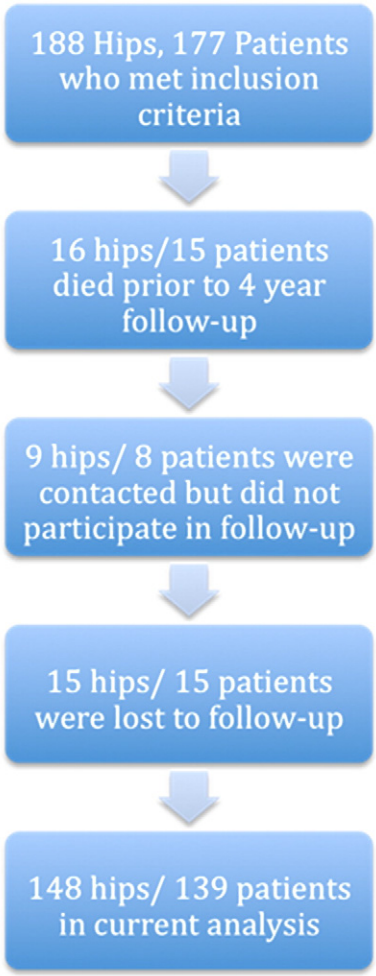


Fig. 3. Flow-diagram of patients included in this study.

Eight patients were unable to schedule follow up after 48 months due to other medical comorbidities or geography and were included in the study (range, 44–47 months).

The control cohort consisted of 61 patients and 69 THAs. Only patients under 70 years were eligible for this implant at the time of surgery and study inception. The average patient age at the time of arthroplasty was 56 years (range, 16–69) and at follow-up was 61 years (range, 22–75). The cohort had an average BMI of 28.9 (range: 20.3–44.1). Eighty custom-made short stems were inserted in 72 patients; however, of these 72 patients, 5 died secondary to causes unrelated to the THA and six patients were lost to follow-up (no patients declined follow-up). These 11 exclusions left 61 patients (69 THAs, 86% follow-up) with minimum five-year follow-up (mean, 66; range, 60–81). Demographics of both the off-the-shelf cohort and the custom implant cohort are summarized in Table 1. The metaphyseal-engaging femoral stems (Biomet, Warsaw, IN) in the control cohort were customized for each patient based on pre-operative CT scans. 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. The femoral stem was made of titanium alloy with a hydroxyapatite coating on a titanium plasma-spray in the proximal 1/3 to 1/2 of the stem. The average stem length was 90 mm (range: 70–105 mm) and the average stem diameter was 14 mm (range: 9–23 mm).

The off-the-shelf implant (Citation, Stryker, Mahwah, NJ) 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. The femoral stem was made of a polished titanium alloy with a hydroxyapatite coating on a titanium plasma-spray in the proximal 1/3 of the stem. The stem lengths varied between 90 and 105 mm.

Table 1
Demographics of Both the Off-The-Shelf Cohort and the Custom Implant Cohort.

	Off-The-Shelf Implant			Custom Implant		
Demographics	Mean	SD	Range	Mean	SD	Range
Patients	139			60		
Male (no. of patients)	79			35		
Female (no. of patients)	69			25		
Number of hips	148			65		
Left hip	67			22		
Right hip	81			43		
Bilateral short stem of respective design (no. of patients)	9			5		
Male (no. of hips)	79			37		
Female (no. of hips)	69			28		
Age at surgery (years)	64.5	11.65	30–86	56	9.1	16–69
≤70 y.o. at surgery (no. of hips)	95			65		
>70 y.o. at surgery (no. of hips)	53			0		
Age at follow-up	70	11.95	36–92	60	8.88	22–79
Follow-up (months)	67	11.99	44–96	32		22–44
BMI	28.71	7.00	19.66–67.1	29.1	6.2	26.3–54.6

A porous-coated acetabular component was used in all cases. The bearing surface was metal-on-highly cross-linked polyethylene. The standard femoral head size was 32 mm.

The same surgeon performed all of the arthroplasties with a standardized operative technique through a less-invasive posterolateral approach. The femur was prepared in a broach-only fashion, and the prosthesis was impacted until a tight metaphyseal fit was obtained. Full weight-bearing was allowed immediately following surgery.

Data gathered included intra-operative and post-operative complications, need for revision surgery, pre-operative and post-operative clinical data, as well as digital analysis of AP and lateral x-rays. All patients returned to a prescheduled outpatient clinic appointment 4 weeks after surgery for clinical and radiographic examination. Subsequent routine follow-up examinations occurred at 3, 6, and 12 months and then annually thereafter. This information was used to calculate Harris Hip Scores (HHS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain subscale scores [21–23].

Pre-operative radiographs were assigned a Dorr classification to stratify patients based on bone quality [24]. In the study cohort, 71 patients were Type A (48%), 49 patients were Type B (33%), and 28 patients were Type C (19%). In the control group, 19 patients were Type A (28%), 39 patients were Type B (56%), and 11 patients were Type C (16%).

Post-operative radiograph analysis included measures of implant stability and alignment. Varus/valgus positioning (≥5° from neutral) of the implant was measured by direct measure of angulation along the stem relative to the femoral shaft. Length measurements from the superior tip of the greater trochanter to the distal tip of the implant were compared between immediate post-operative and long-term follow-up visits; differences ≥ 2 mm were used to detect subsidence. Bony in-growth was assessed by noting bone bridging or endosteal condensation in the seven adapted Gruen Zones [25]. The presence of a fracture or a bony shelf at the tip of the component was documented. 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.

GraphPad software (GraphPad Prism Version 6, GraphPad Software Inc., La Jolla, CA) was used to assess statistical significance. A Student's t-test was used to analyze differences in sample means between custom and off-the-shelf implant cohorts, pre-operatively and post-operatively as well as to compare different stratified groups within a cohort [26]. Paired t-tests were used to assess significant differences in pre-operative and post-operative values for each cohort. Fisher's exact test was used to evaluate differences in categorical variables. An *a priori* significance level was set at $P < .05$ for all comparisons; P values are reported throughout.

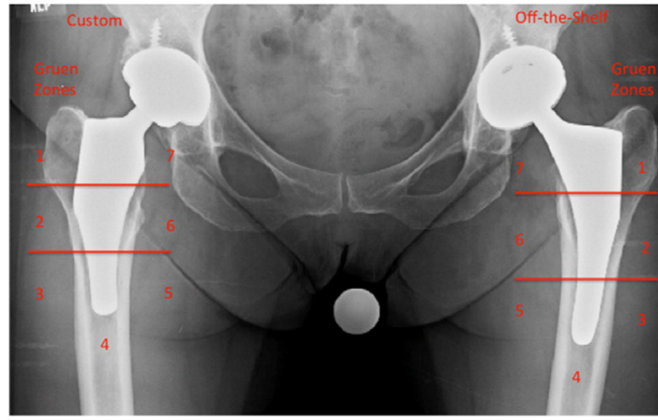
Results

At average five-year follow-up, the mean HHS was 94 in the off-the-shelf cohort (range, 55–100) and 96 (range, 55–100) in the custom cohort ($P = .2734$). The mean WOMAC score for the off-the-shelf cohort was 3 (range, 0–27) and 4 (range, 0–35) in the custom cohort ($P = .8673$). Both of these were significantly improved compared to their pre-operative scores (Table 2). No patients in either group complained of thigh pain.

One off-the-shelf implant was found to have subsided on the four-week postoperative radiograph. The patient denied a sense of instability or thigh pain. The implant was stable on all subsequent follow-up radiographs and there was no evidence of loosening. Radiographic analysis of the custom group did not reveal evidence of subsidence in any implant.

All implants in the custom and off-the-shelf cohorts had radiographic evidence of bony in-growth as seen by bone bridging and endosteal condensation, including those placed in varus. Adapted Gruen zones 2, 3, 5, and 6 most consistently showed this pattern in both groups (Fig. 4). While bone remodeling was seen in the proximal zones, there was greater positive bone remodeling laterally in the custom short stem group and medially in the off-the-shelf group. Observable calcar rounding was noted in nine hips (15%) in the custom stem cohort and in sixteen hips (15%) in the off-the-shelf cohort. There was no evidence of lucency surrounding the stem in either group. A distal bony pedestal was appreciated in 2 hips (3%) in the custom stem cohort and 1 hip (1%) in the off-the-shelf cohort. There was evidence of fibrous sclerotic lines in 7 hips in Gruen Zone 5 (6%), 3 hips in Gruen Zone 6 (3%), and 1 hip in Gruen Zone 3 (1%) in the off-the-shelf cohort.

There were 28 Dorr Type C femurs (19%) in the off-the-shelf cohort and 11 Type C femurs (17%) in the custom cohort. When both cohorts were compared, no significant differences existed in post-operative HHS ($P = .2529$) and WOMAC ($P = .9832$) scores between Dorr C groups. There were no significant differences in HHS and WOMAC scores between the Dorr C group and Dorr A & B groups in each respective cohort (Table 3).



Bony In-Growth

Custom				Off-The-Shelf		
Bone Resorption	Cortical Hypertrophy	Endosteal Condensation	Gruen Zone	Endosteal Condensation	Cortical Hypertrophy	Bone Resorption
19%	21%	28%	1	1%	0%	13%
3%	63%	79%	2	22%	9%	6%
0%	75%	81%	3	20%	10%	0%
0%	2%	2%	4	2%	1%	0%
0%	60%	74%	5	58%	37%	2%
2%	58%	75%	6	88%	60%	6%
15%	11%	14%	7	8%	5%	3%

Fig. 4. Bone Remodeling by original Gruen Zones. Numbers indicate the percentage of hips with bone in-growth (endosteal condensation or cortical hypertrophy) or resorption in the respective zone.

Forty implants (27%) were found to be placed in varus (range, 5.2°–10°) in the off-the-shelf cohort. No stems were placed in varus in the custom cohort. The mean post-operative HHS ($P = .2226$) and WOMAC ($P = .7180$) scores did not differ significantly between the stems placed in varus compared to implants placed in neutral or slight valgus. The mean native femoral neck angle of the hips placed in varus was 131° (range, 125°–137°) and the mean in the neutral and valgus hips was 132° (range, 124°–140°) ($P = .1326$) (Fig. 5).

Fifty-three off-the-shelf hip implants were placed in patients greater than 70 years of age at the time of implant. No patients over the age of 70 underwent THA with the custom short stem implant per study exclusion criteria. The proportion of hips placed in varus in patients over and under 70 years of age were not significantly different ($P = .8479$). A statistically significant portion of the patients

Table 2
Comparison of Clinical Results in Both Implant Groups.

	Custom	Off-The-Shelf
Harris Hip Score(Pre-op)	55(range: 20–90)	52(range: −10–100)
Harris Hip Score(Post-op)	96(range: 55–100)	94(range: 55–100)
P value	$P<0.001$	$P<0.001$
Custom vs. Off-The-Shelf P value	Pre-op: $P=.2034$ Post-op: $P=.2734$	
WOMAC(Pre-op)	51(range: 13–80)	48(range: 2–91)
WOMAC(Post-Op)	3.5(range: 0–35)	3.3(range: 0–27)
P value	$P<0.001$	$P<0.001$
Custom vs. Off-The-Shelf P value	Pre-op: .3114 Post-op: $P=.8673$	
Thigh Pain	0	0
Complications	2 Dislocations (1 cup revision) 0 Fractures	1 Intra-op fx 1 Post-op fx & subsidence Tx: non-surgical 2 Dislocations 2 Revisions

Table 3
Clinical Comparison of Dorr C Bone With Dorr A & B Bone.

	Dorr Type C	Rest of Cohort	*P* Value
Off-the-Shelf	28	118	
Pre-op HHS	46(range: 20–70)	53(range: −20–100)	.0699
Post-op HHS	92(range: 55–100)	92(range: 50–100)	.9422
Pre-op WOMAC	43(range: 9–82)	50(range: 12–91)	.0412
Post-op WOMAC	2.7(range: 0–22)	4.1(range: 0–27)	.3502
Custom	11	54	
Pre-op HHS	56(range: 20–80)	54(range: 20–90)	.7570
Post-op HHS	98(range: 90–100)	96(range: 55–100)	.5117
Pre-op WOMAC	49(range: 30–69)	51(range: 13–80)	.6259
Post-op WOMAC	2.7(range: 0–8)	3.6(range: 0–35)	.7182
Off-the-Shelf vs. Custom		*P* value	
Post-op HHS		.2529	
Post-op WOMAC		.9832	

over 70 years of age undergoing THA had Dorr Type C bone ($P = .0106$). There was no significant difference in post-operative HHS ($P = .4237$) or WOMAC ($P = .78$) between patients over 70 and patients under 70 (Table 4).

Six (6) complications were identified in the off-the-shelf group and two (2) complications were identified in the custom group (Table 2). In the off-the-shelf cohort, there was one intra-operative non-displaced fracture in a patient with Dorr Type C femur. The fracture was treated with cerclage wires and was stable immediately and at long-term follow-up. In the custom cohort, two acetabular revisions were performed for recurrent dislocations within two years of the initial surgery date. There were no revisions for aseptic loosening in either cohort (0%). The overall rate of complication was 4% in the off-the-shelf group compared to 3% in the custom short stem cohort.

Discussion

A wide range of proximally coated femoral implants achieve a high degree of biologic fixation and clinical success [27–29]. A relatively recent renewed interest in short stem femoral implants has led to the development of multiple new designs. Short stem implants typically have a distance of 110 mm or less from the level of the top of the prosthesis neck to the distal stem tip. The theory of metaphyseal fixation and stability renders the distal portion of conventional implants essentially irrelevant. The proximal bone contact results in stable axial and rotational fixation, while promoting proximal load transfer, and positive bone remodeling, to the femur. Arno et al performed a cadaveric study evaluating changes in femoral strain based on stem length. Longer stem lengths were associated with decreased proximal femoral strain, and theoretically by Wolff's law, increased stress shielding [30]. Chen et al investigated bone stock in patients who had undergone THA with the Mayo short stem. Through DEXA analysis the investigators found only an average bone loss of 3.3% with short stem implants compared to 20% with conventional length implants [31].

The results from this study show that an off-the-shelf metaphyseal engaging short stem femoral prosthesis provides similar results to a custom-made short stem implant designed for metaphyseal fit up to eight years after surgery. Both the custom short stem and off-the-shelf short stem have provided reliable fixation in the proximal metaphysis at latest follow-up. While customized stems have their role in the treatment of complex femoral deformities or when avoidance of osteotomy is desired, customization adds additional costs as well as increasing radiation exposure. The clinical and radiographic success of the off-the-shelf implant suggests that reliable metaphyseal fixation can be achieved without incurring the costs and time of customization.

Short stem femoral implants provide similar results to conventional length uncemented femoral implants. Söderman et al examined the Swedish National Total Hip Arthroplasty Registry between 1986 and 1995, finding the average five-year HHS and WOMAC scores were

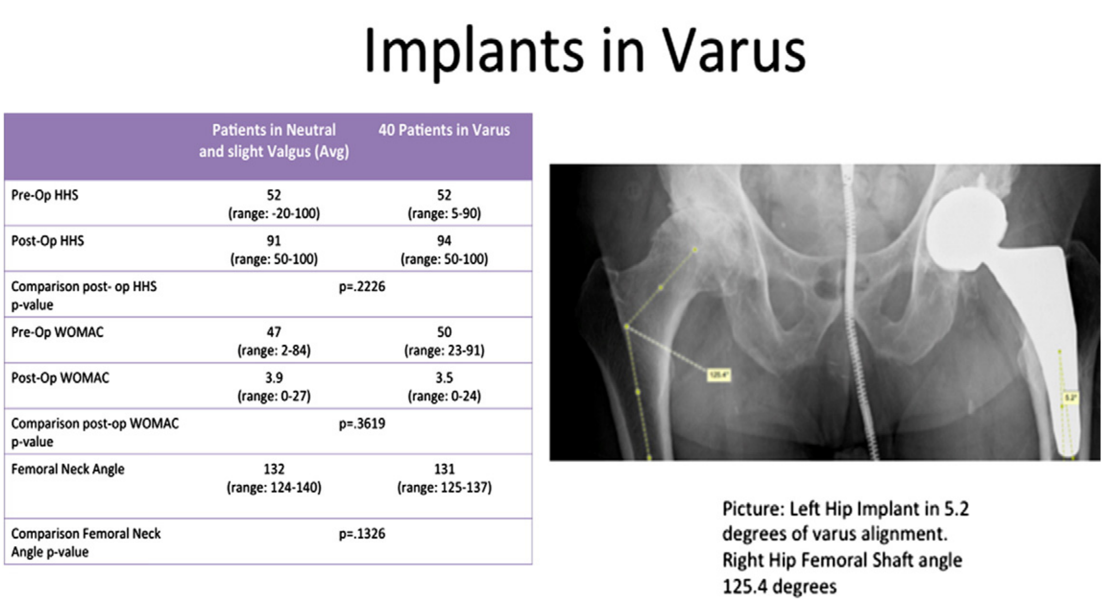


Fig. 5. Clinical scores of stems aligned in varus.

Table 4
Comparison Between Patients 70 Years of Age and Younger and Patients Over 70 Years of Age.

	Over 70 Years of Age	70 Years of Age or Younger	*P* Value
Off-the-Shelf			
Pre-op HHS	46 (range: 20–75)	54(−20–100)	.0320
Post-op HHS	93 (range: 55–100)	95 (range: 60–100)	.4237
Pre-op WOMAC	47 (range: 9–82)	49 (range: 2–91)	.4374
Post-op WOMAC	3.1 (range: 0–22)	3.4 (range: 0–27)	.78
Varus	15	25	.8479
Dorr C	15	10	.0106

87 and 71 (WOMAC scores transformed to a 100 point scale), respectively [32]. Meding et al reported an average five-year HHS of 93 in 127 THAs with no cases of aseptic loosening (0%). These results suggest equivocal outcomes between conventional and short stem uncemented femoral implants at 5 years with the potential benefits of eliminating proximal–distal mismatch, better optimizing load transfer to the proximal femur promoting bone preservation, reducing the incidence of intra-operative and post-operative fractures, allowing ease of removal in revision surgery, and facilitating minimally-invasive surgical techniques. Preserving bone stock may be especially important in younger, active patients who may require revision surgery long-term [13]. Popularity for minimally invasive techniques, such as the direct anterior approach, has increased for various reasons including potential short-term gait enhancement and muscle preservation [33]. Short stem implants better facilitate minimally invasive techniques, which can limit visualization of the femur [34,35]. If interest in the direct anterior approach continues to increase, prostheses to accommodate this approach should be developed and their results validated.

Standard neck resection short stem femoral implants require a similar surgical approach as a conventional length femoral implant. Unlike hip resurfacing and femoral neck preserving hip arthroplasty, standard neck resection short stem hip arthroplasty allows for reproducibility without a steep learning curve. Generalized adaptability of new surgical approaches and implants may introduce an element of increased complication rate. In joint reconstruction, success and use of new implants depend on complication and failure rates as various implants have proven long-term durability and efficacy.

Intra-operative peri-prosthetic fractures have a greater prevalence in uncemented THA compared to cemented THA. Berry reported a 5.4% rate of intra-operative fracture in primary uncemented THA of many designs [36]. This study had one (1) intra-operative fracture and one (1) subsequent femoral shaft fracture (1.0%). One potential explanation for the lower rate is that a shorter stem avoids issues of proximal–distal mismatch as in young patients with broad metaphyses and narrow Dorr Type A diaphyses. In addition, the anatomic design of these implants provides extensive contact proximally and avoids point loading that could initiate a peri-prosthetic fracture during insertion.

Dislocation rates vary depending on approach. All surgeries in this study utilized a less-invasive postero-lateral approach with a 32 mm femoral head and had an overall dislocation rate of 1.4% (2 total dislocations). A large epidemiologic study showed the 90-day rate of dislocation after primary total hip arthroplasty in the United States to be 3.1% [37]. Similarly, Morrey et al report a 3.5% dislocation rate in THAs performed with a 32 mm head and a posterior approach [38].

Lastly, no patients in this study complained of thigh pain, even those patients who had relative varus placement of the off-the-shelf implant. Thigh pain, while reduced with the introduction of tapered implants, remains a complication in conventional uncemented implants [39]. This difference is likely attributed to less potential for distal micromotion leading to thigh pain [39].

The bone remodeling observed in this study suggests that bone in the proximal femur is being preserved compared to conventional length implants. This observation was similar for both the off-the-shelf and customized implants. Bone preservation provides increased bone if future revision is necessary. However, no off-the-shelf short or custom implant has to date required a revision surgery to remove the implant and prove preservation of bone stock. Although proximal bone growth was most consistently seen in modified Gruen Zones 2, 3, 5, and 6 in both cohorts, a much greater proportion of bone ingrowth was seen in zones 2 and 3 in the custom stem cohort compared to zones 5 and 6 in the off-the-shelf cohort. In other words, there was greater positive bone remodeling laterally in the custom short stem group and medially in the off-the-shelf group. The off-the-shelf implant was wider at the proximal shoulder region, which could provide greater coronal fit and increased load to the compressive aspect of the femur which would load more stress medially and proximally rather than laterally. Despite similar design characteristics, minor differences in design can notably impact contact and fixation and, subsequently, remodeling.

The incidence of implants in varus in the off-the-shelf group was 27%, while it was 0% in the custom short stem cohort. The difference between the two study groups is again likely attributable to the larger lateral flare of the off-the-shelf implant which would produce a net varus effect if the starting point is not established appropriately lateral. While similar rates have been published in conventional length femoral prostheses, the higher rate of varus may be of specific concern with short stem implants [40–42]. The shortened stem lacks extension into the diaphysis and therefore is unable to aid in overall directional placement of the implant. Nevertheless, varus placement in uncemented femoral components has been proven not to be detrimental to clinical function [43–45]. All forty stems placed in varus had good biologic fixation via bony in-growth and no observed subsidence. Furthermore, these patients all had HHS and WOMAC scores similar to the rest of our cohort. These results are similar to those reported for uncemented stems of conventional length placed in varus and suggest that the extensive metaphyseal fixation achieved with the devices protects against adverse clinical and radiographic outcomes [41,42]. It has previously been hypothesized that a valgus femoral neck angle would increase the probability of placing the stem in a varus position [46]. However, this was not the case in the off-the-shelf cohort as there was no significant difference in femoral neck angles between patients with varus alignment and implants placed in valgus or neutral ($P = .1326$). Long-term results secondary to varus placement remain unknown. Early experience with short stem implants have shown that they are prone to varus placement, thus these findings emphasize the importance of developing short stem designs as well as instrumentation and surgical techniques that minimize varus alignment.

Osteoporotic bone exhibits diminished cellular and structural characteristics, potentially compromising in-growth/out-growth of the implant. Conventional length proximally coated tapered or cylindrical stems have proven clinical and radiographic success in patients of all ages and bone quality [47–49]. However, initial stable fixation of a femoral implant does not require a conventional-length cylindrical or tapered stem [18,50–52]. The short-stem model achieves stability with rigid primary fixation and extensive metaphyseal contact for osteointegration [46]. The advantages of a short-stem implant include lessening the risk of femoral perforation from a long stem [53]. In a previous study, we demonstrated stable initial and durable fixation in short-stem metaphyseal-engaging implants in patients over the age of 70 years at a minimum follow-up of 2 years [53]. This study demonstrates solid, dependable fixation of off-the-shelf short-stem femoral implants in osteoporotic bone in patients at average five-year follow-up. Berend et al evaluated 49 hips in patients 75 years and older with an uncemented double-tapered conventional length implant at an average five years postoperatively and found a mean HHS of 84 [48].

Meding et al and Kelly et al observed no difference in HHS and pain scores when patients were stratified based on Dorr classification [47,49]. However, Dorr et al concluded that the increased incidence of thigh pain in patients with Dorr Type C bone was secondary to delayed remodeling [24]. The successful function and pain scores in our study were not influenced by the presence of Dorr Type C bone. The extensive metaphyseal contact of the off-the-shelf short stem implant appears to make its use in osteoporotic bone safe and reliable [54].

This study has a number of limitations. First, it is a series of patients representing a single surgeon's experience and approach. The procedure for implanting short-stem devices is similar to that for inserting stems of conventional length so techniques and outcomes can be expected to be replicable despite surgeon preference and experience. Second, although the positive bone remodeling observed in this study is encouraging, x-ray analysis is inferior to roentgen stereophotogrammetric and dual-energy xray analysis in regards to accurate measurement of component migration, remodeling and bone mass surrounding the prosthesis[55,56]. Third, HHS and WOMAC scores are intuitively based on patient report and are subject to patient reporting bias. However, any bias effect would be no greater in our study than other published studies using the widely acknowledged hip pain and function scoring systems.

The durable fixation and desirable bone remodeling we obtained with the use of an off-the-shelf short stem metaphyseal-engaging prosthesis were consistent with the results obtained with a custom-made metaphyseal device and encourages further investigation of this design concept. The device can be inserted with a minimal learning curve and should be easily adopted by surgeons familiar with conventional uncemented total hip arthroplasty techniques.

References

1. Mancuso CA, et al. Indications for total hip and total knee arthroplasties. Results of orthopaedic surveys. J Arthroplasty 1996;11(1):34.
2. Mancuso CA, Salvati EA. Patients' satisfaction with the process of total hip arthroplasty. J Healthc Qual 2003;25(2):12 [quiz 18–9].
3. Keisu KS, et al. Primary cementless total hip arthroplasty in octogenarians. Two to eleven-year follow-up. J Bone Joint Surg Am 2001;83-A(3):359.
4. McLaughlin JR, Lee KR. Total hip arthroplasty in young patients. 8- to 13-year results using an uncemented stem. Clin Orthop Relat Res 2000;373:153.
5. Dodge BM, Fitzrandolph R, Collins DN. Noncemented porous-coated anatomic total hip arthroplasty. Clin Orthop Relat Res 1991;269:16.
6. McLaughlin JR, Lee KR. Total hip arthroplasty with an uncemented femoral component. Excellent results at ten-year follow-up. J Bone Joint Surg Br 1997;79(6):900.
7. Kim YH, Kim JS, Cho SH. Primary total hip arthroplasty with a cementless porous-coated anatomic total hip prosthesis: 10- to 12-year results of prospective and consecutive series. J Arthroplasty 1999;14(5):538.
8. Aldinger PR, et al. A ten- to 15-year follow-up of the cementless spotorno stem. J Bone Joint Surg Br 2003;85(2):209.
9. Bojescul JA, et al. Results of porous-coated anatomic total hip arthroplasty without cement at fifteen years: a concise follow-up of a previous report. J Bone Joint Surg Am 2003;85-A(6):1079.
10. Sinha RK, Dungy DS, Yeon HB. Primary total hip arthroplasty with a proximally porous-coated femoral stem. J Bone Joint Surg Am 2004;86-A(6):1254.
11. Callaghan JJ RA, Rubash HE. The adult hip. 2nd ed. Lippincot Williams and Wilkins; 2007.
12. Lewallen DG. Hip arthroplasty in patients with Paget's disease. Clin Orthop Relat Res 1999;369:243.
13. Saleh KJ, et al. Complications of total hip arthroplasty. Am J Orthop (Belle Mead NJ) 2002;31(8):485.
14. Berend ME, et al. Long-term outcome and risk factors of proximal femoral fracture in uncemented and cemented total hip arthroplasty in 2551 hips. J Arthroplasty 2006;21(6 Suppl 2):53.
15. Sherry E, et al. *Minimally invasive techniques for total hip arthroplasty*. J Bone Joint Surg Am, 2002. **84-A**(8): p. 1481; [author reply 1481–2].
16. Chimento GF, et al. Minimally invasive total hip arthroplasty: a prospective randomized study. J Arthroplasty 2005;20(2):139.
17. Ranawat CS, Ranawat AS. Minimally invasive total joint arthroplasty: where are we going? J Bone Joint Surg Am 2003;85-A(11):2070.
18. Stulberg SD, Dolan M. The short stem: a thinking man's alternative to surface replacement. Orthopedics 2008;31(9):885.
19. Patel RS, SD, Metaphyseal-engaging short stem femoral implants: five-year follow-up. In Press, 2011.
20. Hungerford MW, Hungerford DS, Jones LC. Outcome of uncemented primary femoral stems for treatment of femoral head osteonecrosis. Orthop Clin North Am 2009;40(2):283.
21. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg Am 1969;51(4):737.
22. Bellamy N, et al. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol 1988;15(12):1833.
23. Harris WH. Etiology of osteoarthritis of the hip. Clin Orthop Relat Res 1986;213:20.
24. Dorr LD, et al. Structural and cellular assessment of bone quality of proximal femur. Bone 1993;14(3):231.
25. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res 1979;141:17.
26. S., D., *The basic practice of statistics*1995: NY: Freeman and Co.
27. Capello WN, et al. Hydroxyapatite coated stems in younger and older patients with hip arthritis. Clin Orthop Relat Res 2002;405:92.
28. Sychterz CJ, Claus AM, Engh CA. What we have learned about long-term cementless fixation from autopsy retrievals. Clin Orthop Relat Res 2002;405:79.
29. D'Antonio JA, et al. Hydroxyapatite femoral stems for total hip arthroplasty: 10- to 13-year followup. Clin Orthop Relat Res 2001;393:101.
30. Arno S, et al. Evaluation of femoral strains with cementless proximal-fill femoral implants of varied stem length. Clin Biomech (Bristol, Avon) 2012;27(7):680.
31. Chen HH, et al. Bone remodeling characteristics of a short-stemmed total hip replacement. J Arthroplasty 2009;24(6):945.
32. Soderman P, et al. Outcome after total hip arthroplasty: part II. Disease-specific follow-up and the Swedish National Total Hip Arthroplasty Register. Acta Orthop Scand 2001;72(2):113.
33. Mayr E, et al. A prospective randomized assessment of earlier functional recovery in THA patients treated by minimally invasive direct anterior approach: a gait analysis study. Clin Biomech (Bristol, Avon) 2009;24(10):812.
34. Wade FA, et al. Femoral perforation complicating contemporary uncemented hip arthroplasty. J Arthroplasty 2006;21(3):452.
35. Matta JM, Shahrdar C, Ferguson T. Single-incision anterior approach for total hip arthroplasty on an orthopaedic table. Clin Orthop Relat Res 2005;441:115.
36. Berry DJ. Epidemiology: hip and knee. Orthop Clin North Am 1999;30(2):183.
37. Siguier T, Siguier M, Brumpt B. Mini-incision anterior approach does not increase dislocation rate: a study of 1037 total hip replacements. Clin Orthop Relat Res 2004;426:164.
38. Morrey BF. Instability after total hip arthroplasty. Orthop Clin North Am 1992;23(2):237.
39. Brown TE, et al. Thigh pain after cementless total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg 2002;10(6):385.
40. Mahomed NN, et al. Rates and outcomes of primary and revision total hip replacement in the United States medicare population. J Bone Joint Surg Am 2003;85-A(1):27.
41. Khalily C, Lester DK. Results of a tapered cementless femoral stem implanted in varus. J Arthroplasty 2002;17(4):463.
42. Min BW, et al. The effect of stem alignment on results of total hip arthroplasty with a cementless tapered-wedge femoral component. J Arthroplasty 2008;23(3):418.
43. Zeh A, et al. A prospective dual-energy X-ray absorptiometry study of bone remodeling after implantation of the Nanos short-stemmed prosthesis. Acta Orthop Belg 2013;79(2):174.
44. Patel RM, et al. Stable fixation of short-stem femoral implants in patients 70 years and older. Clin Orthop Relat Res 2012;470(2):442.
45. Westphal FM, et al. Migration and cyclic motion of a new short-stemmed hip prosthesis—a biomechanical in vitro study. Clin Biomech (Bristol, Avon) 2006;21(8):834.
46. Callaghan J, Rosenberg A, Rubash H. The adult hip. 2 ed. Philadelphia, PA: Lipincott Williams & Wilkins; 2007.
47. Meding JB, Galley MR, Ritter MA. High survival of uncemented proximally porous-coated titanium alloy femoral stems in osteoporotic bone. Clin Orthop Relat Res 2010;468(2):441.
48. Berend KR, et al. Cementless double-tapered total hip arthroplasty in patients 75 years of age and older. J Arthroplasty 2004;19(3):288.
49. Kelly SJ, et al. Use of a hydroxyapatite-coated stem in patients with Dorr Type C femoral bone. Clin Orthop Relat Res 2007;465:112.
50. Morrey BF. Short-stemmed uncemented femoral component for primary hip arthroplasty. Clin Orthop Relat Res 1989;249:169.
51. Santori FS, Santori N. Mid-term results of a custom-made short proximal loading femoral component. J Bone Joint Surg Br 2010;92(9):1231.
52. Santori N, et al. Bone preservation with a conservative metaphyseal loading implant. Hip Int 2006;16(Suppl 3):16.
53. Patel R, Smith MC, Woodward C, et al. Stable fixation of short-stem femoral implants in patients 70 years and older. Clinical Orthopaedics and Related Research 2011 In press.
54. Meding JB, et al. Minimum ten-year follow-up of a straight-stemmed, plasma--sprayed, titanium-alloy, uncemented femoral component in primary total hip arthroplasty. J Bone Joint Surg Am 2004;86-A(1):92.
55. Karrholm J. Roentgen stereophotogrammetry. Review of orthopedic applications. Acta Orthop Scand 1989;60(4):491.
56. Cohen B, Rushton N. Accuracy of DEXA measurement of bone mineral density after total hip arthroplasty. J Bone Joint Surg Br 1995;77(3):479.