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Original Research

Optimal Bone Preparation for Triple-Tapered Stems: Does the Sagittal Taper Affect Optimal Femoral Sizing?

Jeff Shi, MD[a, b], Kevin Salomon, MD[a, c, *], Victor Shen, BS[a], Andrew Moore, MD[a, b], John T. Wilson, MD[a, b], Brian Palumbo, MD[a, b]

[a] *University of Southern Florida Health Morsani College of Medicine, Tampa, FL, USA*
[b] *Florida Orthopaedic Institute, Temple Terrace, FL, USA*
[c] *Foundation for Orthopaedic Research and Education, Tampa, FL, USA*

A R T I C L E I N F O

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Background: Conventional single-tapered, total hip arthroplasty stems achieve fixation namely through coronal, metaphyseal fit. Triple taper stems have a sagittal taper to optimize fixation in the antero-posterior (AP) plane as well; however, limited guidance exists on appropriate bone preparation. Often, similar preparation techniques are used despite geometric differences which may lead to under-preparation. We've defined a novel technique in which a small portion of posterior femoral neck and cancellous bone is removed to permit preparation collinear to the diaphyseal sagittal femoral axis. We hypothesize this will optimize stem fit and stability compared to conventional techniques.
Methods: This is a retrospective review of 38 cementless primary total hip arthroplasty cases performed by a single surgeon. In each case, broach preparation was initially performed through the center of the femoral neck as although it was a single-tapered stem. Once tactile sensation of adequate fit was achieved, fluoroscopic images were taken to document AP and mediolateral fit, and stem size was recorded. Then that broach was removed, and a standardized one-third of the posterior femoral neck and posterior cancellous bone was removed, permitting broaches to prepare the femur collinear to the femoral diaphyseal sagittal axis— triple-tapered preparation (TTP). Outcomes included change in stem size from initial broach trial to final stem selection and radiographic stem fill on AP and lateral views.
Results: Median single-tapered preparation broach size was 8 (range, 5-12) and final stem size after TTP was 11 (range, 6-13). The TTP overall mean percent metaphyseal fill was 74 ± 6% in the AP view and 71 ± 5% in the lateral view, both significantly higher than single-tapered preparation which was 67 ± 7% and 65 ± 7%, respectively ($P < .001$). No fractures or loosening occurred in this series.
Conclusions: Preparation of triple-tapered stems collinear to the diaphyseal sagittal femoral axis improves stem size, fit, and fill.

Introduction

Cementless stem fixation for primary total hip arthroplasty (THA) continues to be the predominant mode of fixation in the United States [1]. Many contemporary stem designs are metaphyseal fitting, have a coronal taper, and varying sagittal geometries. The single taper (ST) or blade style stem has a coronal taper to engage the mediolateral (ML) cortex of the metaphysis and is relatively flat in the sagittal plane (Fig. 1). Dual-tapered (DT) and triple-tapered (TT) stems have a sagittal taper meant to fill and gain fixation in the antero-posterior (AP) metaphysis (Fig. 2b). Compared to ST stems, DT and TT designs have been shown to improve metaphyseal cortical contact thereby optimizing load transfer and mitigating stress shielding [2-8].

DT and TT stems have become increasingly popular in the United States over the past several decades [2]. According to the 2021-2022 American Joint Replacement Registry Annual Report, these stems have become the predominant design for primary THA [9,10]. Their short length facilitates implantation through anterior-based

* Corresponding author. University of South Florida, Morsani College of Medicine, USF Health Morsani College of Medicine, 560 Channelside Dr, Tampa, FL 33602, USA. Tel.: +1 813 415 7141.
E-mail address: ksalomon813@gmail.com

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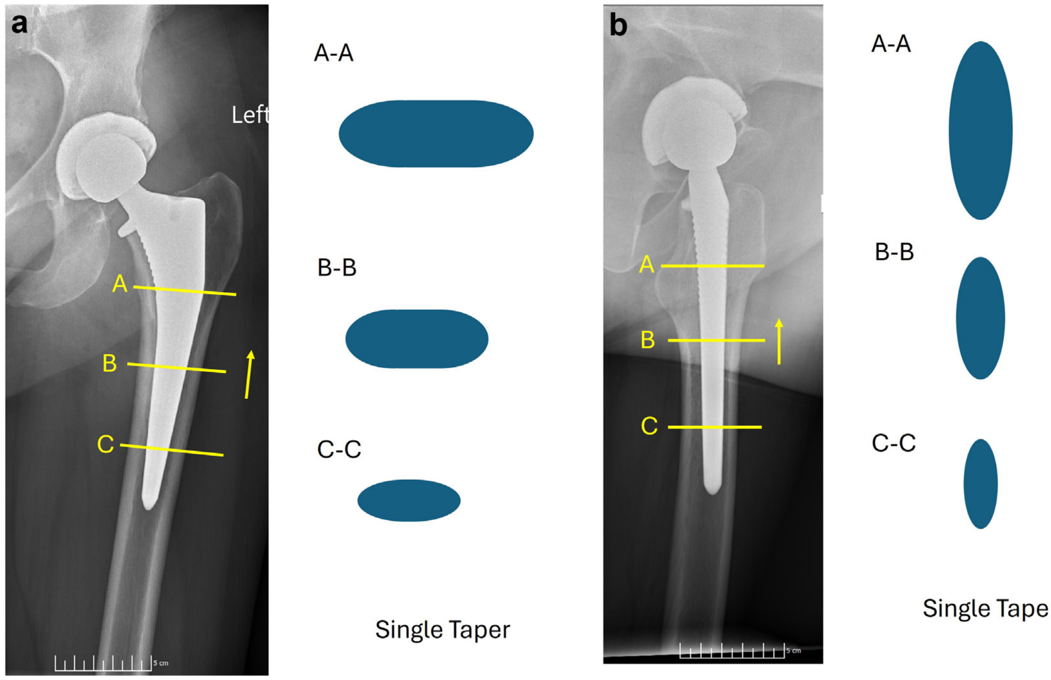

Figure 1. This demonstrates the tapering profiles of a single taper stem in the AP (coronal) view (a) and lateral (sagittal) view (b). The image demonstrates the cross-sectional views of the taper at 3 different levels of the stem. An arrow is added to show the direction of the cross-sectional views. AP, antero-posterior.

and minimally invasive approaches. Achieving appropriate metaphyseal fill has been deemed critical for initial fixation and osseointegration of single-tapered stems. Suboptimal coronal fill is directly associated with increased risk of subsidence, loosening, and revision [2,11-13]. The current literature lacks similar guidance for DT and TT stems.

The senior author (B. T. P.) transitioned from an ST to a TT stem in 2017; however, he used a similar femoral preparation technique despite the additional sagittal taper. In the early adoption period, he observed the broaches would at times fill the AP dimension of the metaphysis before adequate ML fill was achieved fluoroscopically. Presumably, this was due to the proximal sagittal taper engaging the posterior femoral neck, effectively overanteverting the stem relative to a ST stem. In these circumstances, lateral fluoroscopic images often demonstrated impingement of the broach tip against the posterior femoral cortex limiting the ability to safely upsize the component and achieve optimal ML fill (Fig. 3b). To safely upsize the broach and optimize AP and ML contact, the senior author began removing posterior cancellous bone and a small portion of the posterior femoral neck to prepare the stem in a more neutral position and in line with the femoral diaphyseal sagittal axis. In doing so, broach tip impingement against the posterior cortex was diminished, permitting safe increase in stem size and metaphyseal fill.

There is limited guidance on the appropriate method for bony preparation for DT and TT stems. We suspect that underpreparation of the femur may be an underappreciated reason for loosening and failure of these stem designs in contemporary literature. Surgeons

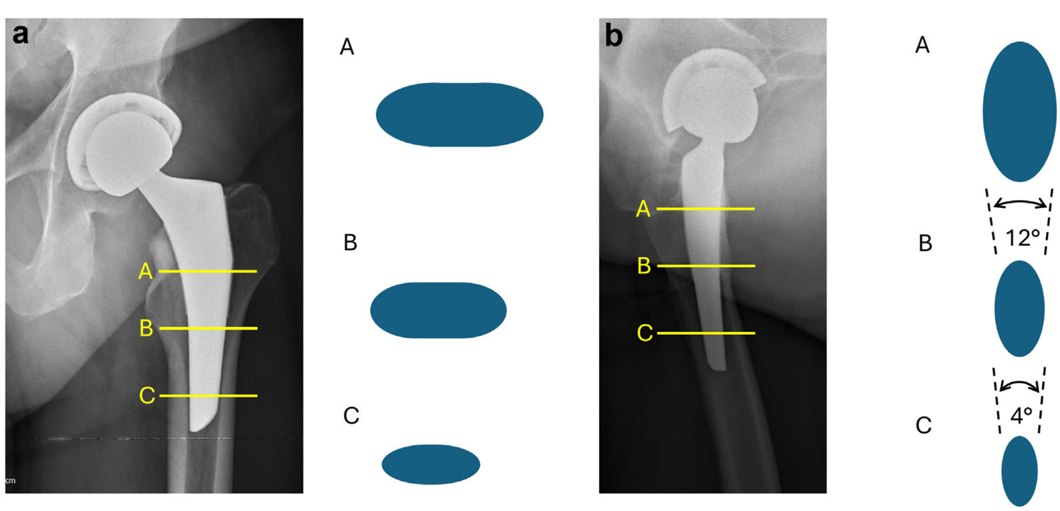

Figure 2. This demonstrates the tapering profiles of a triple taper stem in the AP (coronal) view (a) and lateral (sagittal) view (b). The image demonstrates the cross-sectional views of the taper at 3 different levels of the stem. AP, antero-posterior.

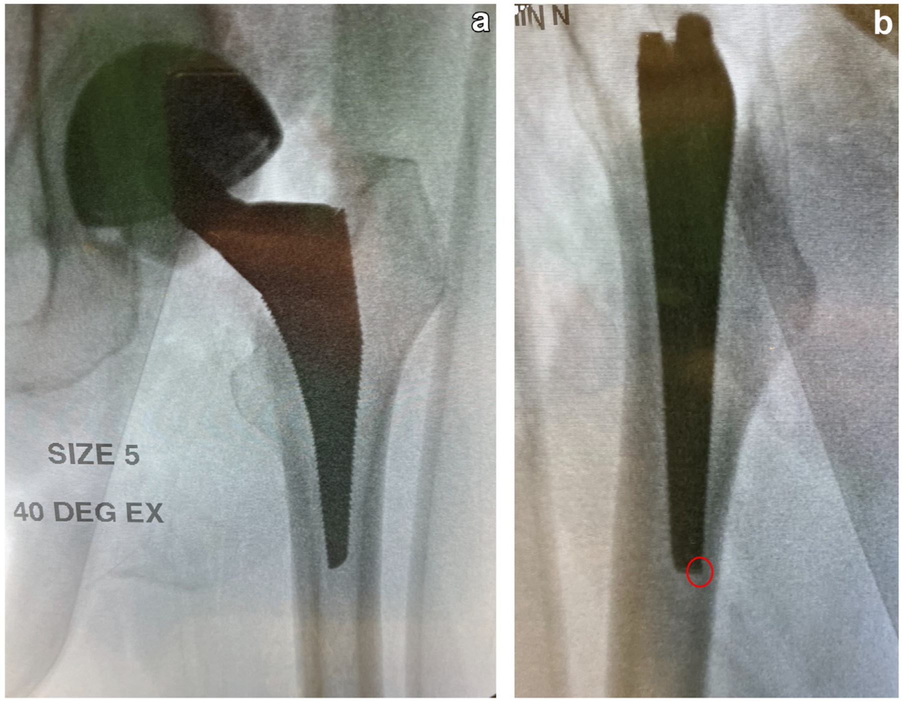

Figure 3. Fluoroscopic images of the broach trials in (a) AP and (b) lateral view are shown. (b) A red circle highlighting the suspected area of impingement. AP, antero-posterior.

transitioning from an ST to a DT or TT stem may be unfamiliar with this phenomenon and assume that the gross geometric similarities of these 2 stem designs necessitate a similar femoral preparation technique. We pose that this phenomenon may lead to stem undersizing, poor metaphyseal fill, and subsequent loosening and subsidence. We hypothesize that preparing the femur in line with the femoral diaphyseal sagittal axis will optimize radiographic AP and ML metaphyseal fit and fill.

Material and methods

Investigational review board approval was obtained prior to initiation of this study. This is a retrospective review of 54 THAs performed by a single, fellowship-trained adult reconstruction surgeon (B. T. P.) between September 2022 and July 2023 at a single center. All THAs were performed through a direct anterior approach with Hana table using the same TT stem, TaperFill (Enovis, Austin, TX), and a cementless hemispheric shell. All patients aged more than 18 years who underwent primary THA between September 1, 2022 and July 6, 2023 with a diagnosis of osteoarthritis or avascular necrosis were included in the study. Patients with a prior hip operation or congenital or acquired deformity of the same hip were excluded. A total of 54 patients met inclusion criteria; however, 16 patients were later excluded because all fluoroscopic images were not saved by the radiology technician for review and were deleted before retrieval could be performed. There were 38 patients with complete intraoperative fluoroscopic imaging included in the final analysis. Preoperative radiographs were reviewed and classified according to the Dorr classification [14]. Complications, specifically loosening, subsidence, fracture, and dislocation were recorded for a minimum of 1 year.

Standard protocol

Perioperative, pain management, and rehabilitation protocols remained consistent among all patients per the standard protocol of the senior author. Perioperative antibiotics (cefazolin or vancomycin if methicillin-resistant *Staphylococcus aureus* nares swab test was positive on admission) and antithrombotic agents (aspirin, rivaroxaban, apixaban, low molecular weight heparin, or warfarin) were administered to all patients. All patients were permitted to bear weight as tolerated and encouraged to ambulate as tolerated on postoperative day 0 within several hours after THA. Physical therapy occurred in the hospital setting or exclusively outpatient if the patient was discharged on day of operation.

Femoral preparation technique

Standard direct anterior approach was performed, and femoral neck osteotomies were performed approximately 1 cm proximal to the top of the lesser trochanter (LT). Socket preparation and implantation was performed and attention was turned toward the femur. The femur was initially prepared using TT broaches; however, we prepared the femur as although we were using a ST broach/stem (single-tapered preparation [STP]). Preparation commenced through the midsagittal aspect of the femoral neck and the anterior and posterior cancellous and cortical bone was preserved (Fig. 4a). To ensure maximal ML fit, the lateral femoral neck cortex and cancellous bone were carefully removed to ensure maximum lateralization of the broach and stem. Preparation began with the smallest broach and increased sequentially without skipping sizes. When maximum fit was deemed appropriate based on the tactile sensation of the senior author, AP and lateral fluoroscopic images (General Electric OEC 9900) were obtained, and adequacy of coronal and sagittal fill was recorded. Fluoroscopic images were performed by the radiation technician under direct guidance of the senior author to ensure images were taken in a standard way to optimize the profile of the broach in the AP and lateral planes. This completed the STP. The broach was then removed, and all posterior femoral neck cancellous bone was removed with a curette. Additionally, a small portion of the posterior femoral neck cortex was removed with a rongeur (width: the lateral half of the posterior femoral neck; depth: 5 mm) (Fig. 4b). By doing this, in theory, we were neutralizing the effect of the stem's sagittal taper or slightly retroverting the stem relative to an ST broach. After removal of the posterior femoral neck bone, femoral preparation was restarted with the broach used to take the last series of fluoroscopic images. Femoral preparation commenced until maximal fit and fill was achieved based on the senior author's tactile sensation. Once achieved, repeat AP and lateral fluoroscopic images of the stem were again taken, and trial reduction was performed.

Canal fill

Intraoperative metaphyseal canal fit was assessed with AP and lateral fluoroscopic views. We used similar metrices previously described by Warth et al. on AP fluoroscopic views; however, we added 2 additional landmarks on the lateral view to evaluate the metaphyseal canal fill in the sagittal plane (Fig. 5) [11]. The 4 landmarks on AP fluoroscopic images were (1) the neck cut, (2) top of the LT, (3) at the apex of the LT, and (4) at the midpoint between the apex of the LT and the distal tip of the stem (Fig. 5). Lateral view landmarks included (1) the apex of the LT and (2) the midpoint between the apex of the LT and the distal tip of the stem (Fig. 5). Two measurements were performed at each of the landmarks: (1) The metaphyseal canal width: measured from the inner edges of the cortices on AP and lateral views and (2) the implant width recorded at each landmark. Because magnification could not be standardized with fluoroscopy, canal fill was described as a ratio between implant width divided by the canal width at each bony landmark.

The percentage of overall canal fill on AP views was calculated based on an average of the 4 landmarks. Similarly, on lateral views, canal fill was calculated at the 2 landmarks described. The stem-femur angle was measured on the AP radiograph by drawing an orthogonal line along the femoral stem axis and another along the femoral anatomical axis, forming an angle at the intersecting lines (Fig. 6) [15]. In addition, proximal-distal matching ratios were calculated using the ratio of percent canal fill at proximal landmarks compared to distal landmarks (Table 1) [16].

Radiographic measurement reliability

Two orthopaedic surgeons (J. S. and J. W.) measured each radiograph twice. An average was calculated for each pair of measurements [17]. Interclass correlation coefficients (ICCs) for consistency between raters' measurements were found at each landmark. The final ICC values are shown in Table 2. Two orthopaedic surgeons (A. M. and J. W.) also measured the femoral canal indices to establish Dorr classification and ICC values according to Nakaya et al. (Table 3) [18].

Statistical analysis

An a priori power analysis was performed according to the data presented in the manuscript by Warth et al. to determine the appropriate sample size required [11]. A minimum of 29 patients were required to increase canal fill ratio by a minimum of 7% which

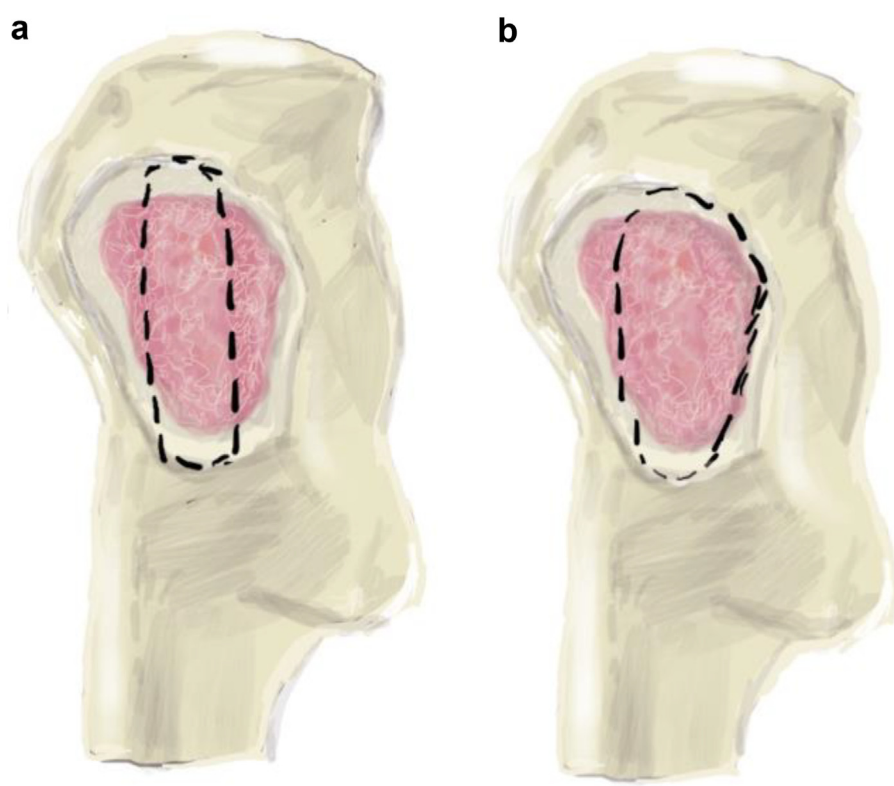

Figure 4. (a) Preparation of the femur for a single taper or blade style stem preserving cancellous bone and cortical neck anterior and posteriorly to the envelope. (b) Triple taper preparation of the femur in a fashion to remove all cancellous bone from the posterior femur and a small portion of the posterior lateral femoral neck cortex.

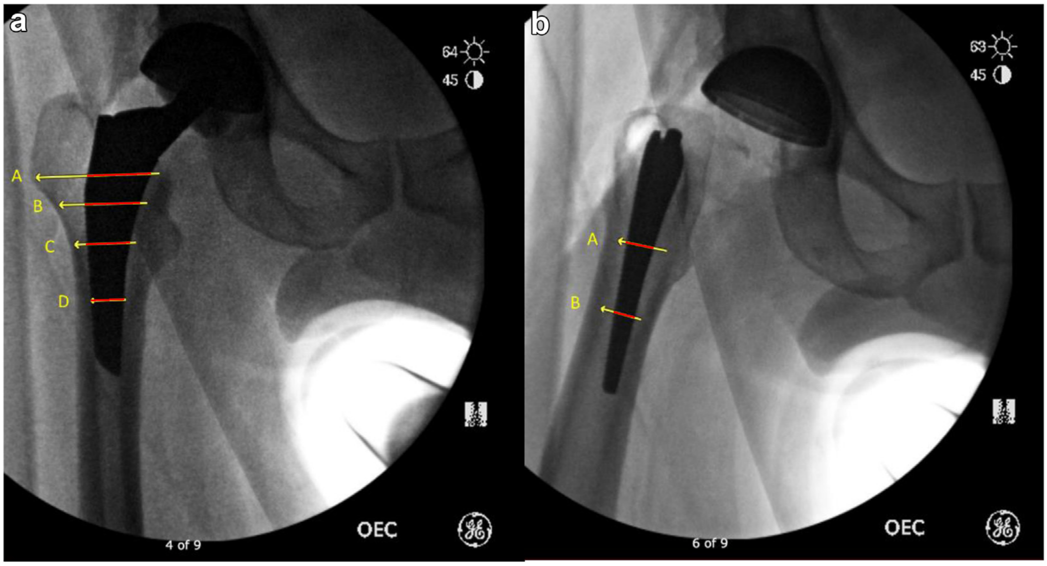

Figure 5. (a) Four locations on AP fluoroscopic imaging: (A) neck cut, (B) top of the lesser trochanter (LT), (C) apex of the LT, (D) 50% distance (midpoint) between the apex of the LT and distal tip of stem. (b) Two locations on lateral fluoroscopic imaging: (A) Apex of the LT and (B) 50% distance between apex of LT and distal tip of stem. AP, antero-posterior.

was the percent difference of successful and failed osseointegration in the report by Ishii et al. [12]. Measured characteristics are expressed as means and standard deviations. Descriptive analytics were used for clinical parameters (age, sex, and body mass index). A paired *t*-test was performed for analysis of the continuous variables including all radiographic measurements (canal fill ratios at all landmarks, implant stem-femur angle, and proximal-distal matching ratios). Measurements according to Dorr classification were also analyzed by analysis of variance. A P value of < .05 was considered statistically significant, and all related tests were 2-sided. All data were analyzed using IBM SPSS Statistics, version 29 (IBM Corp, Armonk, NY).

Results

A total of 38 hips were included in the final analysis. The mean age of patients was 64.2 years (range, 31-76) and included 19 males and 19 females. There were 22 right and 16 left hips and mean body mass index was 31.1 (range, 20.4-48.1). The indications for THA were primarily osteoarthritis in 35 cases (92%) and 3 cases (8%) of avascular necrosis. There were 20 Dorr A femurs, 15 Dorr B, and 3 Dorr C femurs.

The mean broach size on initial trial after STP was a size 8, and the mean final size after TTP technique was 11 ($P < .001$). Figure 9 shows the increase in size from initial broach to final implant.

After STP, the mean overall metaphyseal canal fill was 67 ± 7% on AP view and 65 ± 7% on lateral view. After TTP, the mean overall canal fill increased to 74 ± 6% and 71 ± 5%, respectively ($P < .001$). Canal fill ratios demonstrated a statistically significant increase at every landmark on both the AP and lateral views (Table 2). The greatest increase in percent canal fill occurred on the AP view at the midpoint between the LT and the distal tip of the stem (76 ± 9% to 88 ± 7%, $P < .001$). Although still statistically significant, the smallest increase in percent canal fill was at the neck cut (57 ± 6% to 61 ± 6%, $P < .001$).

The proximal-distal matching ratio was lowest at the neck cut on the AP view, yet still showed a significant increase after TTP technique (76 ± 9% to 82 ± 6%, $P < .001$). All landmarks showed an increase in proximal-distal matching ratio with the greatest increase occurring at the top of the LT (95 ± 8% to 103 ± 4%, $P < .001$).

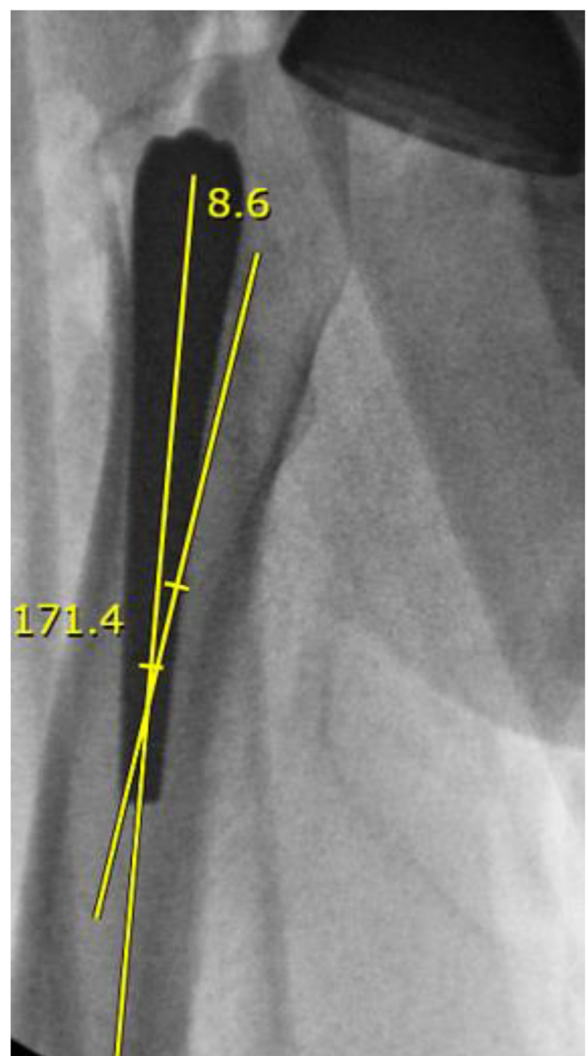

Figure 6. This is a fluoroscopic image in lateral view showing the Cobb angle between the implant and the femoral canal.

Table 1
Relationships between canal fill ratio and preparation technique after THA with a cementless tri-tapered stem.

Measurements	STP AP	TTP AP	*P* value	STP lateral	TTP lateral	*P* value
Canal fill ratio (%)						
At neck cut (P1)	57.4 ± 5.8	60.6 ± 5.6	<.001			
At top of LT (P2)	63.4 ± 8.5	69.4 ± 7.8	<.001			
At apex of LT (P3)	72.4 ± 9.2	79.5 ± 8.3	<.001	70.0 ± 8.1	76.9 ± 6.6	<.001
At midpoint from LT to distal tip (D1)	76.4 ± 9.1	88.1 ± 7.0	<.001	59.7 ± 7.2	65.2 ± 6.1	<.001
Mean total canal fill	67.4 ± 7.3	74.4 ± 6.2	<.001	64.8 ± 6.7	71.0 ± 5.3	<.001
Proximal-distal matching ratio (%)						
P1/D1	75.7 ± 8.6	81.7 ± 6.0	<.001			
P2/D1	83.2 ± 9.3	91.4 ± 5.1	<.001			
P3/D1[a]	94.9 ± 7.7	103.0 ± 4.3	<.001	118.5 ± 14.0	118.9 ± 12.2	.844
Position						
Stem-femur angle (°)	6.84 ± 3.21	6.30 ± 2.73	.033			

AP, antero-posterior; LT, lesser trochanter; STP, single-tapered stem; THA, total hip arthroplasty; TTP, triple-tapered preparation.
[a] P3 and D1 values correlated to their respective AP or lateral view and used for each ratio calculation.

The lateral landmarks showed statistically similar proximal-distal matching ratio at 118.5% and 118.9% by STP and TTP technique, respectively. The stem-femur angle was 6.8 ± 3.2° with STP and then significantly decreased to 6.3 ± 2.7° with TTP (P = .033). Table 2 includes all calculated ratios. There were no cases of periprosthetic fracture, loosening, and/or subsidence in the current series to date. The mean postoperative period for these patients to date was 17 ± 3 months (range: 12-22 months).

Subgroup analysis by Dorr classification revealed no significant different in canal fill ratio. However, Dorr A femurs had significantly higher P1/D1 ratio compared to Class B femurs (Table 3). No significant difference was found in stem size increase between femurs of different Dorr classifications.

Discussion

Despite the increase in popularity of DT and TP stems for THA, there is a paucity of guidance on the optimal method for their bone preparation and implantation. It is well known that standard femoral preparation techniques for metaphyseal fitting, tapered stems seek to optimize the stem's ML fit and is often determined solely by AP radiographic views. In the case of an ST stem without a significant sagittal taper, this is an acceptable strategy [19]. The design rational of DT and TT stems was, in part, to optimize both AP and ML cortical contact thereby improving initial fixation and proximal femoral loading [2-8]. Despite the different design rationale, a specific technique to account for the sagittal preparation has yet to be reported. We submit that obtaining lateral x-rays during supine THA can be technically challenging, time consuming, and an obstacle to evaluating fit in the sagittal plane. However, we speculate that if bone preparation and stem fit in the AP dimension is ignored, stem undersizing and loosening may occur.

In the present study, we demonstrated that removal of a small portion of the posterior femoral neck and cancellous bone permitted improved sizing and metaphyseal fit and fill in both the coronal and sagittal dimensions. We propose that with the removal of this bone, we effectively neutralized the effect of the stem's sagittal taper in directing the stem tip toward the femoral cortex. In theory, the greater the sagittal taper the more the stem will antevert as it engages the posterior femoral neck bone. If this bone is not removed and the stem is not prepared in line with the diaphyseal sagittal femoral axis, the broach tip may impinge against the posterior femoral cortex giving the surgeon the tactile sensation of adequate fit. We termed this effect "premature impingement" (Fig. 3). In this circumstance, the posterior femoral neck is effectively inhibiting optimal sizing. It is the senior author's experience that this bone tends to be rather weak and unsupportive despite being obtrusive to optimal sizing. We theorize that with repetitive, in vivo axial and rotational loads, this relative weak bone fails, permitting micromotion and subsidence. We are currently examining this theory in a biomechanical study at our institution.

The stem used in this series, TaperFill (Enovis, Austin, TX), was introduced in 2013 and was the first TT stem of its kind introduced to the market. Since then, several competitive designs have been introduced; however, outcomes and survivorship specific to these designs remain limited [5,19-24]. Historical experience of predicate, ST designs has demonstrated a clear and distinct connection among coronal fill, stem ingrowth, and survivorship. Ishii et al. reported similar canal fill ratios in their cohort of 81 patients with a notable 69% canal fill at 2 cm above the LT for those who achieved osseointegration and 62% which had failed osseointegration [12]. The percent canal fill of the patients who did not osseointegrate were significantly lower than the patients who were able to osseointegrate [12]. Of note, the TTP technique used in this study permitted an increase in the percent canal fill ratio at every

Table 2
Interclass correlation coefficients.

Measurements	STP AP	TTP AP	STP lateral	TTP lateral
At neck cut (P1)	0.84 (0.70-0.92)	0.80 (0.61-0.90)		
At top of LT (P2)	0.64 (0.31-0.81)	0.63 (0.29-0.81)		
At apex of LT (P3)	0.85 (0.72-0.92)	0.76 (0.53-0.87)	0.85 (0.72-0.92)	0.70 (0.42-0.84)
At midpoint from LT to distal tip (D1)	0.94 (0.88-0.97)	0.71 (0.43-0.85)	0.80 (0.62-0.90)	0.74 (0.51-0.87)
Stem-femur angle (°)	0.91 (0.83-0.95)	0.88 (0.77-0.94)		

Notes: ICC expressed as value (95% confidence interval).
AP, antero-posterior; LT, lesser trochanter; STP, single-tapered stem; TTP, triple-tapered preparation.

Table 3
Subgroup analysis of canal fill ratio and proximal-distal matching ratio after TT preparation based on Dorr classification.

Measurements	Dorr A femurs (n = 20)	Dorr B femurs (n = 15)	Dorr C femurs (n = 3)	*P* value
Canal fill ratio (%)				
AP				
At neck cut (P1)	+3.1 ± 2.4	+3.4 ± 2.1	+3.5 ± 1.8	.9
At top of LT (P2)	+6.6 ± 3.5	+5.8 ± 5.6	+2.8 ± 0.9	.393
At apex of LT (P3)	+7.2 ± 5.3	+7.4 ± 5.1	+4.4 ± 3.1	.653
At midpoint from LT to distal tip (D1)	+10.7 ± 6.6	+13.2 ± 7.8	+11.0 ± 8.4	.582
Mean total canal fill	+6.9 ± 3.7	+7.4 ± 4.7	+5.2 ± 3.2	.685
Lateral				
At apex of LT (P3)	+6.5 ± 7.4	+8.4 ± 4.4	+2.9 ± 6.4	.364
At midpoint from LT to distal tip (D1)	+4.5 ± 5.3	+6.6 ± 3.8	+5.8 ± 2.0	.425
Mean total canal fill	+5.5 ± 5.0	+7.5 ± 3.6	+4.4 ± 2.2	.318
Proximal-distal matching ratio (%)				
AP				
P1/D1[a,b]	**+9.1 ± 6.7**	**+2.6 ± 6.7**	+2.3 ± 14.6	**.035**
P2/D1	+8.9 ± 6.6	+7.8 ± 7.7	+4.7 ± 18.1	.699
P3/D1	+10.6 ± 8.6	+5.8 ± 6.5	+2.3 ± 14.7	.131
Lateral				
P1/D1[a]	+1.1 ± 13.8	+0.6 ± 7.8	−5.9 ± 11.5	.628
Position				
Stem-femur angle (°)	−0.95 ± 1.39	−0.98 ± 1.53	−1.18 ± 1.17	.158

AP, antero-posterior; LT, lesser trochanter; TT, triple-tapered.
Bold indicates $P \leq .05$ is considered significant.
[a] P1 and D1 values correlated to their respective AP or lateral view and used for each ratio calculation.
[b] On pairwise analysis, exclusively Dorr A and B femurs were significantly different.

landmark on both the AP and lateral views in all cases. Additionally, a statistically significant increase of a mean 3 stem sizes was found using the TTP technique. Furthermore, proximal-distal matching ratios increased across all landmarks which is similar to previously reported results [11,12]. Proximal-distal mismatch with consideration of femoral morphology must be anticipated and accounted for when choosing femoral stem design and size [25]. Canal fill ratio and proximal-distal matching ratio were also analyzed according to Dorr classes, and these results can be seen in Table 3. Due to the limited sample size in this study, future research is required to determine potential differences among Dorr classes. Finally, despite removing a small portion of the posterior femoral neck, we observed no cases of fracture and no other complications in the current series.

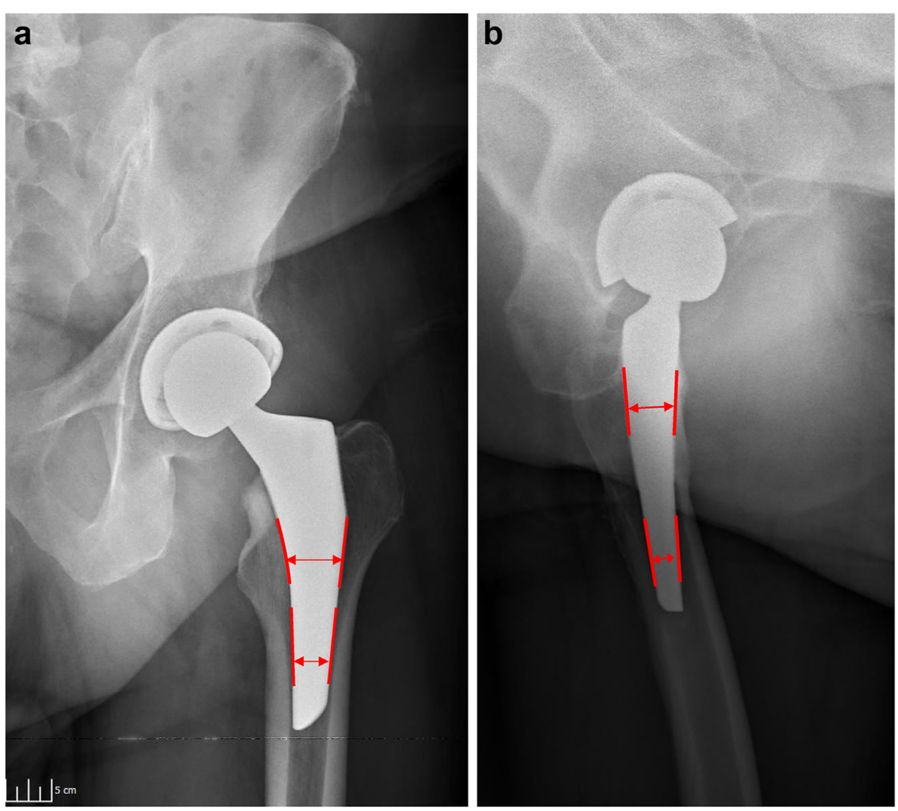

Figure 7. (a) This fluoroscopic image demonstrates the single coronal taper of a triple taper stem in the AP view. (b) This image demonstrates the 2 sagittal tapers of a triple taper stem in the lateral view. AP, antero-posterior.

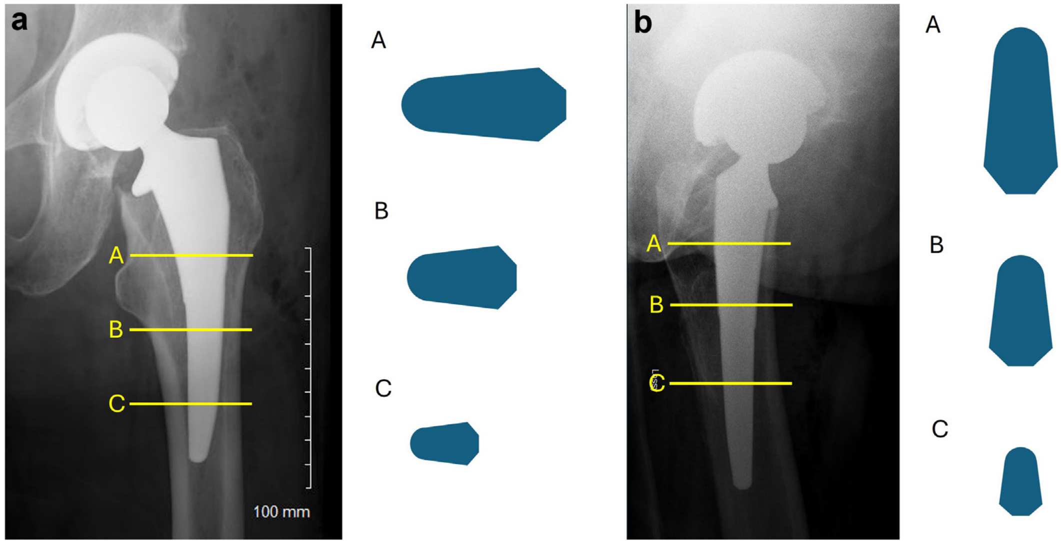

Figure 8. This demonstrates the tapering profiles of another definition of a triple-tapered stem in the AP (coronal) view (a) and lateral (sagittal) view (b). The image demonstrates the cross-sectional views of the taper at 3 different levels of the stem. The lateral side of the stem is wider and tapers to a thinner side medially. AP, antero-posterior.

Interestingly, as we investigated the details of different stem designs, it became apparent to us that different manufacturers defined the third, less conspicuous taper of TT stems differently. One definition is that the stem includes a third, sharper coronal taper that starts at the distal stem meant to mitigate diaphyseal engagement of the stem tip (Fig. 2b). The Enovis TaperFill stem is an example of this style of TT stem and consists of a 7° coronal taper, proximal 12° sagittal taper, and third distal 4° distal sagittal taper (Fig. 7). A second definition of a TT stem includes an additional axial taper where the lateral side of the stem is wider than the medial side of the stem (Fig. 8) [20]. Understanding the geometric details and how they impact metaphyseal fit and femoral preparation may be helpful and technically relevant.

There are several limitations to this study. The retrospective nature of this study has inherent limitations. It should be noted we only reported on one of several TT stem designs, and the study is based on a single surgeon's experience with a single stem design, which may introduce bias in both the surgical technique and intraoperative assessments of fit and fill. Different stem designs with varying sagittal tapers may impact intraoperative bony preparation in the sagittal plane differently and should be considered when applying the observations of the present study to individual practices and techniques. The small sample size of 38 patients may be difficult to generalize to large populations who undergo THA with cementless TT stems. However, this was an adequate sample size for our research hypothesis, as calculated by a power analysis from a similar, published study [11]. Another limitation is that the sagittal, lateral plane was only analyzed by 2 original landmarks and therefore only provided 1 proximal-distal matching ratio. The landmarks at the neck cut and at the top of the LT were determined to be too difficult to distinguish prior to initiating this study. Furthermore, the use of fluoroscopy hindered acquiring standardized measurements between films, and therefore we chose to use ratios to determine canal fill to account for this. Finally, we mainly report radiographic findings and complication rates and don't include clinical outcomes. However, this does not detract from the intent of the study which was to highlight a femoral preparation technique and its impact on radiographic fit and fill. The lack of complications such as fracture and subsidence to date is promising. However, further investigation is warranted.

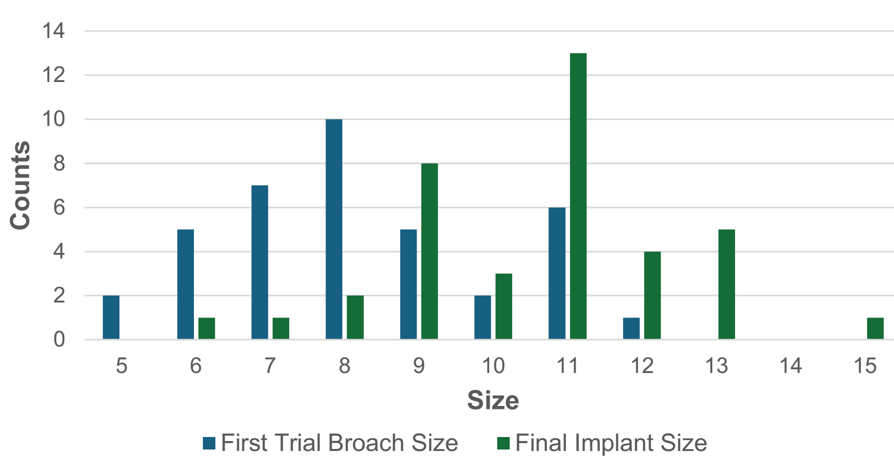

Figure 9. Femoral stem size increase graph.

We also did not simultaneously investigate other factors which may impact femoral preparation, such as native femoral neck anteversion and bone density.

In the future, larger studies should be done to further elucidate the clinical benefits of our technique and its implications to fixation and loosening. It would also be of interest to compare the varus and valgus angles of stem implants with our TTP compared to those done with an STP. We would hypothesize that our preparation, which prepares the stem collinear to the femur axis, would prevent the stem from being put in too much varus or valgus.

Conclusions

In conclusion, when preparing for DT or TT stems in THA, removing a small portion of the posterior femoral neck and cancellous bone to permit preparation collinear to the femoral diaphyseal sagittal axis was shown to increase stem size, fit, and fill in the present study. Further evaluation with a larger patient sample and correlation with clinical outcomes is warranted.

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Conflicts of interest

Brian Palumbo received royalties from Enovis, Maxx Ortho, and Conformis; is a paid consultant for Enovis, Maxx Ortho, and Conformis; owns stock or stock options in Actuos Med, LLC; and received research support from Enovis. All other authors declare no potential conflicts of interest.

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CRediT authorship contribution statement

Jeff Shi: Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation. **Kevin Salomon:** Writing – original draft, Project administration, Formal analysis, Data curation. **Victor Shen:** Writing – review & editing, Project administration, Formal analysis, Data curation. **Andrew Moore:** Writing – review & editing, Methodology, Formal analysis, Data curation. **John T. Wilson:** Writing – review & editing, Formal analysis, Data curation. **Brian Palumbo:** Writing – review & editing, Visualization, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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