Brief Report

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Biomechanical Comparison of Impaction Techniques and Cross-Sectional Femoral Stem Shapes for Cementless Total Hip Arthroplasty

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ABSTRACT

Introduction. Traditional mallet broaching and stem seating in cementless total hip arthroplasty (THA) can result in femoral stem misalignment, potentially reducing implant longevity. This study aimed to compare the pullout strength of cementless THA femoral stems with different cross-sectional designs achieved through the powered impactor method versus the traditional mallet method.

Methods. The authors utilized 24 polyurethane foam femurs and two femoral bone preservation stems with different proximal cross-sectional shapes (double taper: ACTIS®, size 5; flat taper: TRI-LOCK®, size 5). A single orthopedic surgeon broached each femur from size 0 to size 5 using either the powered impactor or mallet impaction methods. Broaching time and component implantation times were recorded. A load-to-failure pullout strength test was conducted, and the ultimate pullout load was recorded.

Results. The broaching time for the TRI-LOCK® stem showed a statistically significant difference between the two impaction methods (powered: 37±7 seconds, mallet: 75±29 seconds, $F[3, 20] = 4.56$, $p = 0.002$), but no statistically significant difference was detected for the ACTIS® stem between the two impaction methods (powered: 47±22 seconds, mallet: 59±9 seconds, $F[3, 20] = 4.56$, $p = 0.304$). There was a statistically significant difference in pullout strength between the two impaction groups, and this strength was influenced by the implant cross-sectional shape (ACTIS®: 774±75N versus 679±22N, $F(3,20) = 16.38$, $p = 0.018$; TRI-LOCK®: 616±57N versus 859±85N, $F(3, 20) = 16.38$, $p < 0.001$).

Conclusions. The technique used for femoral bone preparation (powered impactor versus mallet) and the cross-sectional design of the cementless femoral stem are crucial factors that affect initial stem stability and operation time. ***Kans J Med 2024;17:30-33***

INTRODUCTION

Periprosthetic femoral fractures and implant loosening are key reasons for revising cementless total hip arthroplasty (THA).[1-11] The preparation of the femoral bone and the design of the femoral stem are critical for achieving initial stem stability and facilitating biological osseointegration between the implant and surrounding bone.[12-17] Traditionally, femoral bone preparation involves using toothed broaches and a mallet, a technique sensitive to variations in swing, force vector, and speed.[18-23] These variations can lead to off-axis strikes, unintentional cavity space, implant malalignment, or intraoperative fracture, reducing primary stem stability. Such variations are influenced by implant size, initial cavity preparation, stem shape, and impaction vectors during insertion.[15,20,24-27] Mallet insertion can cause misalignment, leading to micro-motion between the prosthesis and bone, hindering bony ingrowth and reducing long-term implant survivability.[9,17,23]

A powered impactor device has been recently introduced to assist surgeons in achieving more consistent results during cavity preparation and stem insertion compared to manual impaction. This device also has the potential to reduce surgeon intraoperative fatigue and the risk of work-related injuries by decreasing the need for mallet use.[28,29] However, there is limited literature comparing the biomechanical bone-femoral stem holding power of this technique for the cementless THA femoral component intraoperatively. The specific aim of this study was to compare the pullout strength of cementless THA femoral stems with different cross-sectional designs resulting from the powered impactor method versus the mallet method.

METHODS

The authors of this biomechanical study utilized 24 polyurethane foam femurs (Sawbones, Vashon Island, WA) with pre-osteotomies in the femoral head and neck (six femurs/group). These foam femurs mimicked normal anatomy and were made of rigid polyurethane foam, simulating a cortical shell with inner cancellous material.

Each femur underwent preparation through broaching and implantation with the corresponding implant using either the powered impactor (Kincise, Depuy Synthes, Warsaw, IN; Figure 1A) or mallet methods (Figure 1B). Stabilization was achieved using a standard femur holder (Depuy Synthes KINCISETM Broaching System Holder, Sawbones, Vashon Island, WA), and a single orthopedic surgeon performed the procedures using a standard THA implantation technique, broaching from size 0 to size 5. Broaching time and component implantation times were recorded using a stopwatch. Broaching time was defined as the time from broach insertion to extraction for each broaching size, and component implantation time was the time from femoral stem insertion to appropriate seating within the femur.

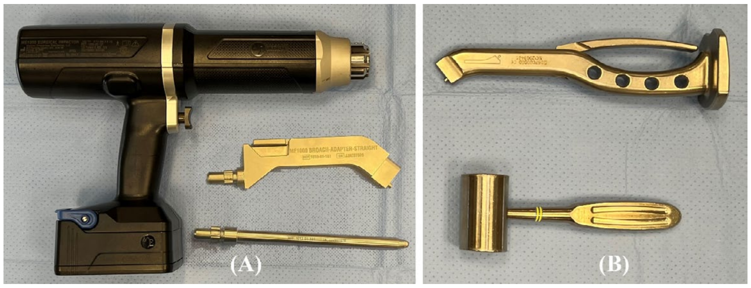

Figure 1. Femoral bone preparation technique. (A) Powered impactor, and (B) traditional mallet.

Two size 5 femoral bone preservation stems were used in the study (Figure 2). The ACTIS® femoral stem (DePuy Synthes, Warsaw, IN) features a cementless collared design with a medial collar and a double taper cross-section. The proximal portion is flared in both coronal and sagittal planes. In contrast, the TRI-LOCK® femoral stem (DePuy Synthes, Warsaw, IN) has a reduced lateral shoulder and a flat taper cross-sectional geometry with a proximal coating tapered wedge.[15,30]

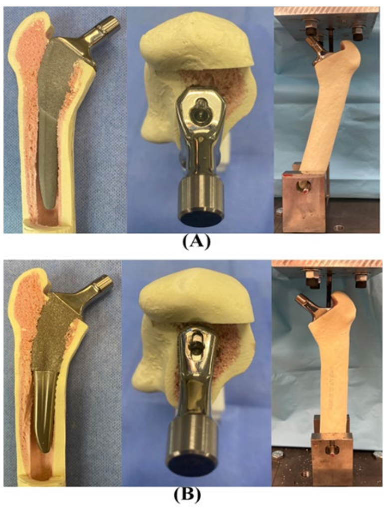

Figure 2. Femoral stems utilized in this study and the pullout strength test experimental setup. (A) ACTIS® femoral stem and (B) TRI-LOCK® femoral stem.

After each prosthesis was implanted, each THA/femur model underwent a single load-to-failure pullout strength test using a servo-hydraulic materials testing system (Model 8874; Instron, Norwood, MA). A tensile load was steadily increased to failure at a crosshead speed of 10 cm/min. Load and displacement data were collected at 100 Hz, and the ultimate failure load was recorded for each repair.

Statistical Analysis. Descriptive statistics including the mean, standard deviation, and range were calculated for the measured variables. One-way analysis of variance (ANOVA) with the least significant difference (LSD) multiple comparisons post hoc test was employed to compare notable effects among different parameters between the groups. All statistical analyses were conducted using IBM SPSS Statistics software (Version 24.0; IBM Corporation, Armonk, NY). A significance level of $p < 0.05$ was used to determine statistical significance.

RESULTS

For the ACTIS® femoral stem, the average broaching time using the powered impactor was 47±22 seconds, while with the mallet method, it was 59±9 seconds. No statistical difference was found between these two methods ($F[3, 20] = 4.56$, $p = 0.304$; Figure 3A). For the TRI-LOCK® femoral stem, the average broaching time using the powered impactor was 37±7 seconds, and with the mallet method, it was 75±29 seconds. A significant difference was found between these two methods ($F[3, 2]) = 4.56$, $p = 0.002$; Figure 3A).

In each broaching size during the bone preparation phase, completing size 0 took slightly longer for both groups compared to other sizes. For sizes 1 to 5, the powered impactor technique took about 3 to 5 seconds per size, while the mallet technique took about 5 to 10 seconds per size. Overall, there was no statistically significant difference in broaching the bone between the two techniques for each size for the TRI-LOCK® femoral stem (powered: $F[4, 25] = 1.21$, $p = 0.332$; mallet: $F[4, 25] = 0.37$, $p = 0.827$). However, a statistically significant difference was detected for the ACTIS® femoral stem (powered: $F[4, 25] = 6.06$, $p = 0.001$; mallet: $F[4, 25] = 12.0$, $p < 0.001$; Figure 3A).

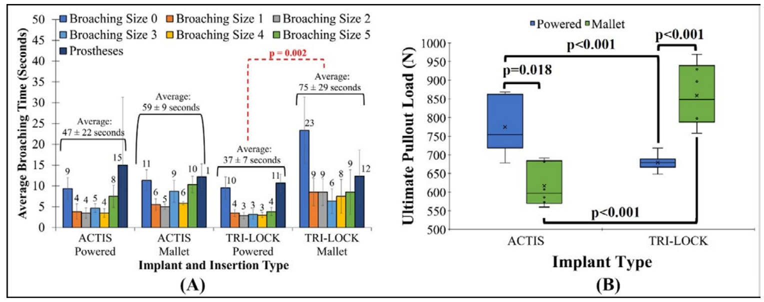

Figure 3. Experimental results. (A) Average broaching time results for each implantation technique and for each femoral stem, and (B) Ultimate pullout strength results.

The mean ultimate pullout force for the ACTIS® femoral stem was significantly higher when the powered impactor was used compared to the mallet technique (powered: 774±75 N, mallet: 616±57 N, $F[3, 20] = 16.38$, $p = 0.018$; Figure 3B). Conversely, for the TRI-LOCK® femoral stem, the result was significantly lower with the powered method than with the mallet technique (powered: 679±22 N, mallet: 859±85 N, $F[3, 20] = 16.38$, $p < 0.001$; Figure 3B).

When comparing the powered impaction method between the two femoral stems, the ACTIS® femoral stem had higher pullout strength (ACTIS®: 774±75 N, TRI-LOCK®: 679±22 N, $F[3, 20] = 16.38$, $p < 0.001$). However, when comparing the mallet technique, the TRI-LOCK® femoral stem had a higher pull-out strength (ACTIS®: 616±57 N, TRI-LOCK®: 859±85 N, $F[3, 20] = 16.38$, $p < 0.001$; Figure 3B).

DISCUSSION

This study is the first to use a well-controlled environment to simulate in vivo conditions for cementless THA, comparing the clinical application of a powered impactor to the traditional mallet method for femoral bone preparation. The current study reveals that the stability of femoral stem seating in cementless THA is influenced by both the implant impaction technique and the cross-sectional shape of the femoral components used in standard implantation techniques.

Thalody et al.[31] and Bhimani et al.[19] found, in retrospective studies, that the average operative time was reduced by an average of 12 minutes and 8 minutes, respectively, when using a powered impactor compared to the mallet technique in their THA studies with the ACTIS® stem. These findings support the results of this biomechanical study, which found that using a powered impactor in a cementless THA reduces average broaching times.

An interesting observation was made regarding the average broaching time between the two different proximal cross-sectional shape stem designs, which had similar results when using the powered impactor but different results when using the mallet method. We suspect that the femoral cross-sectional stem geometry design (ACTIS®: dual wedge, TRI-LOCK®: flat-wedge) affects the overall operative time.

Results from component extraction testing showed that the powered impactor technique does not necessarily lead to increased ultimate pull-out strength. If a stem is inserted with a slight offset from the final broach, parts of the surfaces would be prevented from bone contact. This effect could potentially result in initial stem seating instability. Prior literature has shown that failure to optimize canal fill can increase the risk of early subsidence, aseptic loosening, and migration of the prosthesis.[24,25]

Anecdotally, the powered impactor technique decreased operator intraoperative fatigue, which is consistent with previous studies.[19] The mallet impaction technique, on the other hand, may cause physical fatigue in the operator due to repeated mallet striking coupled with longer broaching times. Previous studies have reported significant variability in the applied impaction forces among surgeons using manual impaction.[32,33] High impaction forces during femoral bone cavity preparation and implant insertion increase the risk of periprosthetic fractures, while low impaction forces could result in insufficient implant seating and failure.[2,34,35]

Limitations. This study has several limitations. Firstly, synthetic bone models were used, which may not fully replicate the mechanical environment of a live human patient. Secondly, only a single load-to-failure pullout test was performed to assess stem seating, which may not fully capture the complexities of real-world scenarios. Additionally, there is a lack of direct comparison from published studies defining the optimal pullout load and correlating it to primary stem seating stability or comparing pullout strength to long-term implant survivability. Moreover, the study only used one femoral stem size and did not confirm final implant placement prior to pullout using radiographic imaging. Future research should include a larger randomized clinical study with a variety of femoral stem sizes, involvement of multiple orthopedic surgeons, and a longer follow-up period to further validate the findings of this study.

CONCLUSIONS

The choice of femoral bone preparation technique (powered versus mallet technique) and the design of the femoral stem cross-section are crucial factors influencing both the initial stability of the stem and the duration of the operation.

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