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Original research

The Impact of Varying Femoral Head Length on Hip External Rotation During Posterior-approach Total Hip Arthroplasty

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A B S T R A C T

Background: Prior investigations of total hip arthroplasty (THA) have studied the effects of prosthetic femoral head size and stem offset on hip range of motion (ROM), impingement risk, and overall hip stability to optimize the return to activities of daily living. However, the relationship between femoral head length and hip ROM, specifically external rotation (ER), has not been evaluated. The aim of our study was to intraoperatively assess how femoral head length affects hip ROM during a posterior approach THA.

Methods: Thirty-two patients undergoing a primary elective THA through a posterior approach were prospectively included. After final femoral stem insertion, femoral head trials were performed using the targeted head length, followed by the shorter (−3.0 to −3.5 mm) and longer (+3.0 to +4.0 mm) head length configurations. At each length, hip ER was measured using an intraoperative goniometer from an imageless navigation system. ER values across the three head lengths were compared using a repeated-measures analysis of variance and paired *t*-tests.

Results: Varying femoral head lengths demonstrated a statically significant and reproducible effect on intraoperative ER range (analysis of variance; $P < .001$) in each patient. An increased femoral head length (mean 3.4 mm) significantly decreased ($P < .001$) ER range by 10.8 ± 3.3° while a shortened femoral head length (mean 3.5 mm) significantly increased ($P < .001$) the ER ROM by 6.0 ± 3.8°.

Conclusions: The results of this study demonstrate the sensitivity of hip ROM to incremental changes in femoral head length. As ER is important for activities of daily living, inadvertent lengthening should be avoided.

Introduction

The basic principles of total hip arthroplasty (THA) are durable implant fixation, hip stability, and restored hip biomechanics [1,2]. While reduced hip range of motion (ROM) resulting from hip osteoarthritis is a common patient complaint and reason to undergo THA [3–5], surgeons rarely consider restoring intraoperative hip ROM as a primary goal. However, restoring optimal hip ROM after THA is important for patient-reported outcomes and overall satisfaction. Namely, optimized hip ROM has been correlated with improved postoperative hip function and reduction in postoperative THA complications [6,7].

Optimized hip ROM, particularly external rotation (ER) ROM, is critical for optimal postoperative hip functioning. Prior literature investigated which ROM parameters, including flexion, abduction, ER, internal rotation (IR), and the presence of hip flexion contractures, had the greatest association with "high" and "poor" hip function after THA. Of all hip motions, reduced ER (19.3 ± 10.2°) had the strongest correlation with poor patient-reported hip function, and greater ER (34.4 ± 8.4°) was the second most important hip motion associated with higher hip function. In addition, there was a significant positive correlation between hip motion (specifically ER) and overall hip function [8]. Indeed, hip ER is essential for several activities of daily living (ADLs) such as crossing legs and

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putting on socks and shoes, with a kinematic study reporting that patients conduct most ADLs within a maximum hip ER ROM angle of 40° [9].

Given that hip ROM is an important factor in hip stability, specifically ROM until bone, soft tissue, or component impingement, previous works have focused on how implant-related factors, such as femoral head diameter and femoral offset, influence impingement-free ROM after THA [10–19]. However, the relationship between changes in femoral head length and intraoperatively recorded ER values remains unclear. Given the importance of ER ROM in overall hip function and patient satisfaction [8,9] and how modularity in femoral head length allows for easy intraoperative adjustment of hip length and offset, the purpose of our study was to quantify the impact of varying femoral head length on ER ROM during a posterolateral THA using a goniometer from an imageless computer-assisted navigation system.

Material and methods

Patients

Data were collected prospectively and included 32 patients (32 hips) undergoing THA using a standard posterior approach from three high-volume surgeons at our institution from 2018 to 2019. Inclusion criteria included all patients with end-stage osteoarthritis between the ages of 18 and 85 years. Exclusion criteria included body mass index greater than 40 kg/m^2 and the use of dual-mobility implants. To specifically study ER ROM changes across various head lengths, hips with evidence of bone or component impingement during surgery were further excluded from the study.

Using an alpha of 0.05, a paired *t*-test power analysis indicated that a sample size of 15 was necessary to achieve 80% power in comparing ER between the target head length and the longer head length. From preliminary results, the estimated ER ROM difference was 8°, and we used a standard deviation of 10° for the power analysis.

Surgery

All procedures were performed using a standard posterior approach. The short external rotators and capsule were taken down in 2 layers and tagged for later repair, and all femoral and acetabular osteophytes were removed. At the time of surgery, femoral version was assessed, and then the acetabular component was placed using image-less computer navigation (Intellijoint Surgical Inc., Waterloo, Canada). Both neutral and elevated liners were utilized based on surgeon preference. The femoral component was prepared to match the patient's native femoral version. Hip stability was assessed prior to final stem insertion and femoral head length selection.

Measurements

The leg was placed in neutral hip extension/flexion, the hip was placed in 10° abduction, and the knee was flexed to 90°. With the surgeon's hand supporting the knee and the tibia parallel to the horizontal, the hip was externally rotated until a natural endpoint was reached. We ensured that the operative table was not contacting the operative foot, preventing additional ER. The angle between the horizontal and the long axis of tibia was measured using the digital protractor function of the Intellijoint Hip optical computer-assisted surgical (CAS) alignment system (Intellijoint Surgical Inc., Waterloo, Canada) [20–22] (Fig. 1).

ER ROM was measured once each time after implanting the definitive stem with three different femoral head lengths. Head

Figure 1. The long axis of tibia demonstrating external rotation of hip. The Intellijoint camera was mounted on a Mayo Stand at the end of the bed, and the surgeon zeroed the alignment rod parallel to the horizontal axis. The surgeon's hand then supported the leg under knee and tibia and allowed the leg to rotate under gravity to make ER measurements.

lengths were chosen according to the surgeon's "target" length based on the surgeon's assessment of optimal offset and leg length restoration on standard anteroposterior pelvis radiographs. The ER ROM was measured with the "target" head length and recorded. The femoral head length was then increased 1 size above the target, and the ER hip ROM was again recorded. Finally, the femoral head was decreased 1 femoral head length below the "target" head length, and the ER ROM was recorded. Typically, head lengths varied by ±3.0 mm-4.0 mm according to manufacturer. Component-to-component impingement was assessed in all cases to confirm the femoral neck did not contact the liner or cup during ER. Patients were excluded if component-to-component impingement or trochanter-on-pelvis bone contact was directly visualized when the hip in maximum ER.

All patients included in our study also underwent postoperative imaging for evaluation of component positioning after THA. Femoral version and combined anteversion were measured using 3D reconstruction of biplanar 2D EOS imaging (EOS Imaging, Paris, France). Postoperative cup anteversion was based on the functional pelvic plane in the standing position.

Statistical analysis

Joint ER ranges were compared using a femoral head of the same size and offset but with shorter (−3.5 to −3.0 mm from target) and longer (+3.0 to +4.0 mm from target) head length configurations for each patient. In order to specifically assess whether there were significant differences in the ER ROM range between the shorter, target, and longer femoral head lengths in each patient, statistical analyses were conducted using a repeated-measure analysis of variance (ANOVA) and paired *t*-tests, which controlled for implant variability between patients and removed potentially confounding factors including baseline combined anteversion and target head lengths. The targeted femoral head length configuration was used as the control group in this study, and $P < .05$ was considered significant. Statistical analysis was conducted with R software.

Results

Of the 32 patients included in this study, six were excluded due to 1 of the following reasons: failure to collect ER ranges intraoperatively, evidence of bone impingement, inability to fit all trial head lengths (up 1 head size or down 1 head size from the target head length), or a significant flexion contracture limiting ROM assessment. After these exclusions, 26 total hip replacements were available for analysis. Of these 26 cases, eight utilized lip liners without evidence of component impingement. The demographic and implant information is presented in Table 1. Femoral and combined anteversion values were 9.5° ± 10.6° (range, −11° to 28°) and 32.2° ± 10.9° (range, 9°-50°), respectively.

Figure 2 represents all ER measurements across the three different head lengths for each of the 26 patients. Pairing the ER measurements for each patient demonstrates a decrease in ER ranges with greater head lengths irrespective of initial target head length and baseline ER ranges.

Individual ER ranges for each patient for the shorter, target, and longer femoral head lengths are represented in Figure 3. While hip ER ranges varied significantly between patients (ANOVA, $F(25,50) = 29.50$, $P < .001$), there was a statically significant effect of varying femoral head lengths on intraoperative ER range (ANOVA, $F(2,50) = 235.22$, $P < .001$) in patients. The mean ± standard deviation of hip ER ranges in the shorter, targeted, and longer femoral head length configurations is summarized in Table 2. The mean ER range with the targeted head length was 38.8° ± 9.2°, the mean ER range for the longer femoral head length was 28.0° ± 9.3°, and the mean ER range for the shorter femoral head length was 44.8° ± 9.2°. When comparing the longer head length configuration to the targeted head length configuration, a paired, two-tailed *t*-test indicated that the longer head length resulted in lower ER ranges ($T(25) = -16.54$, $P < .001$). Longer head lengths (average +3.5 ± 0.2 mm) were associated with a significant decrease in ER range of 10.8° ± 3.3°. Conversely, when comparing the shorter head length configuration to the targeted head length configuration, a paired, two-tailed *t*-test showed that the shorter head length (average 3.4 ± 0.2 mm) resulted in a mean increase in hip ER of 6.0° ± 3.8°.

Discussion

The purpose of our study was to investigate the effect of varying femoral head lengths on intraoperative ER range in patients undergoing THA. We demonstrated through repeated-measures analysis that there was a significant effect of varying head lengths on ER range in patients. Paired *t*-tests revealed that there was a significant decrease in ER range with the use of 1-size-longer

Table 1
Demographic and implant information.

Variable	Mean or (N), N = 26
Demographic	
Age	65.2 ± 10
Body mass index	28.4 ± 6.2
Females	(15)
Implant type	
DePuy[a]	(22)
Smith and Nephew[b]	(1)
Zimmer[c]	(2)
Zimmer/DePuy	(1)
Acetabular cup head size[d]	
28 mm	(1)
32 mm	(6)
36 mm	(18)
Acetabular cup	
Cup size	52.2 ± 3.1 mm
Cup anteversion	23.5 ± 4.4°
Cup inclination	42.4 ± 2.4°

[a] Warsaw, IN.
[b] Andover, MA.
[c] Warsaw, IN.
[d] Information was unavailable for 1 patient.

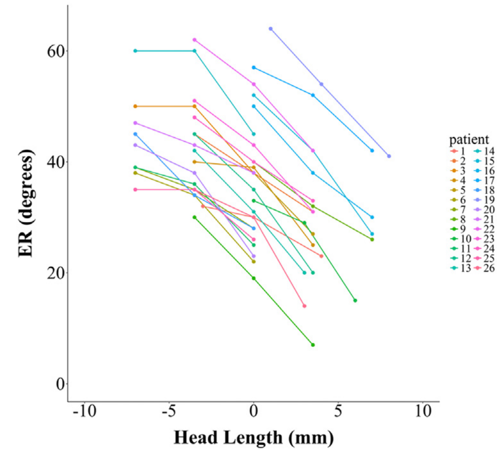

Figure 2. Scatter plots of ER ranges (degrees) vs the head length (mm) of all 78 measurements. Matched patient data show general decreases in ER range with increasing head length. Target head length represented by 0 mm.

femoral head compared to the target head length (10.8° ± 3.3°). Furthermore, shortening the femoral head length in each patient by 1 size was associated with increased ER ranges as well, but to a lesser extent (6.0° ± 3.8°). Together, these results emphasize the sensitivity of hip ER ROM to relatively small changes in femoral head lengths when selecting lengths to restore leg length discrepancies and achieve hip stability.

Because each hip was assessed carefully for any evidence of bone or component impingement, the ER ROM values were primarily influenced by soft-tissue tension. All combined anteversion values were also equal to or below 50°, making it unlikely that there was component impingement in our cohort. We postulate that longer femoral head lengths, which increase both vertical length and horizontal offset, limit the joint ER range through increased soft-tissue tension of the anterior and lateral capsules. In particular, previous biomechanical studies provide support for the important role of the pubofemoral and iliofemoral ligaments in limiting hip ER, acting as check-reigns to motion in this plane. The pubofemoral ligament controls ER in extension, whereas the iliofemoral ligament contributes to ER in both flexion and extension [23]. Myers et al. conducted a cadaveric study where they compared the ER range of hips after sectioning and repairing the iliofemoral ligament and acetabular labrum [24]. After sectioning the iliofemoral ligament, ER range

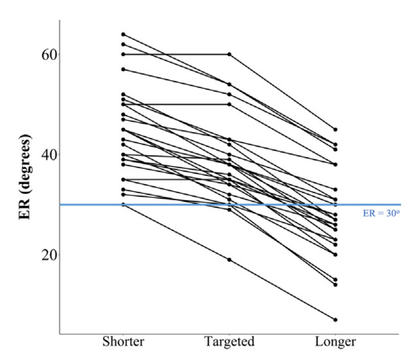

Figure 3. A line plot showing ER ranges (degrees) for every patient in shorter, targeted, and longer head length configurations. Shorter, targeted, and longer configurations were dependent for each patient due to the type of implant used. Femoral head size was kept constant for each patient. Paired *t*-tests show significant differences between longer and targeted head lengths ($P < .001$) and between shorter and targeted head lengths ($P < .001$).

Table 2
Summary of external rotation range measurements by head length.

Head length	Mean (°)	Standard deviation (°)	Minimum (°)	Maximum (°)
Shorter	44.81	9.15	30	64
Targeted	38.81	9.18	19	60
Longer	27.96	9.26	7	45

significantly increased, and after repairing the iliofemoral ligament, ER range significantly decreased [24]. In addition, another cadaveric study by Johannsen et al. found that increasing the laxity of the anterior capsule expands hip rotation in both IR and ER [25]. Given this relationship between soft-tissue tension and joint ER, it is possible that longer head lengths in our study increased the anterior capsule stretch and tension, consequently decreasing laxity and limiting ER ROM. Interestingly, we found that increasing the femoral head length resulted in larger differences in the ER ROM than did decreasing the femoral head length. This may be because longer head lengths, compared to shorter head lengths, altered soft-tissue and capsular tension to a greater degree.

There were three patients that did not show any difference in ER ROM from the shorter to target head length. In these patients, it is possible that the shorter head length did not alter the soft-tissue tension of the hip at all compared to the "target" head length. To support this mechanistic explanation, further investigations are necessary to evaluate whether (1) ER is specifically limited by increased anterior capsular tension and (2) longer femoral head lengths increase anterior capsular tension. Sectioning studies in cadavers could aid in establishing these relationships.

Although previous literature has focused on ROM as a critical measurement to assess the functionality and dislocation risk of THAs, they have only tested the effects of implant-related factors such as femoral head size [10,12–19] and head offset [11,12,16] on hip ROM. Burroughs et al. evaluated, via experimental models, the effect of larger head sizes for THA on the type of impingement, ROM, and joint stability, demonstrating that larger femoral heads provide greater hip ROM and joint stability [10]. Girard et al. also examined femoral head diameter and demonstrated improvement in ROM, delayed cam-type impingement, and reduction in dislocation [11]. Matsushita et al. quantified the effects of both femoral offset and head size ROM in a cadaveric model where increasing the femoral offset to 4 and 8 mm resulted in 21.1° and 26.7° of improved flexion and 13.7° and 21.2° of improved IR, respectively, [12]. Thus, increased femoral head size in addition to the selective use of increased-offset femoral stems to restore hip offset has been associated with decreased risk of impingement, dislocation, and optimized clinical outcomes [13,14]. However, no demonstration of the effect of head size and/or offset on ER was assessed in these studies, with its important clinical patient-reported implications. In a comprehensive review, Cross et al. detailed the trend towards increasing the femoral head size in THA to improve stability and impingement-free ROM. They did not find any studies specifically commenting on the effect of head length on hip ROM such as ER [15]. Previous studies, however, do indicate that femoral head diameter does not significantly affect ER ranges [16], and another study reported that patients with an increased femoral stem offset had larger intraoperative ER ranges [17]. Our findings add to this growing literature on implant-related factors of ROM, showing that head length also plays an important role in ER, likely through anterior capsular tensioning.

The results of this study highlight the sensitivity of hip ER ROM to changes in head length, and this may have clinically important ramifications. As Davis et al. highlighted, ER ROM has large implications for quality of life and hip functionality after THA [8]. In their study, patients were placed into three motion groups with ER ROM means at 34.4° (±8.4°), 30.3° (±9.1°), and 19.3° (±10.2°) for high, average, and poor hip motion, respectively. There was a positive correlation between hip motion and clinical outcome scores, with high and low hip motion groups scoring 100 ± 0.2 and 81.2 ± 14.6 on the Harris hip score [26], respectively, [8]. Regarding ER ROM in ADL, a cross-sectional study by Hyodo et al. measured the hip kinematics in healthy adults conducting various tasks [9]. Notably, all ADLs reported in their study, except putting on shoes while sitting with legs crossed, required a maximum ER angle of 40° [9]. These values are critical given that 45% of patients report having difficulty with ADL including washing and dressing after THA [27].

In our study, we found that increasing the femoral head length decreased the hip ER below 30° for 16 of 26 patients (61.5%) and below 20° for 3 of those patients (11.5%). Taking the motion groups, as from Davis et al. [8], as markers for hip functionality, this indicates that increasing the femoral head length would have decreased the functional category of the majority of our patients from "high" to "average" or to "poor." Thus, femoral head length should be carefully selected to optimize hip biomechanics and to allow for adequate hip motion in patients after THA. To our knowledge, there is currently no defined threshold for target intraoperative ER ROM to improve a patient's ability to conduct ADL. However, given that maximum ER angles of 40° afford patients the ability to conduct most ADLs [9] and an ER of 34.4° was classified as "high hip motion" with high functional scores in a separate study [8], we suggest that femoral head lengths are adjusted to achieve an intraoperative ER range between 35° and 40°. However, these targets should be considered with respect to first achieving hip stability and restoring leg length discrepancy. Our findings show that increasing the femoral head length by just 1 configuration (~3.5 mm) can significantly reduce a patient's ER ranges through a decrease of approximately 10.8°. In this way, although increasing femoral head length to improve hip stability impacts leg length, it can significantly decrease hip ROM. Decreased ROM then negatively impacts clinical outcomes given that achieving intraoperative ER ranges of 35°-40° correlates with higher functioning hips [8] and ultimately a higher quality of life.

Finally, our work has implications for patients undergoing posterior-approach THA who have tensioned anterior capsular ligaments. In these patients, appropriate tension of the anterior capsule ligaments through careful femoral head length selection could optimize ER range after THA [25]. While selecting configurations with a shorter head length increases hip ER ROM values, caution must be used as a shorter leg length with reduced offset could increase the risk of postoperative instability. The key to optimized hip reconstruction is achieving hip stability as well as careful and appropriate leg length and offset restoration that will also lead to optimized hip ER ROM sufficient for daily activities. This study utilized a CAS navigation system to measure hip ER intraoperatively with the hip in neutral position and knee in 90° of flexion. Without a CAS system, the tibia and flexed knee can still serve as an anatomical axis and landmark to measure the ER ROM manually to optimize these parameters for THA.

This study had several limitations. First, measurements were conducted intraoperatively, and ER ROM was not assessed postoperatively at a follow-up visit. However, the intraoperative ER measurements made with targeted head lengths in the current study were comparable to those in other studies with intraoperative and postoperative measurements (36°) [8,16,28]. Studies investigating the clinical effects of increased and decreased intraoperative ER as a result of varying the femoral head length would be of further interest and of clinical value. Furthermore, depending on the type of implant used, the differences between the shorter, targeted, and longer femoral head configurations differed between 3 mm and 4 mm. Nonetheless, we found that ER angles decreased regardless of implant type or exact head length used for the patient as head length configuration increased incrementally for each respective implant system. Each patient also had different implants, cup sizes, head sizes, initial ER ranges, femoral version, and acetabular cup orientation angles, but we attempted to remove these potential confounders through a repeated-measures design to show that regardless of these factors, ER ROM changes due to varying head lengths were patient-specific. Studies investigating the specific effects of these other factors in relationship to ER and the magnitude of ER change with varying femoral head lengths are of interest in larger studies. Additionally, the findings in these studies are limited to the posterior-approach THA. Investigations studying the effects of femoral head length on ER ROM through an anterior-approach THA with anterior capsulotomies are also warranted. Finally, femoral head length affects both offset and leg length, and future studies should investigate these 2 factors individually and their effects on ER

Conclusions

The results of this study highlight the exquisite sensitivity of the hip external ROM to small changes in femoral head length. A longer femoral head length (+3.4 mm) significantly reduced ER ROM by 10.8° in patients undergoing THA. The results of this study emphasize the sensitivity of the hip joint to small changes in femoral head length as only a few millimeters of femoral head lengthening can lead to large reduction in hip motion that could negatively impact clinical outcomes. Further investigations are necessary to assess whether targeting intraoperative ER (of around 40°) increases postoperative hip function and determine the exact mechanism how increased soft-tissue tension limits ER.

Conflicts of interest

P. K. Sculco is in the speakers' bureau of DePuy, A Johnson & Johnson Company, EOS Imaging, and Intellijoint Surgical; is a paid consultant for DePuy, A Johnson & Johnson Company, EOS Imaging, Intellijoint Surgical, Lima Corporate, and Zimmer; has stock or stock options in Parvizi Surgical Innovation and Intellijoint Surgical; and receives research support from Intellijoint Surgical. A. G. Della Valle receives royalties from Orthosensor and OrthoDevelopment; is a paid consultant for OrthoDevelopment, Orthosensor, Intellijoint Surgical, and LinkBio; and receives research support from Intellijoint Surgical. D. J. Mayman receives royalties from OrthAlign and Smith & Nephew; is a paid consultant for Stryker; has stock or stock options in Imagen Technologies, InSight, OrthAign, and Wishbone; and is a board member in Hip Society and Knee Society. The other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.101072.

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