A comparison of seven stems in restoring femoral offset and leg length using three-dimensional templating

Mitsutake R, Tanino H, Ito H
Asahikawa Medical University, Asahikawa, Japan
Email of Presenting Author mitutake@asahikawa-med.ac.jp

Disclosures: Mitsutake R(N), Tanino H(AsahiKasei), Ito H(N)

Introduction: A proper restoration of biomechanical parameters of the hip joint is fundamental to achieve satisfactory outcomes in terms of hip functionality after total hip arthroplasty (THA) [1]. The femoral offset and leg length were identified as relevant predictors of clinical function, and adverse outcomes as a result of inaccurate hip geometry restoration [2]. Preoperative templating in THA can help achieve appropriate femoral offset and leg length [3]. Today, a wide range of femoral implants with varying neck-shaft angles is available, and lateralized variants allow for the restoration of the femoral offset without influencing leg length [4]. Few analyses have addressed restoration of individual hip geometry with regard to differences in the restorative potential of femoral implant concepts [3, 5]. In this study, we investigated how closely anatomical femoral offset and leg length could be restored using three-dimensional (3D) templates for 6 femoral cementless nonmodular stems in common use in the Australia and 1 femoral cementless modular stem [6].

Materials and methods: The study was approved by the institutional review board. We retrospectively compared preoperative templating data in all 144 primary THAs. Between May 2017 and December 2020, 72 consecutive hips (14 men and 58 women) with unilateral osteoarthritis (OA) including all hips with developmental dysplasia of the hip (DDH) have been analyzed using computed tomography (CT) scanning with images processed using ZedHip (Lexi Co. Ltd.,) software [7, 8]. Between January 2015 and December 2020, 72 consecutive hips (37 men and 35 women) with unilateral osteonecrosis of the femoral head (ONFH) have been analyzed using ZedHip software as a control group. CT-based simulation software was used to create computational 3D bone models and to perform computational simulations of the femoral cut and implant setting using the preoperative THA planning mode. The pelvic coordinate system was the functional pelvic plane, and the femoral coordinate system was defined by the center of the femoral head, the knee center, and both femoral condyles. All templating was performed on CT-based simulation software. The hip disease side was used for the templating and the contralateral hip reflected the geometry we wished to restore when performing THA. The simulated acetabular implant was the Continuum Acetabular System (Zimmer) with a polyethylene liner in all cases. The cup size was chosen so as to fill the anterior and posterior acetabular walls at the previously determined the cup implantation site. The cup implantation site was determined as the site where original acetabular contacted the lateral wall of the teardrop. The target angle of the acetabular implants was set at a cup inclination of 40° and a cup anteversion of 20° in a radiographic manner [7]. The 6 most commonly used cementless femoral implants in the Australia in 2015 were identified by reference to the national registry and 3D templates for these designs were obtained from this software [6]. We included one stem (Kinectiv; Zimmer) which has been a commonly used modular stem in Japan [8]. As femoral implants, first, a stem with five different offset choices with two different neck-shaft angles (125°, 135°) was used (Corail; Depuy). Second, a stem with two different offset choices with two different neck-shaft angles (127°, 135°) was used (QUADRA-H; Medacta SA). Third, a stem with three different offset choices with three different neck-shaft angles (126°, 135°, 145°) was used (Polarstem; Smith & Nephew). Fourth, a stem with two different offset choices with two different neck-shaft angles (127°, 132°) was used (Accolade II; Stryker). Fifth, a stem with three different offset choices with two different neck-shaft angles (123°, 133°) was used (Taperloc; Zimmer). Sixth, a stem with two different offset choices with one neck-shaft angle (131°) was used (ANTHOLOGY; Smith & Nephew). The Kinectiv has five offset choices and anteverted, neutral, or retroverted options. The stem was placed in neutral position and stem anteversion was adjusted to the anatomical femoral neck anteversion [7]. The appropriate size of the stem was selected for each femur to maximize both fit and fill in the femoral metaphysis [8]. The neck osteotomy plane was selected in order to restore the correct leg length. To be completely restored, the templating had to result in less than 1 mm of complete correction of femoral offset, similar to Archibeck et al. [3]. In the present comparative study, we questioned whether there is a difference in the restoration of femoral offset between 7 different stems. Additionally, the restoration of femoral offset between 7 different stems was compared with diagnosis (OA and ONFH). P-values of <0.05 were considered significant. All statistical analyses were performed using SPSS version 25 (SPSS Inc.,).

Results: The mean patient age was 64.8 ± 12.2 years. The mean height and weight were 156.6 ± 9.8 cm and 60.2 ± 12.1 kg. The mean stem anteversion was 26.2° ± 10.0°. The mean amount of contralateral anatomical femoral offset was 33.9 ± 5.7 mm. The mean stem anteversion in the OA was 29.3° ± 10.3°, whereas it was 23.2° ± 8.7° in the ONFH. The mean amount of contralateral anatomical femoral offset in the OA was 33.2 ± 6.2 mm, whereas it was 34.6 ± 5.0 mm in the ONFH. Femoral offset was restored to within 1 mm in 86% of cases with the Corail, 43% of cases with the QUADRA-H, 76% of cases with the Polarstem, 61% of cases with the Accolade II, 77% of cases with the Taperloc, 43% of cases with the ANTHOLOGY, and 95% of cases with the Kinectiv. The use of the Corail, the Polarstem and the Taperloc resulted in more frequent ability to restore within 1mm of femoral offset than the QUADRA-H (p=0.000, p=0.000, p=0.000), the Accolade II (p=0.000, p=0.005, p=0.003) and the ANTHOLOGY (p=0.000, p=0.000, p=0.000). The use of the Corail resulted in more frequent ability to restore within 1 mm of femoral offset than the Polarstem (p=0.023) and the Taperloc (p=0.032). The use of the Accolade II resulted in more frequent ability to restore within 1 mm of femoral offset than the QUADRA-H (p=0.003) and the ANTHOLOGY (p=0.003). The use of the Kinectiv resulted in more frequent ability to restore within 1 mm of femoral offset than Corail, the QUADRA-H, the Polarstem, the Accolade II, the Taperloc and the ANTHOLOGY (p=0.007, p=0.000, p=0.000, p=0.000, p=0.000, p=0.000). Femoral offset was restored to within 1 mm in 49% of cases with the stems with two offset options, 77% of cases with the stems with three offset options and 86% of cases with the stem with five offset options. The stems with three offset options resulted in more frequent ability to restore femoral offset than the stems with two offset options (p=0.000). The use of the stem with five offset options resulted in more frequent ability to restore femoral offset than the stems with two offset options (p=0.000) and the stems with three offset options (p=0.025). Femoral offset was restored to within 1 mm in 64% of cases in the OA and 73% of cases in the ONFH. The stems in the ONFH resulted in more frequent ability to restore femoral offset than the stems in the OA (p=0.012).

Discussion: We investigated how closely anatomical femoral offset and leg length could be restored using 3D templates for 6 femoral nonmodular stems and 1 femoral cementless modular stem in Asian patients. In our study, femoral offset was restored to within 1 mm in 43-86% of cases with the nonmodular stems and 95% cases with the modular stem. The use of the modular stem resulted in more frequent ability to restore within 1 mm of femoral offset than the nonmodular stems. The larger number of multiple offset options resulted in more frequent ability to restore within 1 mm of femoral offset. The stems in the ONFH resulted in more frequent ability to restore within 1 mm of femoral offset than the stems in the OA. Accurate restoration of femoral offset and leg length has an important influence on clinical outcome, dislocation risk, range of motion, impingement, abductor muscle strength, and polyethylene wear [2]. To our knowledge, few analyses have addressed restoration of individual hip geometry with regard to differences in the restoration potential of femoral implant concepts [3, 5]. Assessment of femoral offset is an important part of THA planning. Measurement of femoral offset by 3D analysis is more accurate than with two-dimensional (2D) analysis [9]. The strongest determinant of femoral offset is the neck shaft angle. Massin et al. performed a 2D templating study and reported that if a femoral implant has a single 135° neck-shaft angle, up to 67% of patients will not have accurate restoration of femoral offset [4]. Additionally, it was noted that 8 sizes of a single 135° neck-shaft angle would have to be available to restore the geometry in only 49% of patients. Bourne et al. performed a 2D templating study and reported that a single 135° neck-shaft angle would have to be available to restore the geometry in only 40% of patients and a single 131° neck-shaft angle would have to be available to restore the geometry in only 68% of patients [1]. Additionally, it was noted that a single 131° neck-shaft angle with two different offset choices and the option of using lateralized acetabular liner would have to be available to restore the geometry in 90% of patients. However, these were not clear which criterions were chosen for previous templating studies. In this study, the templating had to result in less than 1 mm of complete correction of femoral offset. And, templating was performed on 3D analysis. In our study, femoral offset was restored to within 1 mm in 49% of cases with the stems with two offset options, 77% of cases with the stems with three offset options and 86% of cases with the stem with five offset options. The modular neck stems were introduced in THA to improve restoration of hip geometry. Archibeck et al. performed a 2D templating study and reported that the modular neck stem would have to be available to restore femoral offset and leg length within 1mm in 85% of patients, while the nonmodular neck stem would have to be available to restore completely in only 60% of patients [3]. But some clinical studies did not reveal a clear benefit in restoring hip geometry. Innmann et al. retrospectively evaluated the preoperative and postoperative radiographs and reported that femoral offset and leg length could be restored without any difference between the modular neck stem and the nonmodular neck stem with 3 different neck shaft angles of 125°, 135° and 145° [5]. DDH is the most common underlying condition leading to secondary OA of the hip. In general, femurs in patients with DDH have a straighter, narrow canal, less femoral offset and a short excessively anteverted neck [10]. In our study, OA had less femoral offset in comparison with ONFH. The stems in the ONFH resulted in more frequent ability to restore femoral offset than the stems in the OA. Our results suggest that the larger number of multiple offset options of nonmodular stems or the modular stem can provide better femoral offset restoration. The present findings are of clinical importance because suboptimal hip geometry reconstruction can be associated with post operative abductor weakness, limping, pain, impingement, dislocation, increased joint reaction force, and implant loosening.

SIGNIFICANCE: Multiple offset options offered advantages for femoral offset restoration. Modular necks provide restorable advantages. The stems in the ONFH resulted in more frequent ability to restore femoral offset than the stems in the OA.

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