Clinical Biomechanics 57 (2018) 121–128

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

The effect of cup medialization and lateralization on hip range of motion in total hip arthroplasty

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ARTICLE INFO

Keywords:
Cup position
Range of motion
Bone morphology
Total hip arthroplasty
3-dimensional motion analysis
Impingement

ABSTRACT

Background: There is little description of the effect of cup position on the hip range of motion in total hip arthroplasty. The purpose is to evaluate the effect of cup medialization/lateralization with a compensatory increase/decrease in femoral offset on the hip range of motion, and whether the bone morphology of the anterior inferior iliac spine affects hip range of motion in total hip arthroplasty.
Methods: Using the CT data of 100 patients (male; 30, female; 70), 3D-dynamic motion analysis was performed in four scenarios with cup medialization/lateralization with the same/decreased global offset. We calculated the range of motion before component impingement and bony impingement in flexion, internal rotation and external rotation using the software. Furthermore, we measured bony morphological features of anterior inferior iliac spine, and we analyzed the correlations among them.
Findings: We found that the cup medialization with the same stem offset had negative effects on hip range of motion in flexion and internal rotation due to bony impingement, whereas cup medialization caused external rotation to significantly decrease with the same global offset. On the other hand, cup lateralization with the same global offset had negative effects on flexion and internal rotation, whereas external rotation increased. Furthermore, there were negative correlations among flexion and laterally large and steep anterior inferior iliac spine.
Interpretation: Our results demonstrated that the advantage of cup medialization can depend on the individual anatomy such as bony morphology of anterior inferior iliac spine in flexion.

1. Introduction

Total hip arthroplasty (THA) has been the most popular and successful treatment procedure for patients with severe degenerative osteoarthritis of the hip joint. However, dislocation has continued to be a concern to patients and a leading complication in the postoperative period, occurring between 1.7% and 4% of all primary cases (Bozic et al., 2012; Kelley et al., 1998; Miyoshi et al., 2012; Nadzadi et al., 2003a; Widmer and Majewski, 2005).

It is known that the implant orientation and alignment have great impacts on hip stability and biomechanics after THA (Jolles et al., 2002; Miki et al., 2013; Shoji et al., 2013). Regarding implant orientation, several previous clinical reports have shown the formula for the theoretically optimum combination of cup and stem alignment. **Widmar et al. revealed that severe range of motion (ROM) conditions were created when the formula cup anteversion + 0.7 × stem antetorsion = 37° was fulfilled by a cup inclination between 40° and 42°, combined with a cup and stem anteversion of between 23° and 28°** (Widmer and Zurfluh, 2004). Mathematical models also confirmed combined anteversion to be the measurement that must be considered to avoid impingement (Yoshimine, 2006).

On the other hand, the ideal 'position' of the acetabular cup varies considerably among surgeons, with some surgeons consistently reaming to the medial wall and other surgeons minimizing the amount of acetabular reaming (Archbold et al., 2006; Sariali et al., 2012). Several studies have documented the importance of the hip center of rotation (COR) to both longevity of THA (Baghdadi et al., 2013; Callaghan et al., 1985; Sariali et al., 2012) and muscle function (Abolghasemian et al., 2013; Asayama et al., 2002). Schmalzried et al. (Schmalzried et al., 2000) and Wroblewski et al. (Wroblewski et al., 2004) showed a trend of decreased polyethylene wear with a decrease in acetabular offset. Bonnin et al. (Bonnin et al., 2011) used a three dimensional (3-D) finite

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https://doi.org/10.1016/j.clinbiomech.2018.06.011
Received 6 September 2017; Accepted 22 June 2018

element model of the femur, pelvis, and bundles of the gluteus minimus and medius. They observed an 8% decrease of the joint force with 5 mm medialization. However, there may be tradeoffs associated with medialization of the COR in THA, including potential negative effects on proprioception or bone stock owing to the nonanatomic position of the COR. Furthermore, there may be positive or negative effects on hip ROM by moving the COR and changing the stem offset, although there is little description of the effect of cup position on the ROM in THA. In addition, although bone morphology of the anterior inferior iliac spine (AIIS) is reported to have some contribution to bony impingement (Shoji et al., 2016a), it remains elusive whether pelvic geometries including bone morphology of the AIIS can influence the mechanical effects of cup medialization/lateralization in THA.

Nowadays, preoperative planning is often performed for THA, and computed simulation analysis is often used by many investigators to predict the optimal implant orientations and to analyze the ROM after THA (Hjorth et al., 2014; Lachiewicz and Soileau, 2013a). In our study, we used computed tomographic (CT)-based 3-D dynamic motion analysis to evaluate the effect of cup medialization/lateralization with a compensatory increase/decrease in femoral offset on the ROM and impingement, compared with anatomic reconstruction, and whether the bone morphology of the AIIS can influence the biomechanical effects of cup positions in THA.

2. Methods

Ethics approval was granted by the Institutional Review Board. In this study, we retrospectively reviewed a total of 100 patients (100 hips), including 77 patients with osteoarthritis due to hip dysplasia and 23 patients with idiopathic osteonecrosis of femoral head comprising 30 men and 70 women with a mean age of 60.6 years (range, 41–79 years). We excluded patients with a severely deformed or dislocated hip (≧ II according to Crowe classification) (Crowe et al., 1979), severely deformed contralateral hip, or those who had previously undergone surgery. All patients had a preoperative CT scan, from the anterior superior iliac spine (ASIS) to the knee joint through the distal femoral condyles, using a 320-row multi-detector helical CT scanner (Aquilion ONE, Toshiba Medical healthcare, Tochigi, Japan) (detector configuration: 80 × 0.5, Beam collimation: 40 mm) with a reconstructed slice width of 1.00 mm and a slice interval of 1.00 mm obtained in a 512 × 512 matrix. The CT data were transferred to the CT-based simulation software (ZedHip® Lexi Co., Ltd., Tokyo, Japan) (Shoji et al., 2013; Shoji et al., 2016a). **This software provides images with 0.78–0.82 mm pixel resolution, and the cadaveric study revealed that positional accuracy of this software was 0.20 mm (standard deviation; 0.1) with a slice thickness of 1.00 mm, a matrix size of 640 × 512 and a pixel size of 0.35 × 0.35 mm.**

To evaluate the hip ROM after THA, simulation software was used to create virtual 3D bone models and to perform virtual simulations after THA, using the preoperative THA planning mode (Shoji et al., 2013; Shoji et al., 2016a). This software allows for the generation and separation of femoral and acetabular 3D models independently, and it enables us to analyze the hip ROM after THA by 3D dynamic simulation. Based on a CT scan of pelvis and femur, we firstly digitized the reference points, then a 3D reconstruction of the bone model was made semi-automatically. (Fig. 1A, B) The sizes of the implants and their 3D positions relative to the host bones were planned, and implantation was performed in axial/sagittal/coronal views of multi planner reconstructed (MPR) images. This software allows us to simulate and to calculate the ROM until contact among bones and components. It also allows us to visualize the site of impingement in 3D axial/sagittal/coronal views of the MPR images. The pelvic coordinate system was the anterior pelvic plane, which was defined by the ASIS and the pubic tubercle. If this plane was tilted in sagittal plane when the patient was lying in the supine position due to the spine and pelvic deformities, correction of the anterior-posterior axis was performed according to the 'functional pelvic plane' as a reference plane. The femoral coordinate system was defined by the 'International society of biomechanics' as being the center of the femoral head, the knee center, and both femoral condyles (Wu et al., 2002).

2.1. Implant setting

In the simulation study, we used the Zimmer-Biomet M/L Taper Hip Prosthesis with Kinectiv® Technology (Zimmer Biomet Inc., Warsaw, IN) that would allow us to manipulate the femoral offset and leg length independently in order to analyze the influences of global offset and femoral offset on the resultant ROM. (Fig. 2A, B) The appropriate size of femoral stem was selected for each femur to maximize both fit and fill in the femoral metaphysis under the consideration of stem size used in the actual procedure with a 32-mm-diameter head in all cases. The center of the femoral component was placed in the center of the native femoral diaphysis.

The acetabular side had a Trilogy® Acetabular Hip System with a polyethylene liner without marginal lips in all cases. The acetabular component size was also selected to maximize fit in the acetabulum under the consideration of component size used in the actual procedure. The acetabular component position was determined to place the implant at the site of the 'original' acetabulum under the consideration of contralateral acetabulum. The anteversion of the femoral implant was set at 25°, cup anteversion at 20° (total anteversion was fixed) and cup abduction 40° in a radiographic manner. Any acetabular osteophytes that were attached to the acetabular bony rim were removed.

To evaluate the influences of cup position and stem offset on hip ROM, three stem-neck options; standard offset, elongation and shortening of stem offset by 4 mm (Fig. 2B), and three acetabular cup position; original position, horizontally lateralized or medialized position by 4 mm were used, respectively. (Fig. 2C) 'Global offset' was defined as the sum of the acetabular and stem offset as described before (Fig. 3) (Scheerlinck, 2010). Then the four scenarios were tested: scenario (1); original cup position and standard stem offset (Original) (Fig. 3A), (2); the cup position was medialized by 4 mm and stem offset was also elongated by 4 mm; stem offset is β and cup position is θ (4 mmMed+) (Fig. 3B), (3); the cup position was lateralized by 4 mm and stem offset was shortened by 4 mm; stem offset is α and cup position is γ (4 mmLat) (Fig. 3C), and (4); the cup position was medialized by 4 mm but stem offset was unchanged; stem offset is standard and cup position is θ (4 mmMed−) (Fig. 3D). In these scenarios, the baseline of femoral and acetabular component height was identical with no vertical translation. In the first three scenarios of Original, 4 mmMed+ and 4 mmLat, the acetabular components were horizontally translated but the position of femoral components was not changed, thereby moving the COR while keeping the global offset unchanged. In the scenario of 4 mmMed−, the femoral and acetabular components were simultaneously translated medially from the original position, thereby decreasing the global offset.

2.2. Calculation of the ROM and impingement site

The center of the femoral head is located by fitting a circle to the articular surface of the femoral head. The pelvis was fixed in space, while the femur was free to translate in all directions but was constrained to rotate around the center of hip rotation. The computer software was capable of detecting bone to bone, bone to implant and implant impingement, which allowed the maximum ROM to be defined as the degrees of movement until either bone or implant impingement occurred. We defined the ROM before component impingement as ROMCI and the ROM before bony impingement as ROMBI, and measured ROMCI and ROMBI in each scenario. Based on this computerized analysis, the ROM was measured in three directions, all of which are important for dislocation and activities of daily living: flexion (Flex) with 0° of adduction and internal rotation, internal rotation (Int-R) in