Effects of posterior pelvic tilt on anterior instability in total hip arthroplasty: A parametric experimental modeling evaluation

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A B S T R A C T

Background: Anterior dislocation is one of the concerns of patients with posterior pelvic tilt undergoing total hip arthroplasty. This study aimed to evaluate the magnitude of posterior pelvic tilt constituting a risk for anterior dislocation by measuring the range of motion until impingement and dislocation under various pelvic tilt.

Methods: Using a jig mounted prosthetic hip model, the ranges of external rotation at extension and internal rotation at flexion until reaching dislocation were tested. The site of impingement prior to dislocation was also recorded. Posterior pelvic tilt and the cup version were changed with 10° increments from 0° to 40° and from 10° retroversion to 30° anteversion, respectively. Effects of increasing femoral offset were also tested. We defined a required range of motion as having 30° external rotation at extension and 40° internal rotation at 90° flexion.

Findings: External rotation decreased in a posterior pelvic tilt-dependent manner. In the case with more than 20° posterior pelvic tilt, available external rotation extended beyond required range with the cup anteversion of 20°. Decreasing cup anteversion improved external rotation, however, internal rotation decreased simultaneously. In the case with posterior pelvic tilt more than 20°, only cup anteversion with 0° or 10° satisfied the required range of motion. A + 4 mm horizontal offset improved external rotation by 10° with delaying bony impingement.

Interpretation: More than 20° of posterior pelvic tilt may cause anterior instability and diminish the optimal range of cup version. Increasing the femoral offset improved external rotation without reducing internal rotation.

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1. Introduction

Dislocation is one of the most frequent complications following total hip arthroplasty (THA), with an incidence of 0.6% to 11% in the early postoperative period (Hedlundh et al., 1996; White et al., 2001; Woo and Morrey, 1982). Posterior dislocation is predominant, however, anterior dislocation is seen in approximately 30% of all dislocations (Di Schino et al., 2009; Dorr et al., 1983; Sariali et al., 2012). Factors affecting dislocation include patient characteristics, implant design, and variations in surgical techniques (Amstutz et al., 1975; Matsushita et al., 2009, 2010). Of these factors, 13% to 30% of dislocations are reportedly caused by implant malpositioning (Daly and Morrey, 1992; Hedlundh et al., 1997).

Surgeons place the cup by referencing pelvic bony landmarks or planes such as the anterior pelvic plane (APP), formed by the anterior superior iliac spines and public symphysis (DiGioia et al., 2002; Eddine et al., 2001; Parratte and Argenson, 2007; Parratte et al., 2009). However, as sagittal pelvic tilt changes the version of the cup relative to femoral component, any excessive pelvic tilt may lead to functional implant malpositioning and subsequent dislocation. Previous studies have described large inter-individual variations in pelvic tilt ranging from 20° posteriorly to 20° anteriorly (DiGioia et al., 2006; Eddine et al., 2001). There are also intra-individual variations; decreased lumbar lordosis with aging leads to increasing posterior pelvic tilt in elderly people (Schwab et al., 2009). Likewise, patients with advanced-stage ankylosing spondylitis have a high incidence of posterior pelvic tilt (Bhan et al., 2008; Tang and Chiu, 2000). In these cases with posterior pelvic tilt, anterior dislocation is a concern after THA because posterior pelvic tilt is thought to be accompanied by increased anteversion of the cup. The relationship between pelvic tilt and range of motion after THA needs to be clarified in these particular cases.

The purposes of this study were to evaluate the magnitude of posterior pelvic tilt constituting a risk for anterior dislocation by measuring the range of motion (RoM) until impingement and dislocation under various pelvic tilt with use of hip model and to examine the effects of cup anteversion and horizontal offset of stem in improving the limited RoM.

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2. Methods

2.1. THA model

We developed a jig mounted Sawbones THA model with cementless 52 mm cup, 28 mm ball and cementless stem (Sawbones, Vashon, WA, USA) as previously described (Amstutz et al., 1975; Matsushita et al., 2010) (Fig. 1). This model allows the hip to move in six dimensions and mimics the hip impingement and the subsequent dislocation. Briefly, the pelvis was set so that the APP was perpendicular to the ground and parallel to the frame of the THA model (namely, pelvic tilt was 0° relative to the vertical plane). Following the previous anatomical studies (Hsu et al., 1990; Oswald et al., 1993), the femur was placed in the valgus position, 7° relative to the functional axis, whereas the center of femoral head was set at the center of rotation. A cementless stem (JMM, Osaka, Japan) was inserted into the femoral model using a standard technique. In all cases, a femoral head with a diameter of 28 mm and a neck length of +3 mm was used. A 52-mm cup (JMM, Osaka, Japan) was fixed and a flat liner with a non-elevated rim was used. A spring was placed in the bottom of the jig at distal femur to permit attachment of the cup and femoral head with a force of 20 N. Although the contact force in this study was smaller than the physiological force reported in the biomechanical study (Nadzadi et al., 2003), this study did not evaluate the mechanical force but the geometric hip motion such as the impingement and the subsequent dislocation. Therefore, the contact force does not seem to affect these evaluations. The model allowed the hip joint to be moved in six dimensions (flexion, extension, abduction, adduction, internal rotation, and external rotation), measured with reference to the ante-ro pelvic plane. This model was further modified in this study; the femoral axis had 7° of freedom of motion when impingement occurred, therefore a dislocation following impingement could be mimicked.

2.2. Measurements

To reconstruct posterior pelvic tilt, we configured the anterior pelvic plane from 0° to 40° posteriorly in 10° increments around the axis connecting the femoral head centers. To evaluate RoM, the ranges at which impingement and dislocation occurred were determined using a built-in goniometer (Fig. 1B). Dislocation was defined visually as the point when the marked center of the femoral head crossed the edge of the liner. We determined two ranges of motion: (i) external rotation with 0° of both extension and abduction (ER), and (ii) internal rotation at ranges of flexion from 50° to 90° with 0° of abduction (IR). The flexion angle was defined as the angle between the ground plane and femoral axis regardless of pelvic tilt. In addition, the point of impingement, that is, implant-to-implant or bone-to-bone contact, was recorded in each test. We defined a required RoM for daily life as having 30° of ER with 0° of extension, and 40° of IR with 90° of flexion, according to both in vitro and in vivo studies (Miki et al., 2007; Nadzadi et al., 2003; Seki et al., 1998; Sugano et al., 2012; White et al., 2001).

2.3. Cup anteversion and femoral offset

Anteversion of the cup was determined using the radiographic definition. Briefly, the angle of anteversion was defined as the version angle along the axis of acetabular cup at the coronal plane (Murray, 1993). Cup anteversion required for the case with posterior pelvic tilt was compared to the Lewinnek’s safe zone. Two different horizontal offsets were tested: standard (0 mm) and 4 mm lateral (+4 mm offset.) The neck shaft angles were 135° and 130°, respectively.

3. Statistical methods

All measurements were performed in triplicate; the average was used as the RoM. The IR and ER in each pelvic tilt and cup anteversion were evaluated with linear regression method. The slopes of the liner regression were recorded.

4. Results

Posterior pelvic tilt resulted in a decreased ER in a pelvic tilt-dependent manner with any anteversion of the cup (Fig. 2). In the case with 20° of the cup anteversion, decrease in ER occurred at rate of −0.83° per degree of posterior pelvic tilt (R² = 0.99). The site of impingement was between the posterior greater trochanter and ischium from 0° to 20° posterior pelvic tilt and changed to the implant impingement between neck and liner at more than 20° posterior pelvic tilt.
With pelvic tilt of 20° or more, ER was outside of the required RoM (ER ≥ 30°).

Relation between the cup anteversion and ER under various pelvic tilt was shown in Fig. 3. Linear regression represented that ER was decreased in a cup anteversion-dependent manner (R² = 0.63). Decreasing anteversion of the cup improved limited ER with each pelvic tilt. Increased anterior coverage (reducing anteversion of the cup) led to more jumping distance prior to anterior dislocation and also delayed implant impingement between the posterior aspect of the femoral neck and the liner. In the case with 20° of posterior pelvic tilt, 10° or less of the cup anteversion satisfied the required RoM in terms of ER. In the case with the cup anteversion of Lewinnek’s safe zone (15° ± 10°), the required RoM could not be ensured with the posterior pelvic tilt more than 20° (Fig. 3).

A decrease in anteversion of the cup resulted simultaneously in decreased IR (Fig. 4). More flexion resulted in less IR with each anteversion of the cup. With 90° of flexion, the cup anteversion with −10° failed to satisfy the required RoM (IR ≥ 40°). The site of impingement was between the stem neck and the edge of liner in the cases with the cup anteversion of −10° to 0° and changed to bone impingement between intertrochanteric crest and anterior inferior iliac spine in the cases with 10° to 30°.

Use of +4 mm horizontal offset of stem resulted in improved ER by delaying bony impingement (Fig. 5). This improvement was not accompanied by a decrease in IR (data not shown). In the case with 20° of the cup anteversion and the offset stem, the degree of posterior pelvic tilt satisfying the required RoM of ER increased from 10° to 20°. In the case with implant impingement, increasing the horizontal offset of stem did not improve either ER or IR.

5. Discussion

Using a THA model, we evaluated the magnitude of posterior pelvic tilt constituting a risk for anterior dislocation and examined the effects of the cup anteversion and offset of stem on the hip RoM. Posterior pelvic tilt resulted in a decrease in ER in a pelvic tilt-dependent manner. In the case with 20° or more posterior pelvic tilt, anteversion of the cup needed to be decreased appropriately in order to satisfy the range of both ER and IR. Decreased anteversion of the cup led to an improvement in ER; however, IR decreased simultaneously. A +4 mm femoral offset improved RoM by delaying bony impingement.

Pelvic tilt directly affected anteversion of the cup, leading to limited RoM. Excessive posterior pelvic tilt may cause malpositioning of acetabular placement in the Lewinnek safe zone (Lewinnek et al., 1978), as this zone encompasses only a 20° range of anteversion. Shon et al. reported that the posterior change in pelvic tilt that occurred when patients moved from the supine to standing position was more than 15° in 10% of cases (Shon et al., 2008). They presumed that the safe limit of anteversion of the cup in those with excessive pelvic tilt should fall in a lower range than that of a normal pelvic tilt group to prevent posterior impingement and anterior instability. According to our result, less than 10° of anteversion of the cup satisfied the required RoM in the setting of this study. Because there is also a risk of posterior dislocation due to reduced anteversion of the cup, it could be concluded that there is a narrow range for the optimal acetabular placement in these cases.

Posterior pelvic tilt is observed in patients with diseases such as ankylosing spondylitis. Tang et al. reported two anterior dislocations after primary THA using the posterior approach in a series of 58 patients with ankylosing spondylitis (Tang and Chiu, 2000). They concluded that anterior dislocations were due to excessive posterior pelvic tilt caused by lumbar kyphosis and recommended the placement of the cup with less...

Fig. 3. The relationship between the cup anteversion and ER. ER decreased in a cup anteversion-dependent manner. Solid, dotted and chain lines are regression lines for each pelvic tilt. The shading area represents the Lewinnek’s safe zone for cup anteversion.

Fig. 4. The effect of the cup anteversion on IR. Pelvic tilt was constant at 0°. A decrease in acetabular anteversion resulted simultaneously in decreased IR. Solid, dotted and chain lines are regression lines for each cup anteversion.

Fig. 5. The effect of femoral offset on ER with 20° of the cup anteversion. The posterior pelvic tilt fulfilling required ROM for ER increased from 10° to 20°. Solid and dotted lines are regression lines for each standard and +4 mm offset neck, respectively.
anteverision. Debarge et al. reported that the pelvises of patients with ankylosing spondylitis tilted posteriorly by a mean of 15° compared to normal subjects (Debarge et al., 2010). According to our investigation, 20° of posterior pelvic tilt failed to achieve the safe RoM, when the cup was set in the Lewinnek’s safe zone. The cup anteverision ranging from 0° to 10° appears to be acceptable for this case.

A +4 mm horizontal offset of stem resulted in the improvement of ER by approximately 10°. As this effect was not accompanied by a reduction of IR, increasing the femoral offset was effective for cases of posterior pelvic tilt, especially when the site of impingement was between the pelvis and femur (Matsushita et al., 2009). Although a large femoral offset has some risks such as tip fracture of the greater trochanter and cantilever component failure, increasing horizontal offset of stem is one of the effective choices to avoid anterior dislocation.

This study had several limitations. First, the measurements in this study were derived from a limited number of settings for pelvic tilt, anteverision of the cup, and femoral offset by reason of experimental study. There are several methods to measure RoM; computer simulation, cadaveric measurement and pelvic model. Although more detailed settings can be available with use of computer simulation software, it is difficult for computer simulation to reproduce impingement and following dislocation. Therefore, we performed an experimental study using a THA model. Second, the THA model we used did not contain surrounding soft tissue such as muscles and the joint capsule, which provide substantial contributions to RoM when impingement or dislocation occurs in clinical practice. However, it is difficult at present to reproduce these effects in an experimental THA model. Third, the maximum flexion in the cases with posterior pelvic tilt remained unclear. Although IR was measured with flexion from 50° to 90° and the required RoM for IR was determined with 90° of flexion in this study, there is no literature referencing the flexion—extension arc in these cases. Fourth, the hip RoM in daily life varies among the reports. Required ER and IR ranged from 20 to 40° and from 30 to 40°, respectively (Ellison et al., 1990; Nadzadi et al., 2003; Simoneau et al., 1998; Sugano et al., 2012). According to the 4-dimensional motion analysis reported by Sugano et al., maximum hip rotation during sitting down and standing up were 32° of ER and 20° of IR, with relatively smaller IR. Conversely, Ellison et al. reported the average hip rotation of 100 healthy subjects was 35° of ER and 38° of IR. In this study, a comparatively large range of RoM was used. Theoretically, posterior pelvic tilt results in hyperextension of the hip joint, and therefore the accurate flexion angle in these cases is uncertain. Further clarification is needed.

6. Conclusions

Excessive posterior tilt may cause anterior instability and diminish the optimal range of cup anteverision in THA. Increasing the femoral offset improved ER without reducing IR.

References


