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Original Research

# Intraoperative Pelvic Tilt and Axial Rotation During Total Hip Arthroplasty Through the Direct Anterior Approach is Affected by the Acetabular Retractor and Cup Impactor

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A B S T R A C T

*Background:* Intraoperative pelvic motion during total hip arthroplasty (THA) in the supine position affects acetabular cup placement and occurs at each step of THA; however, there are no reports of pelvic motion changes during each stage of THA via the direct anterior approach (DAA). This study aimed to evaluate pelvic motion at each step of THA through the DAA.

*Methods:* From March to October 2022, 71 hips were prospectively measured for intraoperative pelvic tilt and axial rotation during THA through the DAA at a single center. These parameters were measured during each surgical step using the augmented reality-hip navigation system.

*Results:* Both pelvic tilt and axial rotation were maximal during acetabular cup placement. The mean intraoperative pelvic tilt and axial rotation during cup placement were 4.8 ± 2.6° (95% confidence interval, 4.19-5.41°) and 4.2 ± 3.3° (95% confidence interval, 3.42-4.98°), respectively. The effects of the acetabular retractor and cup impactor on pelvic tilt and axial rotation were comparable. Spearman's correlation tests showed significant correlation between axial rotation and body mass index ($r = -0.444$, $P = .00011$).

*Conclusions:* The pelvis tilts forward and rotates toward the surgical side during THA through the DAA. The effects of the acetabular retractor and cup impactor on pelvic motion are comparable. Cup implantation must take into account pelvic movement, and it must be recognized that the pelvis is moving at that time, even with only the acetabular retractor inserted, compared to before the skin incision.



## Introduction

The acetabular cup placement angle is important in determining the long-term outcomes of total hip arthroplasty (THA) because appropriate acetabular cup angulation results in less dislocation, less polyethylene wear, and better long-term results [1–3]. Since Lewinnek et al. [4] defined the safe zone for acetabular component positioning as 30°-50° of inclination and 5°-25° of anteversion in 1978, the Lewinnek safe zone has been used as the standard for acetabular component placement during THA. However, there have been reports of dislocation even within the bounds of this safe zone; therefore, the ideal safe zone for cup angulation is considered narrower than the Lewinnek safe zone [5,6]. Furthermore, the safe zone range for cup anteversion is narrower than that for inclination in THA [7].

The direct anterior approach (DAA) is performed in the supine position and is an intermuscular approach. Advantages of THA via the DAA include minimal soft-tissue damage and faster recovery [8,9]. Intraoperative pelvic motion during acetabular cup implantation is a major factor affecting acetabular cup positioning [10,11]. THA in the supine position is associated with less intraoperative pelvic motion and a better acetabular cup placement than THA performed in the lateral decubitus position [11]. THA through the DAA results in less dislocation because of better acetabular cup placement angle and lesser soft-tissue damage compared to the posterior approach [8]. Even in the supine position, acetabular cup placement can occur outside the safe zone (the safe zone for acetabular component positioning as 30°-50° of inclination and 5°-25° of anteversion [4]), and the anteversion angle tends to be larger

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in the DAA using the freehand technique [12]. The safe zone of the anteversion angle of the acetabular cup is smaller than that of the inclination angle [7]. Therefore, during supine THA through the DAA, the anteversion angle should be specifically considered when implanting the acetabular cup. The navigation system is useful for monitoring intraoperative pelvic motion during acetabular cup implantation [13]. Navigation systems were expensive and not widely used in THA [14] but are now becoming more widely used for proper cup placement. Portable navigation systems are inexpensive and enable acetabular cup implantation at an appropriate angle, even in the presence of pelvic movement [13].

The augmented reality (AR)-Hip system (Zimmer Biomet Japan, Tokyo, Japan) is a portable navigation system that employs AR technology, wherein the surgeon uses an application installed on a smartphone [14]. Intraoperatively, landmarks are registered, and a 3-dimensional coordinate system is created to define the cup positioning information. The reference plane of the AR-Hip system is the functional pelvic plane, determined by the gravity vector and a line connecting the bilateral superior iliac spines. The AR-Hip system allows the surgeon to view the actual operative field during THA with radiographic definition and to observe the real-time cup placement angle through a smartphone display with functional pelvic plane superimposed on the actual operative field. Pelvic motion can also be observed on the smartphone display. Real-time evaluation allows the measurement of pelvic motion at each step of the surgery.

There have been few reports of intraoperative pelvic motion during THA through the DAA [12,15]; however, intraoperative pelvic motion during each surgical step of THA through the DAA remains unclear. Knowing the real-time intraoperative pelvic motion allows for fine-tuning of the alignment guide and facilitates placement of the cup at the optimal placement angle, even when the cup is implanted using a freehand technique. Therefore, this study aimed to measure intraoperative pelvic motion during each step of THA via the DAA using the AR-Hip navigation system.

## Material and methods

### *Patients and implants*

An institutional review board approved this prospective study. All participants enrolled in this study provided written informed consent preoperatively. Between March and October 2022, cementless THA through the DAA was performed on 71 hips in 65 patients at our hospital. Preoperative diagnoses requiring THA included osteoarthritis, osteonecrosis, and femoral neck fractures. Patients who had undergone preoperative hip surgery were excluded from the study. Acetabular cup components and liners, including G7 and E1 liners (Zimmer Biomet Inc., Warsaw, IN), were used. The following femoral stems were also used: Avenir Complete stem (Zimmer Biomet Inc., Warsaw, IN), SL-Plus MIA HA stem (Smith & Nephew, London, UK), or polar stem (Smith & Nephew, London, UK).

### *Surgical procedure*

All THAs were performed by 2 surgeons through the DAA, with the patient in a supine position on a standard operating table. The AR-Hip system (version 1.0.54) was used as previously described [13]. First, the skin surrounding the iliac crest on the surgical side was disinfected. Two 3.2-mm pins were inserted into the iliac crest on the surgical side in parallel using a guide. Second, we set the pelvic base and marked quick response codes on the 2 pins. Third, we scanned the quick response codes using the AR-Hip app on a smartphone, and the functional pelvic plane was acquired (Fig. 1).

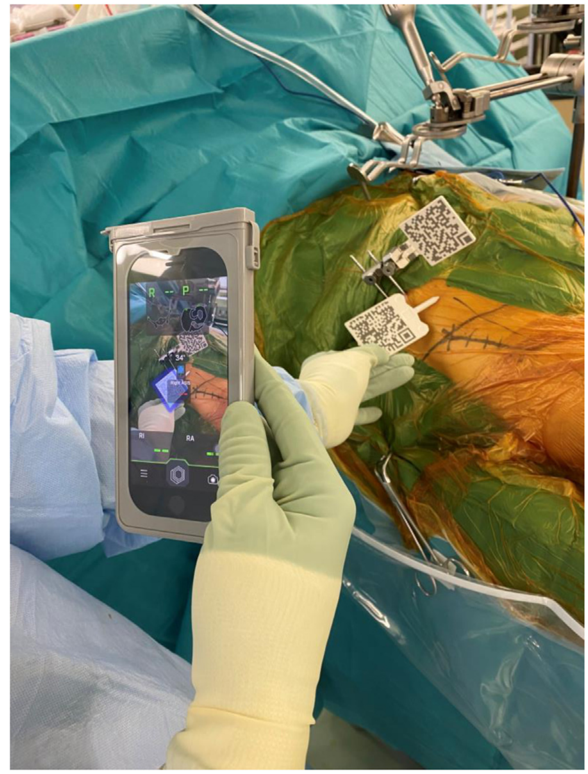

**Figure 1.** The quick response (QR) code was scanned using the smartphone and AR-Hip app and the functional pelvic plane (FPP) was acquired.

An 8-cm skin incision was made to enter the intermuscular plane between the tensor fasciae latae and the sartorius muscle. Three retractors were used for the acetabular operation. The anterior and anteroinferior retractors were held by a Magic Tower (Zimmer Biomet Inc., Warsaw, IN) and the posterior retractor was held gently by the assistant (Fig. 2). Anterior capsule and labrum resection, femoral neck cutting, acetabular reaming, and acetabular cup placement were performed. The cup was then placed using the AR-Hip system. A smartphone holder was attached to the cup impactor, and the acetabular cup was placed in the pelvis, referring to the angle displayed on the smartphone. The target acetabular cup angles were 40° of inclination and 15° of anteversion, which were based on radiographic definitions. All pins and markers were removed postoperatively. The pinholes were small; therefore, sutures were not required.

### *Measurements*

Pelvic angles were measured using the AR-Hip system. Pelvic motion is represented by pelvic tilt and axial rotation in the sagittal and coronal planes, respectively [15]. Pelvic tilt and axial rotation are shown on the display (Fig. 3). The angle of the sagittal plane relative to the horizontal plane was defined as the pelvic tilt. Forward tilt was considered positive and posterior tilt negative. The coronal plane angle was defined as axial rotation. A lean toward the surgical side was considered positive and a rise was negative (Fig. 4). Five relevant surgical steps, during which pelvic motion changes were assumed to occur, were defined as follows: (1) skin incision, (2) just before cup implantation with the acetabular retractor on the pelvis, (3) just after cup implantation using the cup impactor with the acetabular retractor on the pelvis, (4) just after the cup impactor removal, and (5) after the acetabular retractor removal. The pelvic angle at the time of skin incision (1) was used

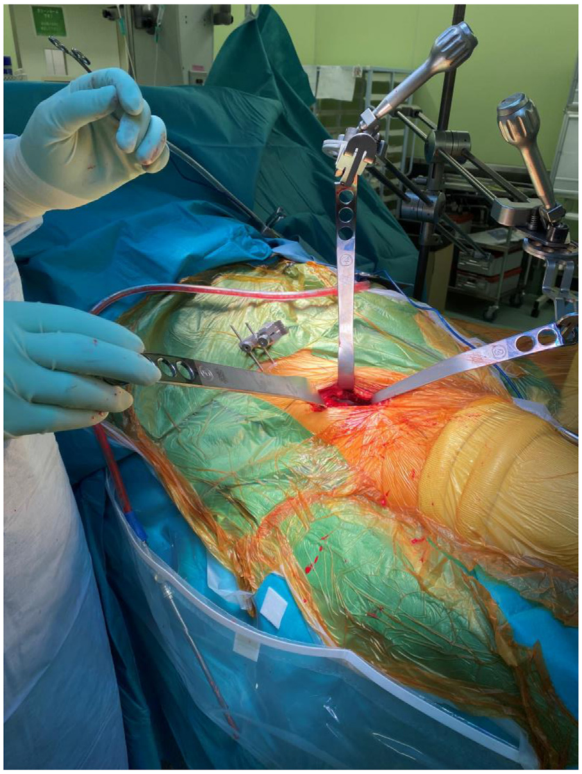

**Figure 2.** The anterior and anteroinferior retractors were held by Magic Tower (Zimmer Biomet Inc., Warsaw, IN) and the posterior retractor was held gently by the assistant's hand.

as the baseline for measurement. Intraoperative pelvic motion (intraoperative pelvic tilt and axial rotation) was defined as the difference between steps (1) and (3).

*Outcomes*

Surgical and patient factors were assumed to affect intraoperative pelvic motion. Surgical factors included the acetabular retractor (difference between [1] and [2]) and cup impactor (difference between [2] and [3]). Body mass index (BMI) and preoperative pelvic tilt were considered patient factors.

Our primary purpose was to measure pelvic tilt and axial rotation using the DAA to determine the effect of the retractor and cup impactor. The secondary purpose was to identify the patient factors that influence pelvic tilt and axial rotation.

*Statistical analysis*

The Mann–Whitney U test was used to compare pelvic tilt and axial rotation at each surgical stage. A $P$ value <.05 was considered to indicate statistical significance. Spearman's correlation tests were performed among BMI, preoperative pelvic tilt, and axial rotation. Statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan). The number of samples required was calculated using G-Power, version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) with an effect size of 0.3, $\alpha = 0.05$, and $\beta = 0.2$.

## Results

Of the 71 operated hips, 57 belonged to 53 women, while 14 belonged to 12 men; the mean age of the 71 hips was 71.0 ± 8.6 (range, 37-89). The average patient height and weight were 153.8 ± 7.8 (range, 136.0-179.0) cm and 54.5 ± 11.4 (range, 37.3-98) kg, respectively, with a mean BMI of 22.9 ± 3.5 (range, 15.7-30.6) kg/m$^2$. The preoperative diagnoses included osteoarthritis in 61 hips, osteonecrosis in 1, and femoral neck fracture in 9. The mean operation time was 42.6 ± 13.3 (range, 26-89) min, and the mean intraoperative blood loss was 221 ± 119 (range, 29-533) ml.

*Intraoperative pelvic motion*

Intraoperative pelvic tilt was 4.8 ± 2.6° (range, −4° to 12°; 95% confidence interval [CI], 4.19-5.41) and intraoperative axial rotation was 4.2 ± 3.3° (range, −2° to 16°; 95% CI, 3.42-4.98). Positive values comprised the majority, and negative pelvic tilt and axial rotation values were observed in 2 and 4 hips, respectively. The mean pelvic tilt and axial rotation at each surgical step are showed in Table 1. The pelvic tilt and axial rotation angles affected by the acetabular retractor (between steps [1] and [2]) were 2.4 ± 1.7° (range, −1° to 9°; 95% CI, 2.00-2.80) and 1.8 ± 2.0° (range, −2° to 8°; 95% CI, 1.33-2.27), respectively. The pelvic tilt and axial rotation angles affected by the cup impactor (between steps [2] and [3]) were 2.4 ± 2.5° (range, −5° to 10°; 95% CI, 1.79-3.02) and 2.4 ± 2.6° (range, −4° to 10°; 95% CI, 1.81-2.99), respectively. For both pelvic tilt and axial rotation, the effects of the acetabular retractor and cup impactor were comparable ($P$ = .898 and .139, respectively). Pelvic tilt and axial rotation did not significantly differ between steps (2) and (4) ($P$ = .188 and .344, respectively); therefore, cup impactor removal

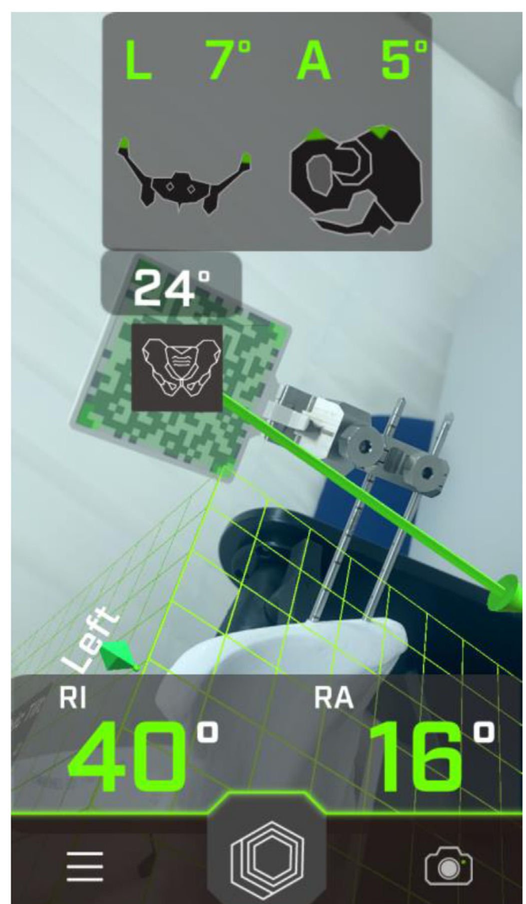


**Figure 3.** Pelvic tilt and axial rotation are shown on the display.

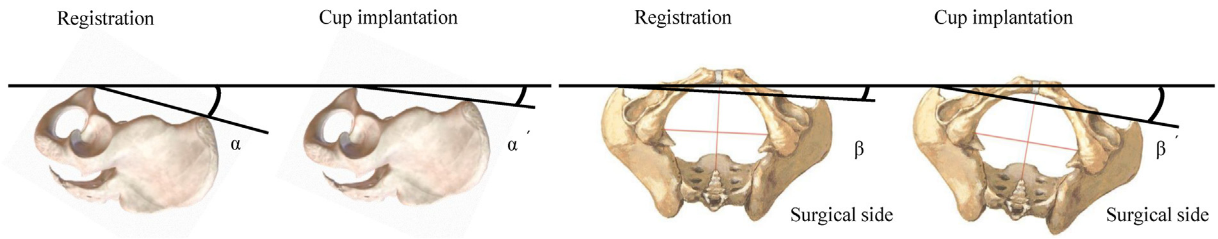


**Figure 4.** The angle of the sagittal plane against the horizontal plane was defined as the pelvic tilt. Forward tilt was positive, and posterior tilt was negative. The angle on the coronal plane was defined as axial rotation. The lean toward the surgical side was positive, and the rise was negative.

restored the pelvic angle. Spearman's correlation tests showed a significant correlation between axial rotation and BMI ($r = -0.444$, $P = .00011$). However, no correlation was found between axial rotation and preoperative pelvic tilt or between preoperative pelvic tilt and BMI. In other words, patients with increased BMI had lesser axial rotation.

## Discussion

The long-term outcome of THA is influenced by the acetabular cup placement angle, which is influenced by pelvic motion [3]. In this study, we investigated intraoperative pelvic motion during THA via the DAA using an AR-Hip portable navigation system. Our results showed that the pelvis tilted forward in the sagittal plane and leaned toward the surgical side in the axial plane.

Several studies have reported that intraoperative pelvic motion occurs in the supine position during THA and is associated with patient BMI. Kamenaga et al. [16] measured the pelvic tilt and axial rotation during THA through the anterolateral supine approach with HipAlign (accelerator-based portable navigation system). The intraoperative pelvic tilt increased by 2.7° and axial rotation by 1.2° from the time of registration to acetabular cup placement. Pelvic tilt was not associated with BMI, but the change in the absolute axial rotation was negatively correlated with it. Okamoto et al. [15] measured pelvic tilt and axial rotation during THA through the DAA with HipAlign. The intraoperative pelvic tilt increased by 7.6° and axial rotation by 3.2° from the time of registration to acetabular cup placement. Low BMI and internal rotation range were predictors of a large pelvic tilt increase, and axial rotation was not associated with BMI. Similarly, in this study, intraoperative pelvic tilt was 4.8° and axial rotation was 4.2°, with pelvic motion direction similar to those previously reported, with a negative correlation between axial rotation and BMI. Regarding the accuracy of the navigation system, the AR-Hip system may enable more precise acetabular cup placement than HipAlign during THA [17]. Pelvic tilt was lesser in this study than in the previous one [15], which used the same approach (through the DAA). Both studies comprised similar patient backgrounds; therefore, the current study may be more accurate because of the improved accuracy of the navigation system used, as reported by Tsukada et al. [17]. Regarding the relationship between BMI and pelvic tilt in supine THA through different approaches, such as the DAA and anterolateral supine, the posterior retractor is firmly pulled to avoid interference with the femur and soft tissue during cup implantation. The retractor caused the pelvis to tilt forward and rotate toward the surgical side in this study. Patients with a lower BMI were more susceptible to this effect. One way to minimize pelvic motion is to remove the retractors. However, it is difficult to say which is better, since removal of the retractors results in a poor surgical field of view.

Brod et al. [18] used a smartphone app to measure the intraoperative pelvic tilt in the ischial spine during each step of THA using the transgluteal approach; however, there are no reports of pelvic motion at each surgical step of THA via the DAA. Therefore, this study is the first to report intraoperative pelvic motion over time in THA using the DAA. In this study, the pelvis was tilted forward and rotated to the surgical side, both under the influence of the acetabular retractor and cup impactor. Conversely, Brodt et al. [18] reported that the transgluteal approach required strong upward traction of the retractor to ensure adequate visualization, with pelvic rotation subsequently performed on the surgical side, in contrast to the axial rotation of the anterior approach. However, even with the transgluteal approach, the pelvis was rotated to the surgical side during cup implantation compared to that during retractor implantation, which is consistent with the results of the present study. Therefore, in supine THA, the pelvis is considered to rotate toward the surgical side owing to cup implantation.

Depending on whether the alignment guide is aligned before or after cup implantation, pelvic tilt will differ from its preoperative state, resulting in a difference in acetabular cup placement angle; therefore, pelvic motion should be considered. Cup inclination increases by 0.21° and 0.28° and cup anteversion by 0.73° and 0.63° per one degree in the pelvic sagittal and coronal tilts, respectively [19]. When the cup impactor and acetabular retractor were removed, the pelvis tilted posteriorly and rotated toward the surgical side. Therefore, cup anteversion and inclination tended to be greater than the target angle, especially for anteversion. Furthermore, the safe zone for the cup anteversion range is narrower than that for inclination in THA [7]. Additionally, cup malalignment primarily results from intraoperative pelvic motion [10]. Therefore, to minimize this error, it is important to know that the pelvis tilts forward and rotates toward the surgical side during the DAA. In addition, it is important to apply gently force to the retractor to prevent the pelvis from tilting as much as possible.

**Table 1**
The mean pelvic tilt and axial rotation at each surgical step are showed.

| Surgical step | Pelvic tilt | Axial rotation |
|---|---|---|
| 1. Skin incision (°) mean + SD (min, max) | 0 ± 0.5 (−1, 1) | 0.4 ± 2.0 (−4, 5) |
| 2. Acetabular retractors (°) mean + SD (min, max) | 2.4 ± 1.6 (0, 8) | 2.2 ± 2.6 (−3, 10) |
| 3. Cup implantation (°) mean + SD (min, max) | 4.8 ± 2.5 (−4, 12) | 4.6 ± 3.9 (−4, 15) |
| 4. Remove the cup impactor (°) mean + SD (min, max) | 2.6 ± 1.4 (−1, 6) | 2.4 ± 2.6 (−3, 11) |
| 5. Remove the acetabular retractors (°) mean + SD (min, max) | 1.1 ± 1.3 (−2, 4) | 0.7 ± 2.4 (−5, 8) |

This study revealed the direction and degree of intraoperative pelvic motion. In THA using a portable navigation system, the navigation system corrects for pelvic motion during cup placement. However, when a freehand technique is used, there is no such correction, so knowing the pelvic tilt at each stage will allow for more appropriate cup placement. When fluoroscopy is used during DAA, it is possible to see the tilt of the cup with common fluoroscopic equipment. Large head C arms are able to visualize the pelvis in almost entirety so the surgeon is able to get information about pelvis rotation as well as flexion/extension of the pelvis, obviously dependent on the surgeons ability to scrutinize the radiographs.

Our study has some limitations. First, we have not been able to quantify the force of impaction on the pelvis, and pelvic motion can vary depending on intraoperative manipulation, such as the position of the retractor, the force with which it is held, and the force applied to the cup impactor. In this study, although we cannot rule out the possibility of pelvic motion due to intraoperative manipulation, the retractor was grasped as gently as possible, and the cup impactor was impacted as gently as possible; therefore, their effects on pelvic motion were considered minimal, and the surgical manipulation was stationary at the time of the pelvic motion comparison, and the only difference in force applied to the pelvis at that point is attributed to the presence of absence of the acetabular retractor. Second, the BMI of the patients was low in this study. The participants were all Japanese, and many had a low BMI. A group with a higher BMI may yield different results. Third, THA in this study was performed on a standard operating table, not on a Hana table. Although DAA using the Hana table has become common in recent years, the Hana table has a post in the center of the operating table, and this post is expected to cause the pelvic motion to be different from that described in this study. Therefore, the results of this study are limited to THA performed on a standard operating table.

In this study, the intraoperative pelvic tilt and axial rotation were around 4 degrees each, but when the pelvis tilts 4 degrees, the cup placement angle tilts as well [19], and there are reports that the safe zone range of the cup is within about 4 degrees [6], so we believe these 4 degrees are important.

## Conclusions

This study revealed a trend in pelvic motion during THA via the DAA. The pelvis tilts forward and rotates toward the surgical side intraoperatively. The effects of the acetabular retractor and cup impactor on pelvic motion were comparable. Without the use of a navigation system, the acetabular cup would result in malalignment if pelvic motion during acetabular cup implantation is not fully considered.

## Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101251.

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