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Preoperative Fluoroscopic Imaging Reduces Variability of Acetabular Component Positioning

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Abstract: We evaluated the preoperative errors in the pelvic tilt of 249 hips before total hip arthroplasty using fluoroscopic imaging while the patients were in the lateral decubitus position. The mean absolute value errors of the pelvic tilt were 2.94° (SD, 2.92°), 2.49° (SD, 2.68°), and 5.92° (SD, 5.20°) in the coronal, transverse, and sagittal planes, respectively. Such preoperative errors in the pelvic tilt contribute to malpositioning of the acetabular component, as is frequently observed on postoperative radiographs. We reduced the incidence of malpositioning by correcting the errors in the pelvic tilt through repositioning of the operating table using fluoroscopic imaging before surgery. The new technique using fluoroscopic imaging described in this article can be performed within a short time without a navigation system. **Keywords:** acetabular component positioning, lateral decubitus position, fluoroscopic imaging, pelvic position, total hip arthroplasty.

Dislocation is a major complication of total hip arthroplasty (THA) and is frequently caused by malpositioning of the acetabular component [1-3]. Such misalignments can also lead to a limited range of motion and increased wear and reduced survival of the prosthesis, thereby greatly affecting the outcome of THA [1-7].

Lewinnek et al [8] defined a safe zone for acetabular component placement against dislocation as 30° to 50° of inclination and 5° to 25° of anteversion. They further described that acetabular components placed within the safe zone have a lower risk of dislocation. However, even for experienced orthopedic surgeons, it is difficult to ensure the placement of the acetabular component within the safe zone freehand [9-11]. As a result, various mechanical alignment guides have been developed to support accurate placement of acetabular components. Nonetheless, even though surgeons have presumably implanted an acetabular component in the targeted position using such guides, many have had the experience of finding that the acetabular component is placed out of the targeted position upon review of postoperative radiographs.

We hypothesized that a preoperative error in the pelvic tilt in the lateral decubitus position has a great impact on malpositioning of the acetabular component. We evaluated the preoperative pelvic tilt using fluoroscopic imaging and then commenced surgery after adjusting the error in the pelvic tilt by repositioning the operating table. After implanting acetabular components with ordinary operative methods, we evaluated the postoperative positions of the acetabular components using standing anteroposterior radiographs.

The purposes of this study were as follows: (i) to clarify the extent and tendency of variability in the preoperative pelvic tilt in the lateral decubitus position and (ii) to evaluate whether or not the accuracy of acetabular component placement is improved by correcting the error in the pelvic tilt before surgery.

Materials and Methods

Between October 2005 and April 2010, a consecutive series of 249 primary THAs (217 patients) were performed at our institution. Two patients were withdrawn from the study. One could not undergo preoperative standing anteroposterior radiographs because of a fracture of the femoral neck, and the other could not undergo standing anteroposterior radiographs because of paralytic polio. The average age of the 217 patients at the time of surgery was 62.1 years (SD, 11.8 years; range, 27-89 years). In

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total, 125 procedures were performed on the left hip, and 124 were performed on the right hip. There were 34 men (39 hips) and 183 women (210 hips). The average body mass index (BMI) was 23.2 kg/m^2 (SD, 4.0 kg/m^2; range, 14.5-40.7 kg/m^2).

The patients were fixed in the lateral decubitus position using a Universal Lateral Positioner (IMP, Plainville, Conn). The Universal Lateral Positioner provides stable fixation of the pelvis even during long surgeries by securing the patient with a pair of anterior and posterior support braces. The anterior support brace supports the bilateral anterior superior iliac spines, whereas the posterior support brace supports the midsacrum. Because all of the components are radiolucent, the pelvic position can easily be evaluated by fluoroscopic imaging. All of the surgeries were performed by 2 experienced surgeons (M.F. and K.U.) using a posterolateral approach with cementless acetabular components and cementless stems. Our targeted acetabular component orientation for all the patients was 40° of inclination and 20° of anteversion, with reference to the pelvic position shown on the preoperative standing anteroposterior radiographs. The acetabular components were placed with mechanical alignment guides.

Evaluation of the Pelvic Tilt in the Lateral Decubitus Position

DiGioia et al [9] expressed pelvic motion in terms of the yaw (abduction and adduction) in the coronal plane, roll (anteversion and retroversion) in the transverse plane, and pitch (flexion and extension) in the sagittal plane. We evaluated the pelvic tilt in terms of each component defined by DiGioia et al using the following methods:

(a) Coronal plane: the C-arm of the fluoroscopic imaging system was set to create a horizontal radiation beam in the anteroposterior direction (Fig. 1A). A thin metal chain was dangled and fixed on the image reception screen (Fig. 1B) to show the perpendicular direction in the monitor display (Fig. 1C). Using this as a reference, the

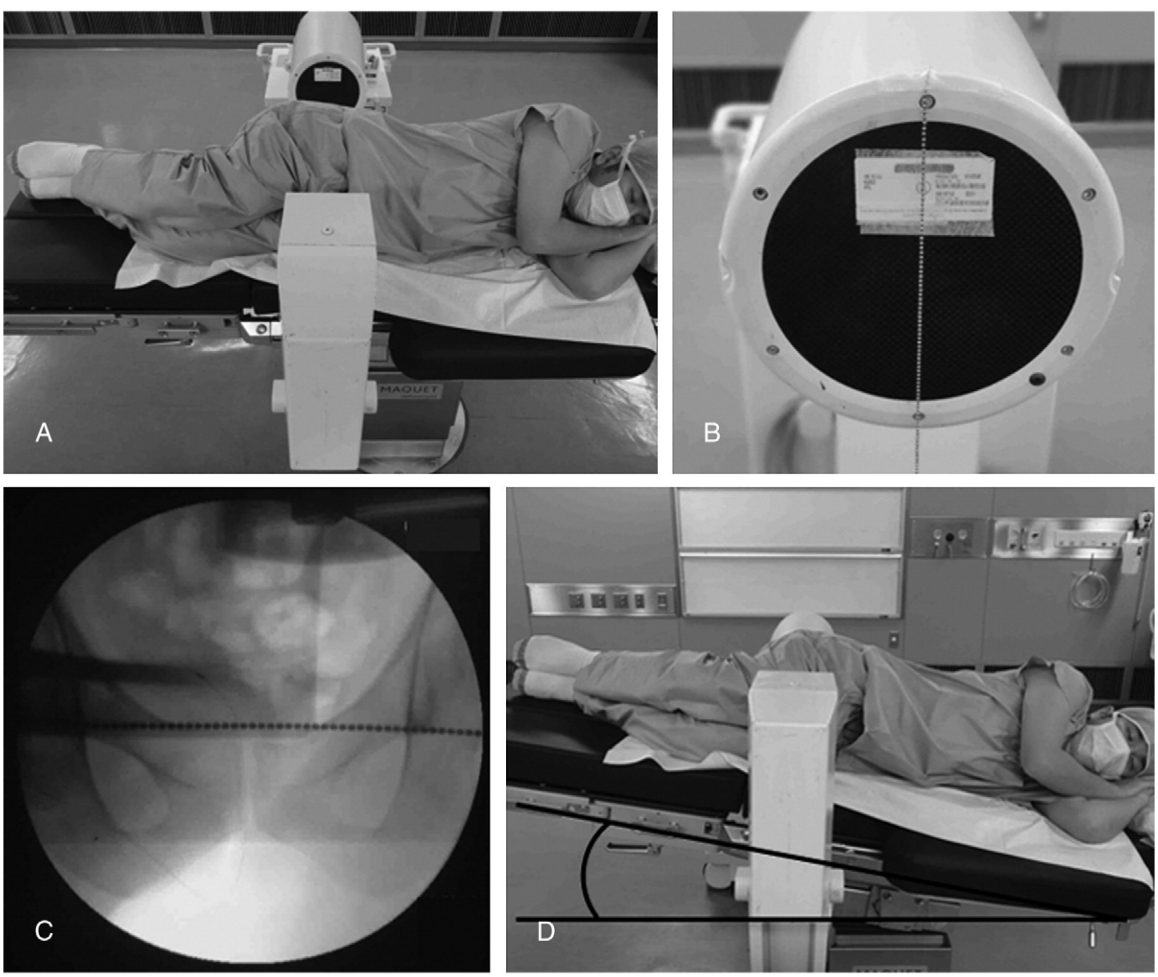

Fig. 1. (A) The C-arm of the fluoroscopic imaging system was rotated in anteroposterior direction. (B) A metal chain was attached perpendicularly on the image reception screen. (C) The line connecting the bilateral tear drops and the chain on the fluoroscopic image display are parallel. (D) The angle of tilt of operating table was measured.

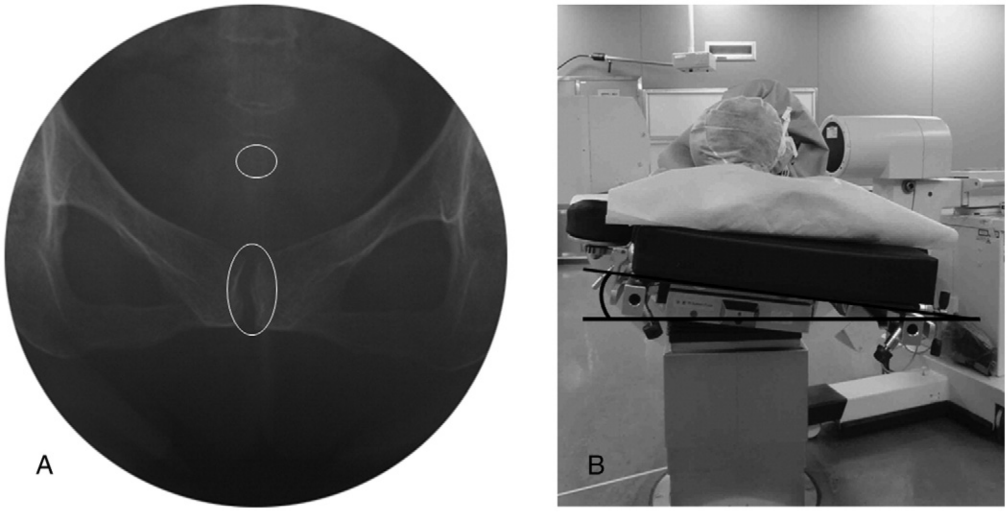

Fig. 2. (A) The center line of the sacrum and coccyx was an extension of midline of the symphysis pubis. (B) The angle of tilt of operating table was measured.

operating table was tilted so that the line connecting the bilateral tear drops became parallel to the chain. The yaw of the pelvis in the coronal plane was evaluated as the angle of the tilt of the operating table (Fig. 1D).

(b) Transverse plane: the operating table was tilted so that the center line of the sacrum and coccyx coincided with the extension of the midline of the symphysis pubis on the fluoroscopic image display monitor (Fig. 2A). The roll of the pelvis in the transverse plane was evaluated as the angle of the tilt of the operating table (Fig. 2B).

(c) Sagittal plane: the C-arm of the fluoroscopic imaging system was rotated horizontally to the floor of the operating room so that the positional relationship between the superior margin of the symphysis pubis and the tip of the coccyx on the fluoroscopic image display monitor was the same as that obtained on the preoperative standing anteroposterior radiographs (Fig. 3A). This alignment adjusted the pitch to the targeted angle. The pitch of the pelvis in the sagittal plane was evaluated as the angle of rotation of the C-arm (Fig. 3B). The orientation of the C-arm was marked on the floor with tape so that it was clearly seen during the surgery. Precise degrees of the anteversion of the acetabular component were determined intraoperatively with reference to this marking at the implantation.

Patients with flexion contracture have pathological extension in the pelvic sagittal tilt in the standing position, and it is expected that THA will release this pathological extension. We consider that the postoperative pelvic sagittal tilt in the standing position can be recreated by having the patient stand with slight flexion of the knee joint at the preoperative reference radiographs. Therefore, in patients with flexion contracture, we took preoperative radiographs when they were standing with their knee joint slightly flexed and regarded the pelvic sagittal tilts on these radiographs as the targeted pelvic angles.

In the case of asymmetry or deformities of the pelvis, it was required to determine the targeted position of the pelvis based on a careful evaluation of the pelvis in advance.

The mean values of the errors in the pelvic tilt in the coronal, transverse, and sagittal planes were calculated, and the extents and tendencies were evaluated. In addition, the mean absolute values were calculated to evaluate the extent of the variability of the pelvic tilt.

Evaluation of the Postoperative Position of the Acetabular Components

In our institution, all THA cases have undergone surgery using the new technique since October 2005. Therefore, we set up a control group of 71 THA cases who underwent surgery at our institution by the same surgeons using the same operative methods but without the use of the new technique from January 2004 to September 2005, representing the period before the introduction of the technique. There were no significant differences between the control group and the new technique group in the demographic data (age, sex, and BMI; Table 1).

Based on the postoperative standing anteroposterior radiographs, the inclination and anteversion of the acetabular components were measured, and the mean values were calculated. The anteversion of the acetabular components was measured using Pradhan's [12] method. The adequate zone was defined as an

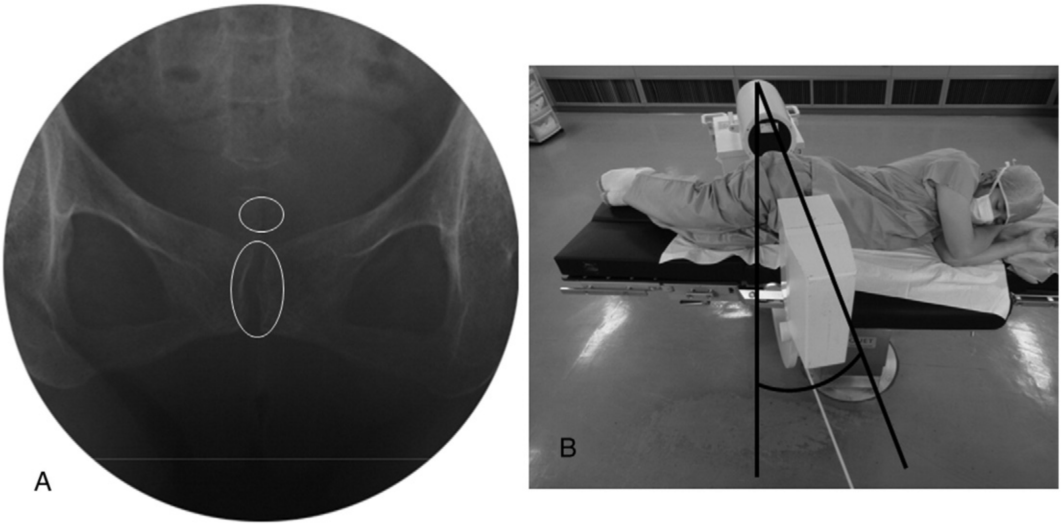

Fig. 3. (A) The positional relationship between the superior margin of the symphysis pubis and the tip of the coccyx was adjusted. (B) The angle that the C-arm was rotated was measured.

inclination of 30° to 50° and an anteversion of 10° to 30° by allowing errors of 10° to the targeted acetabular component position. We judged whether or not the acetabular components were placed within this adequate zone to clarify whether the incidence of malpositioning could be reduced.

Statistical analyses were performed using the χ^2 test for categorical data and Student t test for continuous measurements. Values of $P < .05$ were considered to indicate statistical significance.

Results

Evaluation of the Pelvic Tilt in the Lateral Decubitus Position

The mean errors in the pelvic tilt in the lateral decubitus position were adduction of 1.69° (SD, 3.79°) in the coronal plane, anteversion of 0.58° (SD, 3.61°) in the transverse plane, and flexion of 2.40° (SD, 7.64°) in the sagittal plane. The mean absolute value errors were 2.94° (SD, 2.92°) in the coronal plane, 2.49° (SD, 2.68°) in the transverse plane, and 5.92° (SD, 5.20°) in the sagittal plane. With respect to the sagittal plane, the error was more than 5° in 149 hips (59.8%) and more than 10° in 63 hips (25.3%).

Table 1. Age, sex, and BMI of the patient in the 2 study groups

	The new technique group (n = 249)	The control group (n = 71)	*P*
Age (y),	62.1	60.7	.37
mean (SD; range)	(11.8; 27-89)	(11.1; 36-82)	
Sex (men/women)	39:210	14:57	.41
BMI (kg/m^2),	23. 2	23.6	.52
mean (SD; range)	(4.0; 14.5-40.7)	(3.5; 14.6-33.7)	

Evaluation of the Postoperative Position of the Acetabular Components

The average inclination and anteversion of the acetabular components were 39.6° (SD, 6.9°) and 14.0° (SD, 7.6°) in the control group, and 42.5° (SD, 4.4°) and 16.9° (SD, 5.9°) in the new technique group, respectively.

The acetabular component was placed within the adequate zone in 49 hips (69.0%) in the control group and 210 hips (84.3%) in the new technique group (P = .003). In the control group, the inclination was below 30° in 4 hips (5.6%) and more than 50° in 4 hips (5.6%), and the anteversion was below 10° in 20 hips (28.2%) and more than 30° in no hips. In the new technique group, the inclination was below 30° in no hips and more than 50° in 1 hip (0.4%), and the anteversion was below 10° in 36 hips (14.5%) and more than 30° in 3 hips (1.2%). The error in the inclination was within 10° in 63 hips (88.7%) in the control group and 248 hips (99.6%) in the new technique group. The error in the anteversion was within 10° in 51 hips (71.8%) in the control group and 210 hips (84.3%) in the new technique group.

Discussion

There are 3 major causes of malpositioning of acetabular components, namely, preoperative errors in the pelvic tilt, intraoperative changes in the pelvic tilt, and intraoperative errors in the manual operation. Examples of the errors caused by the pelvic tilt in the lateral decubitus position include greater anteversion of the acetabular components on postoperative radiographs in cases that underwent THA with the pelvis extended and smaller inclination of the acetabular components on postoperative radiographs in cases that underwent THA with the pelvis abducted. An excessively large anteversion of the acetabular component leads to a higher risk of anterior dislocation, owing to posterior impingement when the hip joint is in extension and external rotation. An excessively small inclination leads to a higher risk of posterior dislocation, owing to anterior impingement when the hip joint is in flexion with internal rotation and adduction.

It has been reported that there is variability in the pelvic tilt in the lateral decubitus position [1,9,13]. McCollum and Gray [1] described that the superior acetabulum was adducted in the lateral decubitus position and also that the lumbar lordotic curve is flattened, which results in a flexion of the pelvis. In the present study, we also observed a similar tendency for adduction of the pelvis in the coronal plane. It is inferred that the cause may be the pull of the pelvis by the weight of the lower extremity of the operated side. In the sagittal plane, a tendency for flexion of the pelvis was observed. It is inferred that this flexion may arise because the pelvis is secured at the anterior superior iliac spines on the anterior side and midsacrum on the posterior side, meaning that the posterior securing site is more caudal than the anterior securing sites.

Recently, the use of a navigation system has been reported to allow precision of the preoperative pelvic tilt in the lateral decubitus position. Zhu et al [13] reported errors in the pelvic tilt in the sagittal plane of more than 6° in 41.3% of subjects and more than 10° in 16.1%. In the present study, we observed errors in the pelvic tilt in the sagittal plane of more than 5° in 59.8% of the subjects and more than 10° in 25.3%. Such errors in the pelvic tilt, particularly if complicated with intraoperative changes in the pelvic tilt and errors in the manual operation, readily lead to greater errors in the position of the acetabular component on the postoperative radiographs.

Kalteis et al [14] described that the average inclination and anteversion of the acetabular components in 30 cases in which the acetabular components were placed freehand were 43.7° (SD, 7.3°) and 22.2° (SD, 14.2), respectively. Similar to their results, both the inclination and the anteversion varied greatly in the control group, and the acetabular component could be placed within the adequate zone in only 69.0% of the cases. In contrast, the variations in both the inclination and the anteversion were reduced in the new technique group, and the acetabular component could be placed within the adequate zone in 84.3% of the cases ($P = .003$). The use of the new technique improved the accuracy of the positioning of the acetabular component.

The percentage of cases in which the error in inclination was within 10° was improved to 99.6% in the new technique group compared with 88.7% in the control group, which indicates that we could place the acetabular components at almost the targeted inclination. On the other hand, the percentage of cases in which the error in anteversion was within 10° was improved to 84.3% in the new technique group compared with 71.8% in the control group. However, errors of more than 10° of anteversion were observed in 15.7% of the cases, and most of these cases had an excessively small anteversion. It was inferred that this may occur because the pelvis tilts in the direction of the anteversion, with the femur of the operated side being pulled at the time of the intraoperative reaming procedure. DiGioia et al [15] described that the pelvic tilt can change in response to range-of-motion tests and the impact of hammering on the acetabular component. In addition, Hassan et al [16] described that anteversion or retroversion of the pelvis can easily occur intraoperatively. The new technique cannot reduce the effects of intraoperative changes in the pelvic tilt. If the acetabular component is placed with the pelvis tilting in the direction of anteversion, the anteversion of the acetabular component shown on the postoperative radiographs becomes smaller than the targeted angle. Further efforts are required to secure the pelvis in a way that reduces intraoperative changes in the pelvic tilt.

The use of navigation systems has promoted accurate placement of acetabular components [11,14,15,17,18]. Kalteis et al [14] reported that acetabular components could be placed within the safe zone defined by Lewinnek et al [8] in 25 (83%) of 30 acetabular components with an inclination of 41.6° (SD, 4.0°) and an anteversion of 10.7° (SD, 5.3°) using computed tomography–based navigation and in 28 (93%) of 30 acetabular components with an inclination of 43.2° (SD, 4.0°) and an anteversion of 15.2° (SD, 5.5°) using an imageless navigation system. The use of navigation systems can reduce the effects of all 3 causal factors of malpositioning of acetabular components and allows for more accurate placement of the acetabular components than the new technique. However, the use of navigation raises potential concerns, including increased exposure, higher cost for purchase, and longer operative time. The new technique took us about 10 minutes to complete when we started to use it. However, now that we are familiar with the technique, it takes about 3 to 5 minutes (3 minutes for small pelvic tilt errors and 5 minutes for large errors). In addition, navigation systems have been less popular in the Asia-Pacific region. In 2007, only 146 surgical navigation systems equipped with an orthopedic application were sold in the Asia-Pacific market. Although it is expected that the penetration rate will gradually grow, we still have a long way to go before navigation systems are used at many institutions. Therefore, it is necessary to establish a technique that enables accurate placement of acetabular components without a navigation system.

Park et al [19] reported a technique for improving the accuracy of acetabular component placement by adjusting the position of the acetabular component by taking radiographs before the completion of the surgery. They reported placement of the acetabular components within their adequate zone (inclination of 30°-50° and anteversion of 5°-30°) in 90.0% of the study subjects. Their technique, which directly evaluates the position of the acetabular component, can reduce the effects of all 3 causal factors of malpositioning of the acetabular component. However, fine adjustment of the position of the acetabular component is difficult because the radiographs can only be performed once. Notably, our technique allows for a complete adjustment of the errors in the pelvic tilt before the start of the surgery. Furthermore, with the marking on the floor, it is possible to recognize the correct pelvic position during the surgery.

Adjustment of the pelvic tilt in the sagittal plane can be attained by the method of rotating the C-arm in the plane horizontal to the floor of the operating room and also by the method of rotating the operating table. However, when the required angle of rotation of the operating table is large, the anesthesia apparatus also has to be moved, and the surgeon has to move with the operating table and loses his modified reference point.

The anteversion values that we calculated using the method of Pradhan [12] may contain a margin of error. Pradhan described that his method was proven to be reliable in an in vitro model in which the calculated anteversion was compared with the true acetabular component anteversion. However, in reviewing his data, there was little variation within the observers but more variation between observers, and the discrepancy was between the true value and the calculated value. One case showed an error of as much as about 1.8° between the true value and the calculated value. The error tended to be greater for greater anteversion. In addition, the calculated values are greatly affected by the pelvic tilt. Therefore, we made an effort to minimize the errors in the calculated values by taking postoperative radiographs in the standing position with great attention to the pelvic sagittal and transverse tilts. However, there were a few cases in which the pelvic sagittal tilt in the standing position changed before and after the surgery, and the pelvic sagittal tilt on the postoperative radiographs taken in the standing position could not be completely matched with that on the preoperative radiographs. The calculated values of anteversion in the present study include the error caused by the change in the pelvic sagittal tilt between before and after the surgery.

There is no view that has gained a broad consensus on the ideal position of the acetabular component. The reasons why the targeted acetabular component position is not consistent include changes in the pelvic tilt with aging [20,21] and changes in the pelvic tilt between the standing and decubitus positions [22]. In addition, because the pelvic tilt can change before and after the THA in some cases, the effects of surgery on the pelvic tilt have to be considered. More studies are needed to determine the ideal position of the acetabular component.

In conclusion, there are errors in the pelvic tilt in the lateral decubitus position. Such errors are key factors in contributing to malpositioning of the acetabular component. The incidence of such malpositioning can be reduced by correcting these errors before the surgery. The new technique using fluoroscopic imagining can be performed within a short time before the surgery and is useful for accurately placing the acetabular component without the use of a navigation system.

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