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Measurement of Pelvic Movement during Total Hip Arthroplasty Using a Hip Navigation System

Yoshihito Minami, Hirotsugu Ohashi, Hirotake Yo, Tesshu Ikawa and Takanori Teraoka*

Department of Orthopedic Surgery, Osaka Saiseikai Nakatsu Hospital, Japan

Abstract

Purpose: In total hip arthroplasty, the accuracy of the cup inclination and version is influenced by the intraoperative pelvic movement. We modified the use of a hip navigation system to measure the pelvic movement in three directions at five steps during surgery.

Methods: Forty-seven hips were operated on by the direct anterior approach in a supine position. We monitored the pelvic position at setup, after femoral head resection, at acetabular exposure, after acetabular reaming, after cup implantation, and after maximum limb traction for reduction.

Results: The pelvis tended to move toward the direction of abduction in the frontal plane during surgery (2.1 ± 1.5 degrees after cup implantation). The pelvis tended to move toward the direction of internal rotation by anterior retractor (1.7 ± 2.3 degrees at acetabular exposure) and toward the direction of anterior tilt by caudal retractor at obturator foramen (2.4 ± 1.7 degrees after cup implantation).

Conclusion: Even in a supine position, the pelvis tended to move toward the direction of abduction by limb traction and toward the direction of internal rotation and anterior tilt by retractors. We must pay attention to the pelvic movement when fixing the cup even in a supine position.

Keywords: Total hip arthroplasty; Pelvic movement; Navigation system; Supine position

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Correspondence:
Hirotsugu Ohashi, Department of Orthopedic Surgery, Osaka Saiseikai Nakatsu Hospital, 2-10-39, Shibata, Kita-ku, Osaka, 530-0012, Japan, Tel: +81-6-6372-0333; Fax: +81-6-6372-0339;
E-mail: hohashi@grace.ocn.ne.jp

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Introduction

In Total Hip Arthroplasty (THA), cup malalignment is associated with dislocation, wear, and edge loading. To minimize these risks, a "safe zone" of cup position is proposed. Initially, Lewinnek et al. [1] proposed 40° ± 10° of inclination and 15° ± 10° of anteversion from 300 cases. Widmer et al. [2] developed a mathematical model including the acetabular cup and femoral stem. The proposed cup angle was between 40° and 45° of inclination, and between 20° and 28° of anteversion. When a patient wants to get more range of motion, the sweet spot of cup position is made smaller. Accurate cup placement is one of the most challenging aspects in THA. The cup inclination and version will be more accurate when we use a navigation system or intraoperative image control [3-5]. Ordinarily, surgeons intend to recognize the pelvic position under draping during surgery and decide the cup inclination and version in reference to the pelvic position and the jig. The premise in this situation is that the patient lies on the operating table in a neutral position and the pelvis does not move during surgery. However, the pelvis may be moved in the coronal, axial, and sagittal planes by retractors used for exposing the acetabulum, even if the pelvis is fixed by positioners. Furthermore, the pelvic position may be changed by the movement of the leg and the manipulation of the hip joint. Such pelvic movement can result in errors in cup inclination and version.

Several studies have investigated the degree of intraoperative pelvic movement. Asayama et al. [6] used a digital compass and a Three-Dimensional (3D) direction indicator to evaluate the degree of movement between two points: before dislocating the hip joint and immediately before placing the cup. Grammatopoulos et al. [7] used a photogrammetric technique to evaluate the angular movement of the pelvis between setup and component implantation. Kanazawa et al. [8] superimposed the images reconstructed from Computed Tomography (CT) data onto anteroposterior radiographs taken at setup and after cup placement. These studies quantitatively evaluated the intraoperative pelvic movement, whereas the angle of pelvic movement could be obtained in only one situation.

Brodt attached a Smartphone on the patient's contralateral anterior superior iliac supine and monitored the pelvic movement using the app Sensor Log during THA [9,10]. This was an easy method to monitor pelvic tilt at any time during surgery; however, a Smartphone was not fixed to

Figure 1: Photographs of patient position and the arm with two grippers for the tracker devices (black arrow). (a) A side retainer (white arrow) at the contralateral side of the pelvis. (b) The contralateral leg was elevated on the Mayo table.

Figure 2: Arm with two grippers for the tracker devices was fixed to the side bar of the operating table. (1) Tracker for coronal plane and axial plane. (2) Tracker for sagittal plane.

the bone so the soft tissue can influence the results. Schwarzkopf et al. [11] monitored intraoperative pelvic movement using a navigation device that had an integrated accelerometer. The pelvic movement was recorded during surgery; however, due to a retrospective study, the authors did not know which surgical step caused maximum pelvic movement. This navigation system contained integrated inertial sensors that were configured to measure the movement and the orientation only in 2 orthogonal degrees of freedom. Recently, the pelvic movement was measured using a miniature surgical navigation device during THA in a lateral decubitus position [12]. The purpose of this study was to measure the pelvic movement in the coronal, axial, and sagittal planes during THA in a supine position using a hip navigation system. With this system, we can obtain the angle of pelvic movement at any time. We checked the angles at setup, after femoral head resection, at acetabular exposure, after acetabular reaming, after cup implantation, and after maximum limb traction for reduction.

Materials and Methods

Patients

This study was approved by the ethics committee of our hospital. Between September 2016 and January 2018, we performed 203 THAs. Of these, 47 THAs were recruited for this study. Inclusion criteria were primary or secondary hip osteoarthritis, osteonecrosis, and patients age less than 69 years, and THA by the Direct Anterior Approach (DAA) in a supine position using a hip navigation system without any problems. Exclusion criteria were revision THA, Crowe type IV, and bilateral simultaneous THA. The study included 8 men and 39 women aged 32 to 69 years (mean 59.2 y). The patient demographics are detailed in Table 1.

Table 1: Demographics (means with ranges as appropriate) and surgical details.

Gender	Male	8
	Female	39
Age (y)		59.2 (32-69)
Height (cm)		157.6 (145-171)
Weight (kg)		59.0 (40-93)
BMI (kg/m^2)		23.8 (17.2-34.6)
Stem Bi Contact		22
Trilliance		25
Leg elongation (mm)		9.4 (-3-23)

BMI: Body Mass Index

Figure 3: The pelvic tracker device (white arrow) was placed at the ipsilateral ilium. The tracker device for reamer navigation (black arrow) was fixed at the arm.

Methods

An image-free THA navigation system (Ortho Pilot THA dysplasia, B. Braun-Aesculap, Tuttlingen, Germany) was used for THA with ceramic on ceramic bearings. Our choice to use ceramic on ceramic bearing was due to the patients being under 69 years of age. For patients under 60 years of age, cement less stem (BiContact stem, B. Braun-Aesculap, Tuttlingen, Germany) was selected, and for patients over 61 years of age, a cemented stem (Trilliance, B. Braun-Aesculap, Tuttlingen, Germany) was selected. A cement less cup (Microcup cup, B. Braun-Aesculap, Tuttlingen, Germany) with ceramic on ceramic bearings was used in all cases. The patient in a supine position was supported by a side retainer at the contralateral side of the pelvis (Figure 1a). The contralateral leg was elevated on the Mayo table to achieve maximum adduction of the operated hip (Figure 1b). The operations were performed by a total of four surgeons and a total of eight assistants. All operations were supervised by one senior surgeon (HO). Before surgery, an arm with two grippers, which could fix the tracker devices parallel and perpendicular to the longitudinal axis of the operating table, was fixed to the side bar of the operating table (Figure 2). After draping, two tracker devices, which were used for reamer navigation, were gripped at the arm. The pelvic tracker device was placed at the ipsilateral ilium (Figure 3). The anterior pelvic plane was registered and the surgery proceeded routinely. After capsule exposure, the pelvic position without retractors was navigated as the setup position. In the ordinary use of the navigation system, the pelvic tracker device was recognized as stable, and the angle of the reamer with the tracker device was navigated in reference to the pelvic tracker device. In this study, the tracker device for reamer navigation was fixed at the arm for stability, and then the movement of the pelvic tracker device was navigated in reference to the fixed tracker for reamer navigation. The operation was performed

Table 2a: Angle of pelvic movement in each direction at five points during surgery.

Step	Retractors Abduction Internal rotation Anterior tilt			
(1) After head resection	WO	0.4 ± 1.1 degrees	-0.6 ± 1.7	0.1 ± 1.2
(2) Acetabular exposure	W	1.5 ± 1.2	1.7 ± 2.3	2.0 ± 1.8
(3) Before cup implantation	W	1.8 ± 1.4	0.7 ± 2.1	2.0 ± 1.5
(4) After cup implantation	W	2.1 ± 1.5	-0.5 ± 2.0	2.4 ± 1.7
(5) After traction for reduction	WO	3.5 ± 2.7	-1.1 ± 2.5	0.3 ± 1.9

Table 2b:

Step	Abduction	Internal rotation	Anterior tilt
1	NA	NA	NA
2	*vs.* (1) $p=2 \times 10^{-5}$	*vs.* (1) $p=1 \times 10^{-6}$	*vs* (1) $p=3 \times 10^{-8}$
3	*vs.* (1) $p=9 \times 10^{-7}$	*vs.* (1) p=0.002	*vs.* (1) $p=3 \times 10^{-9}$
			vs. (2) p=0.004
4	*vs.* (1) $p=1 \times 10^{-8}$	*vs.* (2) $p=3 \times 10^{-6}$	*vs.* (1) $p=3 \times 10^{-11}$
			vs (3) p=0.004
5	*vs.* (1) $p=8 \times 10^{-7}$	*vs.* (2) $p=3 \times 10^{-7}$	*vs.* (2) $p=3 \times 10^{-5}$
	vs. (2) $p=7 \times 10^{-6}$	*vs.* (3) p=0.0003	*vs.* (3) $p=1 \times 10^{-5}$
	vs. (3) p=0.0001		*vs.* (4) $p=3\text{-}10^{-7}$
	vs. (4) p=0.002		

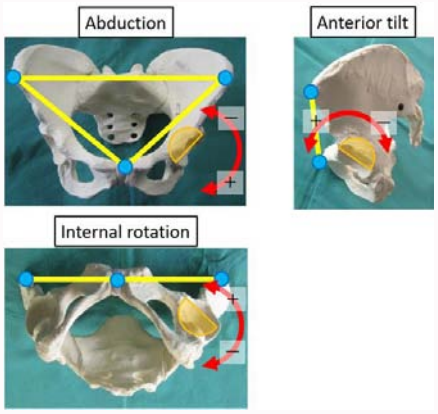

Figure 4: Pelvic coordinate in reference to the APP.

by the DAA. For acetabular exposure, three retractors were used. An anterior retractor was fixed at the anterior edge of acetabulum to retract tensor fascia latae muscle. We resected anterior and superior capsule. A posterior retractor was fixed at the posterior edge of acetabulum to retract femoral shaft. A caudal retractor was fixed at the obturator foramen to retract caudal capsule, iliopsoas tendon, and external obturator muscle. During surgery, the pelvic position was navigated at five steps: (1) after femoral head resection without retractors, (2) acetabular exposure with retractors, (3) immediately before cup implantation with retractors, (4) after cup implantation with retractors, and (5) after maximum limb traction for reduction without retractors. For the purpose of angle measurement, the pelvic coordinate was defined (Figure 4). The Anterior Pelvic Plane (APP) was determined by palpating both Anterior-Superior Iliac Spines (ASIS) and the pubic symphysis. The X-axis referred to the inter-ASIS line. The Y-axis referred to the perpendicular line to the inter-ASIS line in the APP. The Z-axis referred to the perpendicular line to the APP. A distal tilting motion of the operative side on the frontal plane was defined as abduction. A forward rotating motion of the operative side pelvis on the transverse plane was defined as internal rotation. A forward turning motion of the proximal pelvis on the longitudinal plane was defined as anterior tilt.

Data analysis

Data were collected in three directions. The angle of pelvic movement was calculated as the difference between the setup position and each navigated position. The relationship between the angle of pelvic movement and patients' height, body weight, and BMI.

Statistical analysis

Values were expressed as the mean ± standard deviation. The Student test and Pearson correlation coefficient were used. Statistical analyses were performed with SPSS 16.0J (IBM, Chicago, Illinois).

Results

The mean angle of pelvic movement in each direction at the five steps is summarized in Table 2. In the frontal plane, the pelvis tended to move toward the direction of abduction due to limb traction during surgery. The angle was greatest after maximum limb traction for reduction, while the angle was not affected by the retractors. In the axial plane, the pelvis moved toward the direction of internal rotation at the step of acetabular exposure due to the anterior retractor. Anterior capsule resection was performed before cup implantation, and then the position of the pelvis returned to the setup position even with the retractors (steps 3 and 4). In the sagittal plane, the pelvis moved toward the direction of anterior tilt by caudal retractor at obturator foramen. The angles in every direction were not influenced by the patients' height, body weight, or BMI.

Discussion

Compared with the previous studies, we could measure the pelvic movement during THA at any time in three directions. By fixing an arm with two grippers to the operating table before surgery, the navigation system recognized the movement of the pelvic tracker in reference to the tracker for reamer navigation fixed at the arm during surgery, and the angle of pelvic movement was indicated on the monitor in real time. No additional invasive equipment was needed besides the THA with navigation system. Previous studies reported the pelvic movement during THA in the lateral and supine positions. Ezoe et al. [13] reported that the average internal rotation angle immediately before placing the cup was 1.75 degrees with the translateral approach and 14.25 degrees with the posterolateral approach. Grammatopoulos et al. reported that the mean angular movement at cup implantation was 9 degrees with the posterior approach [7]. Kanazawa et al. [8] calculated 3D pelvic movement in THA through the posterolateral approach. The mean movement after cup placement was 0.9 degrees in adduction, 3.9 degrees in internal rotation, and -3.1 degrees in inclination. Brodt et al. [9] monitored pelvic movement using a Smartphone located on the patient's skin in THA through the transgluteal approach in the supine position.

The mean pelvic tilt was 14.9 degrees at maximum in the figure-four position for femoral preparation. At the acetabulum exposure, the mean pelvic tilt was between 5.6 and 6.9 degrees. Schwarzkopf et al. [11] reviewed the data of the navigation system camera for THA performed in the lateral position. The mean movement was 2.7 degrees in adduction and 7.3 degrees in internal rotation. Gonzalez Della Valle et al. [12] recorded the pelvic movement at ten steps during THA in a lateral decubitus position. The mean absolute rotation was 4.13 degrees at acetabular exposure, and the mean absolute abduction was 2.54 degrees at hip dislocation. In this study, the pelvic movement was small compared to previously reported results. The pelvic movement during THA was influenced by the pelvic positioner, the patient position, the approach, and the patient's physique. The reasons are that our patients were slim (mean BMI: 23.8 kg/m^2), and the operation was performed in the supine position. Even in these situations, the pelvis was moved by the retractors and the traction of the leg. From our results, the pelvis tended to move toward the direction of adduction as the surgery progressed due to traction of the leg. The pelvis was moved toward the direction of internal rotation and anterior tilt by anterior and caudal retractors. The limitation of this study was that the total number of hips was small; thus, we could not statistically indicate the effect of patients' height, body weight, and BMI on the pelvic movement. There may be a potential error related to the navigation. The pelvic coordinate was decided by the registration of APP. Palpating both ASIS and the pubic symphysis after draping is a weak point in an image-free navigation system, however, the pelvic movement was measured by navigating the pelvic and the reamer tracker devices without referencing the APP. Thus the results were accurate as far as the pelvic tracker device was stable during surgery.

Conclusion

The pelvic movement in the coronal, axial, and sagittal planes during THA by the DAA was monitored using a hip navigation system. The pelvis tended to move toward the direction of adduction as the surgery progressed. The pelvis was moved toward the direction of internal rotation and anterior tilt by the retractors. We must pay attention to the pelvic movement when fixing the cup even in a supine position.

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