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ORIGINAL PAPER

Pelvic pitch and roll during total hip arthroplasty performed through a posterolateral approach. A potential source of error in free-hand cup positioning

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Abstract

Purpose Intraoperative pelvic motion can alter the perceived cup inclination and version during non-navigated THA. We quantified pelvic motion during different phases of primary THA performed in the lateral decubitus through a posterolateral approach.

Methods Pelvic roll (rotation of the coronal plane) and pitch angles (rotation parallel to the coronal plane) were studied in 75 patients undergoing THA for osteoarthritis by four arthroplasty surgeons. Ten steps of surgery were defined. Angular motion was recorded with a miniature surgical device that utilizes inertial sensors.

Results The mean absolute roll ranged from 0.03° detected at the end of surgery to 4.13° detected during acetabular exposure. The mean absolute pitch ranged from 0.05° detected at the end of surgery to 2.54° detected during hip dislocation. The maximum pelvic roll and pitch detected during surgery averaged 17.62° (SD: 5.08) and 9.3° (SD: 3.39) respectively. Absolute roll and pitch angles were not affected by patient's BMI, sex, pre-operative hip motion, or surgeon. Before cup insertion, the greatest mean change in roll was observed during acetabular exposure (10.02° anteriorly), and for pitch was observed during dislocation (1.88° caudally).

Conclusion During THA performed through a posterolateral approach, there is a progressive anterior pelvic roll that peaks before cup insertion. This can lead to underestimation of cup anteversion during non-navigated THA. The anterior roll does not completely correct, even when all retractors and external forces acting on the pelvis are removed. Pelvic pitch that could affect the perceived cup inclination occurs to a lesser extent than pelvic roll.

Keywords Total hip arthroplasty · Pelvic motion · Cup inclination · Cup version

Introduction

Adequate orientation of total hip arthroplasty (THA) components has been associated with lower rates of prosthetic impingement [1], instability [2], wear [3], and early loosening [4]. When surgery is performed in the lateral decubitus, femoral version can be estimated by utilizing the mechanical axis of the leg, a surrogate for the epicondylar axis [5].

Adequate implantation of the acetabular component is more challenging. The surgeon who uses a "free-hand" or "non-navigated" technique for cup insertion will rely on bony [6, 7] and soft tissue landmarks [8], and on mechanical guides [9]. The latter rely on the assumption that the pelvis is held in a strict and stable lateral position during surgery.

In the experience of the senior author (AGDV), there can be substantial variability in final cup inclination and version even when all these factors are taken into consideration. We therefore questioned if intra-operative pelvic motion during different phases of surgery would account for some of this variability.

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The goal of the study is to characterize intra-operative pelvic angular motion during primary THA performed through a posterolateral approach.

Material and methods

IRB approval was obtained from our institution (IRB-2017-1171). Between January and September 2017, 100 patients from a single institution (Hospital for Special Surgery in New York City) were selected for the study. Patients with diagnosis of primary osteoarthritis requiring computer-assisted THA [5] with the Intellijoint HIP® 3D miniature navigation device, through a standardized posterolateral approach were considered for the study.

The Intellijoint HIP is a miniature surgical navigation device that utilizes infrared optical technology and integrated microelectronics, including inertial sensors, to measure cup implant angle, leg length, offset, and center of rotation in order to assist surgeons with component placement [10, 11].

The surgeries were performed by four fellowship-trained, joint replacement surgeons (MC, PKS, AM, AGDV). Before surgery, patients were evaluated for pain, function and range of motion using the Harris Hip Score [12].

After surgery, patients were excluded if the navigation tool was removed prior to completion of the surgery, if the pelvic platform was unstable precluding accurate measurements, or if the surgeon failed to record pelvic motion during at least one of the operative steps. After exclusion of 25 patients, the remaining 75 were included in the analysis. There were 63% female patients, with a mean age and BMI of 66 years (SD: 11.14) and 29.15 (SD: 5.75), respectively.

Patients were positioned in the lateral decubitus for surgery utilizing a devoted surgical table. It secures the pelvis by compression, achieved with a posterior post that is applied against the sacrum and an anterior one applied against the pubis. In addition, the surgical table allows adjusting the height of the saddle and can roll and pitch to assure a stable and strict lateral decubitus.

Before incision, a pelvic tracker was secured to the iliac bone and the coronal plane was registered [10, 11]. This device allows the tracking of pelvic roll and pitch. Roll was defined as pelvic rotation on the coronal plane. A positive roll angle indicated that the hemi-pelvis on the operative side rotated anteriorly. Pitch was defined as rotation parallel to the coronal plane. A positive pitch indicated that the hemi-pelvis on the operated side rotated in a caudal direction (Fig. 1).

Pelvic pitch and roll were recorded for ten steps:

1. Simulated prepping and draping: the lower extremity was briefly held in abduction of approximately 40°, flexion of 40°, and maximal external rotation to simulate the position in which the lower extremity is held by the unit assistant while the rest of the surgical team is prepping the site for surgery.
2. Capsular exposure: the hip was extended and maximum internal rotation applied with the knee in 60 to 90° of flexion to allow exposure of posterior external rotators and capsule.
3. Hip dislocation: the hip has sequentially flexed, adducted and internally rotated with knee flexion for hip dislocation. After dislocation, the femur was positioned in full extension and internal rotation of 90°.
4. Neck resection
5. Acetabular exposure: It was achieved by sequentially positioning an anterior C-retractor, superior and posterior Steinman pins, and an extracapsular Aufranc retractor caudally.
6. Sequential acetabular reaming to the planned sized.
7. Pelvic position after cup insertion and before removal of acetabular retractors.
8. Femoral exposure: The femur was held in full extension and 90° of internal rotation while a femoral elevator was placed under the anterior aspect of the femoral neck. An Aufranc retractor was used medially in the neck, exposing the lesser trochanter. The femur was then flexed, adducted and internally rotated. A thin, bent Homann retractor was placed superiorly to protect the abductor musculature.
9. Hip relocation: After final prosthetic implantation, axial traction, flexion and external rotation was applied to the femur to relocate the arthroplasty.
10. Pelvic position after relocation with the lower extremity in a neutral position.

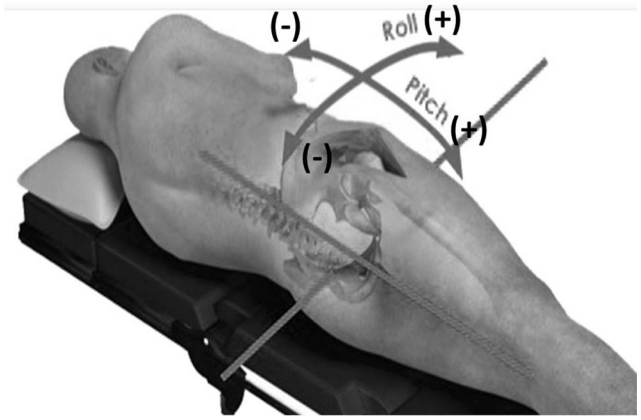

Fig. 1 Definition and convention for quantification of pitch and roll angles

Pelvic motion calculations The integrated inertial sensing system (specifically, the 3-axis accelerometer) contained within the Intellijoint HIP camera is configured to measure inclination in 2 orthogonal degrees of freedom (i.e., similar to a 2-

axis bubble level). Following installation of the camera, an initial measurement is recorded to register the horizontal plane, coinciding with the patient's sagittal plane. The patient's coronal plane is also registered. The coronal and sagittal planes are combined to form the patient registration (the spatial relationship between the camera and the patient's anatomy). Throughout the procedure, changes in patient position are continuously recorded using the accelerometer within the camera. Instrument data was used to determine the magnitude and direction of patient movement utilizing Python (Python Software Foundation, Beaverton, OR).

Outcome variables and statistical analysis are as follows:

1. The beginning and final pitch and roll angles detected during each surgical step were recorded ("pitch angle" and "roll angle").
2. The beginning and final pitch and roll angles during each surgical step were analyzed as absolute magnitudes of movement, regardless of direction: "Absolute pitch" and "absolute roll" were calculated by deducting the final from the beginning pitch or roll angles detected during each surgical step.
3. The pitch and roll angles detected at the beginning and at the end of surgery were analyzed as absolute magnitudes of movement, regardless of direction: "Absolute procedural pitch" and "absolute procedural roll" were calculated by deducting the pitch or roll angles detected at the end of the last step of surgery from the pitch or roll angle detected at the beginning of the first step.
4. The maximum and minimum pitch and roll values detected during surgery were recorded. The "procedural pitch range" and "procedural roll range" was defined by deducting the minimum from the maximum pitch or roll angles detected during surgery.

A proportion analysis was conducted to identify how many pelvises had an absolute pitch or absolute roll greater than 5° and 10° during at least one step of surgery (75 patients with 10 surgical steps for a total of 750 possible calculations for each direction of movement and for each angular threshold).

A subgroup analysis of the cohort was conducted to study the variables that might influence the absolute pitch and absolute roll, as well as the absolute procedural pitch and absolute procedural roll. Specifically, patient's BMI, sex, pre-operative flexion as a surrogate of range of motion, and operating surgeon were investigated. Patients were stratified in three groups for BMI comparisons: low (BMI < 25), medium (BMI 25–30), and high (BMI > 30). Hip flexion was grouped in < 90°, 90–99°, and > 99°.

In order to study the direction of movement, the average starting roll and pitch angles for each of the surgical steps for all 75 patients was compared to the average ending roll and pitch angles. Ninety-five percent confidence intervals for the average start and ending roll and pitch angles were calculated.

Alpha was set at 0.05. All mean values are presented as mean (standard deviation). Means were compared using single-factor ANOVA and/or Student's t tests. Variables demonstrating $p < 0.1$ in the univariate analysis were considered for a subsequent multiple linear regression.

Results

The mean absolute roll during the 10 pre-defined steps of surgery ranged from 0.03° detected after the end of surgery (step 10) to 4.13° detected during acetabular exposure (step 5). In four of the ten steps of surgery an absolute roll of at least 10° was detected in at least one patient. This occurred during hip dislocation (step 3), acetabular exposure (step 5), femoral exposure (step 8), and hip relocation (Step 9) (Table 1).

Fifty-six patients (74.7%) had an absolute pelvic roll greater than 5° in at least one of the surgical steps. The steps most frequently associated with pelvic roll of at least 5° were step 3 (15 patients), step 5 (25 patients), step 8 (18 patients), and step 9 (18 patients). Eleven patients (14.7%) had pelvic roll greater than 10° in at least one of the steps. The steps most frequently associated with pelvic roll of at least 10° were step 3 (3 patients), step 5 (4 patients), and step 9 (3 patients) (Table 2).

The mean absolute pitch during the ten pre-defined steps of surgery ranged from 0.05° detected after the end of surgery (step 10) to 2.54° detected during hip dislocation (step 3). In one of the ten steps of surgery, an absolute pitch of at least 10° was detected in at least one of the patients. This occurred during femoral exposure (step 8) (Table 1).

Twenty-one patients (28%) had an absolute pelvic pitch greater than 5° in at least one step of surgery. This occurred most frequently during dislocation (step 3) (11 patients) and femoral exposure (step 8) (7 patients). One patient (1.3%) had pelvic pitch greater than 10° during femoral exposure (step 8) (Table 3).

Single-factor ANOVA analysis showed that BMI did not significantly influenced the absolute procedural roll ($p = 0.94$) or absolute procedural pitch ($p = 0.87$). Gender showed no significant effect on absolute procedural roll ($p = 0.76$) or absolute procedural pitch ($p = 0.84$). Finally, pre-operative hip flexion did not significantly affect absolute procedural roll ($p = 0.90$) or absolute procedural pitch ($p = 98$).

During capsular exposure (step 2), the patients in the medium pre-operative hip flexion group had significantly less absolute pitch than patients in the low and high flexion hip groups (mean absolute pitch 0.5°, 0.8°, and 1.6°, respectively – $p = 0.001$). During hip dislocation (step 3), the patients in the medium pre-operative hip flexion group had significantly higher absolute pitch than those in the high hip flexion group (mean absolute pitch 3.2° and 1.9°, respectively – $p = 0.01$).

Lastly, the operating surgeon showed no significant difference in absolute procedural pitch ($p = 0.89$) or absolute procedural roll ($p = 0.94$).

Table 1 Step-specific mean absolute roll and pitch

Pelvic angular motion	Step of surgery	Simulated prepping	Capsular exposure	Dislocation	Neck resection	Acetabular exposure	Acetabular reaming	Post cup insertion	Femoral exposure	Hip relocation	Post final implant
Roll	ABS Mean (°)	1.63	2.32	3.04	0.98	4.13	1.40	0.16	3.25	3.27	0.03
	SD (°)	1.80	1.66	3.05	1.10	3.22	1.47	0.58	2.46	3.04	0.18
	Range (°)	0–9.36	0.06–7.93	0.02–15.18	0–6.14	0.16–12.14	0.03–8.74	0–3.95	0.03–12.54	0.02–14.45	0–1.52
Pitch	ABS Mean (°)	1.84	0.86	2.61	0.54	1.06	0.56	0.06	2.17	2.02	0.05
	SD (°)	1.86	0.92	1.85	0.54	0.96	0.53	0.22	2.17	1.53	0.32
	Range (°)	0–8.97	0.001–4.40	0.17–7.44	0–2.83	0–3.96	0.02–2.44	0–1.57	0.01–10.87	0.06–6.65	0–2.69

Table 2 Proportion analysis of patients with absolute roll greater than 5 or 10° during each surgical step

Absolute roll	> 5° *n* (%)	> 10° *n* (%)
Simulated prepping	6 (8)	0 (0)
Capsular exposure	4 (5.3)	0 (0)
Dislocation	15 (20)	3 (4)
Neck resection	1 (1.3)	0 (0)
Acetabular exposure	25 (33.3)	4 (5.3)
Acetabular reaming	2 (2.7)	0 (0)
After cup insertion	0 (0)	0 (0)
Femoral exposure	18 (24)	1 (1.3)
Hip relocation	18 (24)	3 (4)
After final implant	0 (0)	0 (0)

References: *n* number of pelvises

On average, the roll range was 17.62° (SD: 5.08), and the pitch range was 9.3° (SD: 3.39).

Pelvic roll was recorded within 10 surgical steps. The greatest mean change in roll was 10.02°, observed during acetabular exposure (Fig. 2). Following cup insertion, the greatest changes in roll occurred during femoral exposure and hip relocation (Fig. 3). During femoral exposure, the pelvises had an average positive roll of 2.20°, whereas during hip relocation, the pelvises had a reduction in the roll angle of 2.05°. When the beginning and the end of surgery are compared, the pelvises had an average positive roll of 5.55° (Fig. 3).

The greatest step-specific mean change in pitch was observed during dislocation, with pelvises exhibiting a positive pitch of 1.88° (Fig. 4). Following cup insertion, the greatest amount of step-specific change in pitch occurred during both femoral exposure and hip relocation. During femoral exposure, the pelvis pitched 1.53° in the caudal direction, whereas during hip relocation, the pelvis pitched 1.17° in the cephalad direction (Fig. 5). On average, by the end of surgery, the pelvis

Table 3 Proportion analysis of patients with absolute pitch greater than 5 or 10° during each surgical step

Absolute pitch	> 5° *n* (%)	> 10° *n* (%)
Simulated prepping	4 (5.3)	0 (0)
Capsular exposure	0 (0)	0 (0)
Dislocation	11 (14.7)	0 (0)
Neck resection	0 (0)	0 (0)
Acetabular exposure	0 (0)	0 (0)
Acetabular reaming	0 (0)	0 (0)
After cup insertion	0 (0)	0 (0)
Femoral exposure	7 (9.3)	1 (1.3)
Hip relocation	3 (4)	0 (0)
After final implant	0 (0)	0 (0)

References: *n* number of pelvises

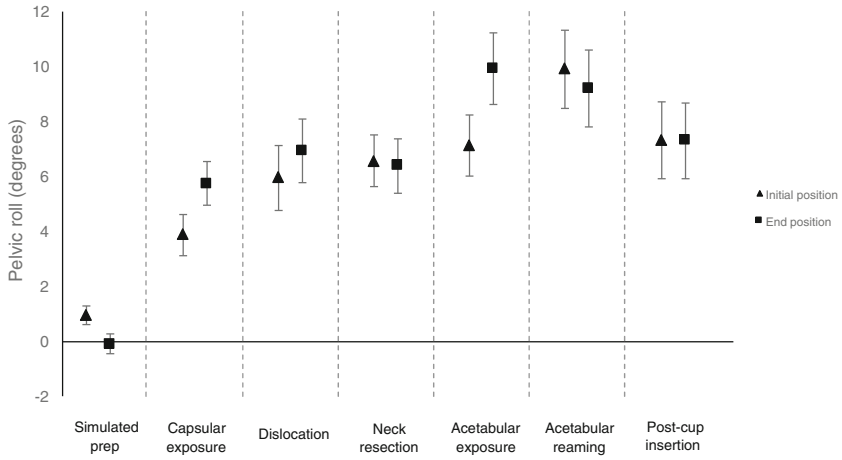

Fig. 2 Step-specific mean pelvic roll until cup insertion. Pelvic roll angle at the beginning (triangle) and the end (square) of each step is expressed as the mean roll angle of all patients, ± 95% confidence intervals are indicated by bars

showed 2.12° of pitch from their starting recorded position towards the cephalad direction (Fig. 5).

Discussion

The use of computer navigation during THA has been associated with increased precision in acetabular placement [13]. Still, only 1.9% of THAs in the United States are performed utilizing technologies such as navigation [14]. Intra-operative pelvic motion occurring as a result of leg manipulation, and the levering effect of retractors needed for adequate exposure, can potentially affect the precision of free-hand acetabular component placement [10, 15–17].

With advances in surgical navigation, intra-operative pelvic motion has been studied by other investigators over the last 15 years [15–17]. Asayama et al. reported that in 30 THA surgeries performed through a posterolateral approach, the pelvises exhibited a positive pelvic roll averaging 14.6° [16].

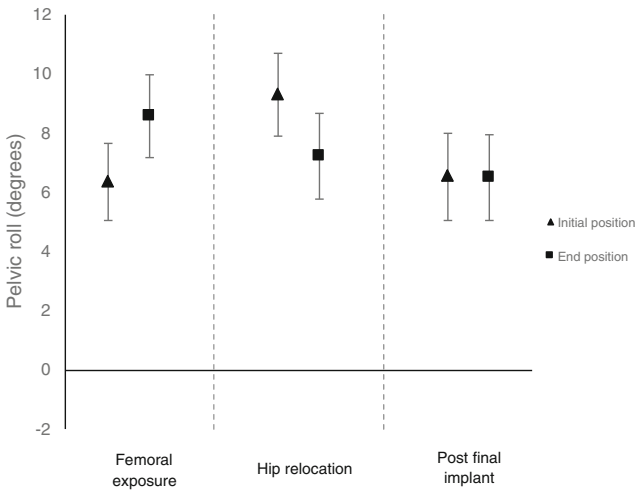

Fig. 3 Step-specific mean pelvic roll after cup insertion. Pelvic roll angle at the beginning (triangle) and the end (square) of each step is expressed as the mean roll angle of all patients, ± 95% confidence intervals are indicated by bars

The same investigators reported, a year later [17] a lower average intra-operative positive pelvic roll with the translateral than with the posterolateral approach (1.75° and 14.25°, respectively – $p < 0.05$). Grammatoulos et al. studied intra-operative pelvic motion in 67 patients undergoing primary, THA or hip resurfacing. The authors compared intra-operative pelvic motion during THA and hip resurfacing, performed by three surgeons, using three different positioning devices and two surgical approaches (posterolateral and anterolateral). They reported an average angular motion of 9° (2SD: 12°), which was not affected by patient's anthropometric factors but was affected by the surgeon, the surgical approach, the type of procedure, and the type of pelvic support used. Angular motion during different steps of surgery was not analyzed [15].

Our observational study showed that substantial motion, predominantly roll, occur during surgery. Changes in pitch, which can potentially affect the perception of cup inclination, predominantly occurred after cup insertion (Fig. 5). However, a steady and substantial increase in pelvic roll, which can affect the perceived acetabular anteversion, occurred early during hip and acetabular exposure (Fig. 2).

Our study has limitations: it is a prospective observational study impeding us from making generalized conclusions. An assumption was made that patients were positioned in a strict lateral decubitus at the beginning of surgery. This was not confirmed by conventional navigation or fluoroscopy. This factor can also result in variability in acetabular component orientation [15, 18]. The results may be different with the use of other surgical tables, other surgical approaches [15, 19], or dependent upon the surgeon's experience with a particular surgical approach [20]. Statistically significant differences may be seen when analyzing a larger group of patients. A quantification of pelvis flexion movement was not performed. Pelvic flexion can affect functional inclination and version [15, 21]. However, the controlled experimental conditions allowed us to study pelvic motion and make educated assumptions and conclusions regarding the effect of external forces

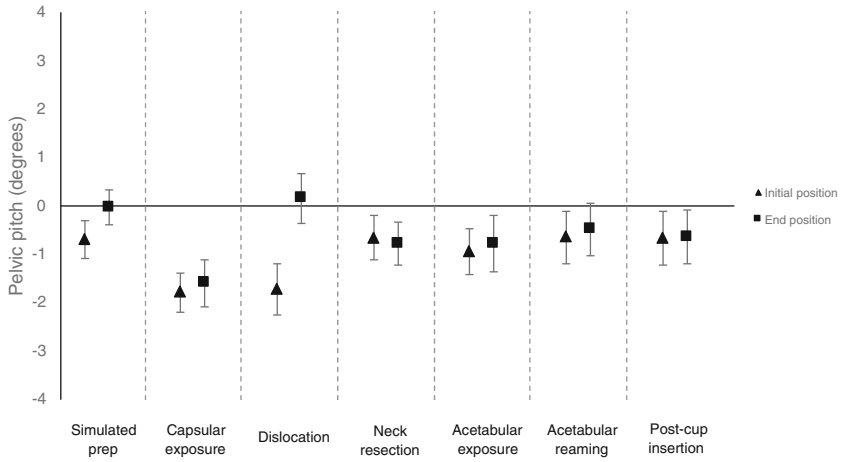

Fig. 4 Step-specific mean pelvic pitch until cup insertion. Pelvic pitch angle at the beginning (triangle) and the end (square) of each step is expressed as the mean pitch angle of all patients, ± 95% confidence intervals are indicated by bars

acting on the pelvis during surgery. Finally, a correlation between intraoperative and post-operative cup positioning was not performed on post-operative X-rays or more accurate CT scan [22, 23].

The highest absolute pelvic roll occurred during acetabular exposure, before acetabular cup placement (Table 1); with patients presenting an absolute pelvic roll as high as 12.1°. This phenomenon is likely due to the effect of the placement of a C-retractor over the anterior acetabular rim, coupled with the characteristics of the surgical table. The C-retractor has a long levering arm that allows exertion of a substantial amount of retraction moving the proximal femur anteriorly, with a minimal effort by the assistant. Asayama et al. detected an average pelvic roll of 14°, with a range from 5 to 31° [16]. They utilized a shorter, straight, conventional Homann retractor to mobilize the femur during acetabular exposure. This straight, shorter instrument is likely to require a greater force to gain acetabular exposure and may explain the higher roll angles detected by the investigators. In addition, the surgical table used in our study uses only a pubic post. Grammatopoulos et al., reported less intra-operative pelvic roll when securing the pelvis with posts over both antero-superior iliac spines [15].

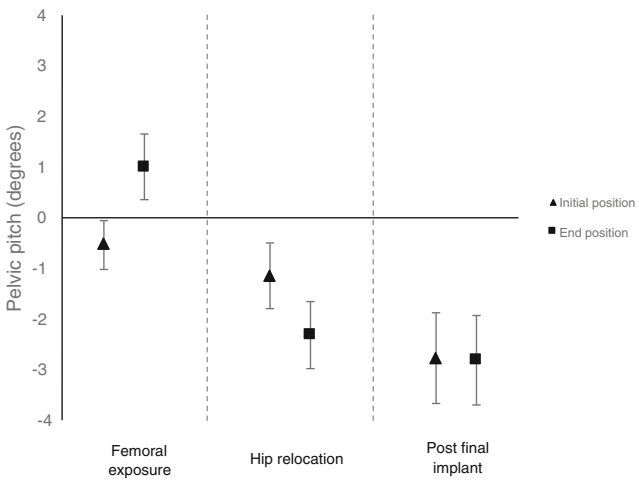

Fig. 5 Step-specific mean pelvic pitch after cup insertion. Pelvic pitch angle at the beginning (triangle) and the end (square) of each step is expressed as the mean pitch angle of all patients, ± 95% confidence intervals are indicated by bars

In spite of the efforts to assure a stable lateral decubitus, there was progressive positive pelvic roll that did not correct even after removing acetabular retractors (Figs. 2 and 3). The highest roll angles that could result in the greatest errors in perceived anteversion were detected during acetabular exposure, just before cup insertion (Table 2). This positive roll will likely make the surgeon to underestimate the anteversion of the acetabular component when utilizing mechanical guides [15].

Changes in pelvic pitch angles were smaller than those of roll angles. It can be speculated that external forces acting on the pelvis, typically generated by levering retractors for exposure, are generally applied in the transverse pelvic plane and consequently would affect roll more than pitch. The stabilizing effect of a secured dependent lower extremity and the relative stiff sacrolumbar junction may provide resistance against pitch.

The highest change in absolute pitch angle was observed during hip dislocation (Table 1). Similar findings have been detected by others [11, 16]. Contrary to pelvic roll, the pelvic pitch angle returned to baseline values after hip dislocation and had minimal changes during the acetabular work (Fig. 4). The negative pitch angles detected during acetabular work and cup positioning are likely to affect acetabular inclination; with the surgeon forced to underestimate the cup inclination angle.

Our findings on pelvic roll and pitch suggest that errors in anteversion should be more frequently observed than error in inclination. This is in line with our previous work that detected a greater variability in radiographic anteversion than inclination in patients who underwent primary THA [6, 24].

The present study builds upon our previous work [11]. In a multicentre study, analyzing intra-operative pelvic roll and pitch during THA performed through a posterolateral approach by 11 surgeons working in seven institutions, the mean amount of roll per patient was 7.3° (range: 0.3 to 31.3°) and for pitch 2.7° (range: 0.1 to 9.9°) [11].

In conclusion, our study provides a detailed analysis of pelvic pitch and roll during THA performed through a posterolateral approach. The surgeon should be aware that in the conditions that have been previously described, positive intra-operative pelvic roll does not correct during surgery, even when all retractors and external forces acting on the pelvis are removed.

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Compliance with ethical standards

Conflict of interest statement Funding for this study has been received by Intellijoint Surgical, Inc.

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