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Pelvic Tilt in Patients Undergoing Total Hip Arthroplasty: When Does it Matter?

Joseph D. Maratt, M.D., Christina I. Esposito, Ph.D., Alexander S. McLawhorn, M.D., Seth A. Jerabek, M.D., Douglas E. Padgett, M.D., and David J. Mayman, M.D.

Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021

Abstract

Pelvic tilt (PT) affects the functional anteversion and inclination of acetabular components in total hip arthroplasty (THA). One-hundred and thirty-eight consecutive patients who underwent unilateral primary THA were reviewed. Most cases had some degree of pre-operative PT, with 17% having greater than 10° of PT on standing pre-operative radiographs. There was no significant change in PT following THA. A computer model of a hemispheric acetabular component implanted in a range of anatomic positions in a pelvis with varying PT was created to determine the effects of PT on functional anteversion and inclination. Based on the study results, tilt-adjustment of the acetabular component position based on standing pre-operative imaging will likely improve functional component position in most patients undergoing THA.

Introduction

Accurate placement of components during total hip arthroplasty (THA) is essential to avoid complications such as dislocation [1], impingement [2], and accelerated bearing wear [3]. Surgical navigation has been demonstrated to improve the accuracy and precision of component positioning compared to traditional freehand techniques [4]. Use of surgical navigation also offers the surgeon the ability to make fine modifications to component position based on patient factors such as pelvic tilt (PT)[5]. For example, a navigation system can calculate the tilt-adjusted anteversion of an acetabular component. Implementations of tilt-adjustment vary by manufacturer. Techniques utilized range from adjustment based on measurement of PT in a supine position by digitizing the floor plane and anterior pelvic plane (APP) to adjustment without measurement of the APP in the lateral position.

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Corresponding author: Christina Esposito Ph.D., Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021, Phone: (646) 714 6121, Fax: (212) 606 1490, espositoc@hss.edu.

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Reports in the literature are conflicting with regard to the extent and frequency of change in PT following THA [6,7]. Surgeons often make adjustments to component position in the setting of conditions like ankylosing spondylitis to protect against anterior dislocation due to the pelvic hyperextension (increased posterior PT) caused by a fixed sagittal spinopelvic relationship [8]. However, subtle PT may exist in patients without grossly evident spinal pathology. Zhu et. al. found that approximately 94% of patients undergoing THA had some degree of PT when positioned supine on the operating table. They also reported that approximately 15% of patients had greater than 10° of anterior or posterior PT and suggested that accounting for PT may improve component position in these patients [9].

Changes in PT in standing and supine positions can confound these techniques of tilt-adjustment [10]. Whether PT changes postoperatively is another cause for concern when using preoperative PT for tilt-adjusted acetabular component positioning. The impact of PT on acetabular component anteversion been studied and quantified as approximately 0.7° increase in anteversion for each degree of posterior PT [11,12], but the effect of PT on acetabular component inclination may be underappreciated.

The purpose of this study was to consider the incidence of standing PT in a patient cohort undergoing primary unilateral THA and to evaluate the utility of tilt-adjusted navigation. Therefore, the following questions were posed:

1. What is the incidence of PT in patients undergoing THA?
2. Does PT change following THA? If so, can pre-operative radiographic parameters, such as PT or pelvic incidence, be used to estimate post-operative PT?
3. How does PT impact anteversion and inclination of the acetabular component?

Methods

Definitions

The anterior pelvic plane (APP) is an anatomic plane defined by the two anterior superior iliac spines (ASIS) and the pubic tubercle. The coronal plane is a functional plane and is defined as any vertical plane that divides the body into ventral and dorsal sections[12]. Pelvic tilt (PT) is the angle between the APP and the coronal plane [7]. A negative PT angle indicates posterior tilt, and a positive PT angle indicates anterior tilt (Figure 1). Pelvic incidence was measured as the angle between a line perpendicular to the sacral plate at its midpoint and a line connecting this point to the center of the femoral heads[13]. Radiographic anteversion is the angle between the acetabular axis and the coronal plane. Radiographic inclination is the angle between the face of the acetabular component and the transverse axis[14]. APP anteversion and inclination are the radiographic anteversion and inclination with the APP parallel to the coronal plane. We defined functional anteversion and inclination as the radiographic measurements of anteversion and inclination of an acetabular component with the pelvic in a standing position. We elected to measure PT on standing lateral radiographs to be consistent with our evaluation of anteversion and inclination on standing AP radiographs.

Radiographic Measurements

One-hundred and thirty-eight consecutive patients who underwent a unilateral primary THA by a single surgeon were included in this study. Patients with prior contralateral THA, conversion THA, and instrumented lumbosacral fusion were excluded. Average age was 56.8 ± 10.9 years, average body mass index (BMI) was 28.3 ± 6.0 kg/m², and 67 patients (48.6%) were female. Patients had standing lateral radiographs taken pre-operatively and six weeks postoperatively. Both PT and pelvic incidence were measured pre-operatively for each patient, and PT was measured on the post-operative imaging. Sagittal PT was defined as the difference between the anterior pelvic plane and the coronal plane. Correlation coefficients were calculated between pre-operative PT and post-operative PT and pelvic incidence and post-operative PT. Student's t-test was used to test the significance of the difference in pre-operative and postoperative PT. Alpha level was set at 0.05 for all tests. Statistical analysis was performed in SPSS Statistics v22 (IBM Corp., Armonk, New York).

Computer Model

To understand the impact PT has on acetabular component orientation, an anatomically accurate three-dimensional model of a male pelvis was obtained from BodyParts3D (Database Center for Life Science, The University of Tokyo, Tokyo, Japan). This model was loaded into Matlab 2013a (The MathWorks Inc., Natick, MA) and a surface mesh of the pelvis was rendered with the center of rotation (COR) of the left hip at the origin of the coordinate system. Neutral or 0° of PT was set such that the APP was aligned to the coronal plane. A 50 millimeter 180° hemispheric acetabular shell was rigidly fixed at the center of rotation (COR) of the acetabulum with 40° APP inclination and 25° APP anteversion (Figure 2). The pelvis and acetabular shell were rotated through the axis defined by the CORs of both hips in 1° increments from 0–30° of anterior (+) PT and 0–30° posterior (–) PT. The functional inclination and anteversion of the acetabular component was calculated for every 1°. This pelvic tilt ranging sequence was repeated for a range of acetabular component orientations with the cup positioned in the pelvis from 0° to 40° of APP anteversion and 35° to 50° of APP inclination in 1° increments.

Results

Pelvic tilt before and after THA

Mean pre-operative PT was $0.6^\circ \pm 7.3^\circ$ (range: -19.0° to 17.9°). A total of twenty-three patients (17%) had 10° of sagittal PT during standing, with 9 patients having 10° of posterior PT and 14 patients having 10° of anterior PT preoperatively. Mean post-operative pelvic tilt was $0.3^\circ \pm 7.4^\circ$ (range: -18.4° to 15.0°). Mean change in pelvic tilt was $-0.3^\circ \pm 3.6^\circ$ (range: -9.6° to 13.5°), with no significant difference between pre-operative and post-operative PT ($p = 0.395$). 19 patients (13.8%) had greater than 5° change in pelvic tilt post-operatively. Only 1 patient (0.7%) had greater than 10° change in pelvic tilt post-operatively. Pre-operative PT was strongly correlated with post-operative PT ($r^2 = 0.88$, $p = 0.0001$; Figure 3). Pelvic incidence did not correlate with change in pelvic tilt ($r^2 = -0.16$, $p = 0.06$; Figure 4). The frequency of PT and change in PT is listed in Table 2.

Effect of pelvic tilt on functional anteversion and inclination

There was a constant linear change in functional anteversion for every 1° PT throughout the range of cup orientations and tilt values (Figure 5a). The mean change in functional anteversion was 0.74° increase in anteversion per degree increase in posterior tilt (range: -0.75° to -0.72°). Functional anteversion and inclination for an acetabular shell implanted at 0, 10, 20, and 30° APP anteversion (α) combined with 40° APP inclination (θ) with a range of PT from -25° to 25° is shown in Table 3. The effect of PT on functional anteversion and inclination is shown in Video 1.

The functional inclination of the acetabular component showed a nonlinear response to change in PT (Figure 5b). This was especially apparent in combination with high APP anteversion. While the mean change in inclination is 0.29° per degree of posterior tilt, the impact on inclination increased significantly with increasing posterior tilt. For example, if the acetabular component is implanted at 30° of APP anteversion and 40° of APP inclination, the functional inclination will increase to 47° when a patient has 15° of posterior PT, which is a change in inclination of 0.47° per degree of posterior tilt.

Discussion

In this study cohort of 138 consecutive patients undergoing primary THA, all but two patients had some degree of standing PT postoperatively. While a few degrees of PT may not cause any clinically significant effect on functional component position, 54% of patients had greater than 5° of anterior or posterior PT and 17% of patients had greater than 10° of anterior or posterior PT. Interestingly, a study measuring supine pelvic tilt with navigation intraoperatively reported similar results, where 17.4% of patients had greater than 10° of anterior or posterior PT [12]. This study uses a large cohort of patients to evaluate standing PT and provides a unique model demonstrating the impact of both pelvic tilt and anteversion on functional inclination.

We found no significant difference between standing preoperative and postoperative PT, with 86.2% of patients of 138 patients demonstrating less than 5° difference after surgery. This was consistent with a previous study that found less than 5° change in pelvic tilt between preoperative and 3-year follow-up radiographs in 50 patients after THA [15]. In a study using a computed tomography model, Nishihara et al [16] found all but one patient had a change in PT of greater than 10° after surgery, and this is the same result as our study. There is disagreement in the literature regarding the amount and frequency of variation in postoperative pelvic tilt. A gait analysis study found 31% of patients had greater than 5° of change in pelvic tilt following THA, with a mean change of $3.01^\circ \pm 5.3^\circ$ [17]. This may be explained by differences in sample size and methodology. Pelvic incidence was not predictive of change in pelvic tilt following THA. We could not predict the relatively rare occurrence of a large change in pelvic tilt, which would confound tilt-adjusted component position. The pelvis is a dynamic link between the axial and appendicular skeleton, and studies have demonstrated the importance of taking into account the condition of the spine for preoperative planning of acetabular component position throughout a range of functional positions [18,19].

We examined both functional anteversion and inclination of the acetabular component and showed substantial variation in response to change in pelvic tilt. While functional anteversion has a linear relationship to change in pelvic tilt throughout the range of APP anteversion, functional inclination is more sensitive to change in pelvic tilt at higher degrees of APP anteversion. For example, our model for pelvic tilt-adjusted acetabular component position shows that posterior pelvic tilt of 15° increases functional anteversion and inclination by 11.1° and 4.9° respectively if the initial target anteversion and inclination was 20° and 40°. Therefore, in patients with high posterior pelvic tilt undergoing navigated THA, a calculated reduction in APP anteversion and inclination would be useful to compensate for the increased functional cup position that will otherwise be apparent on standing postoperative radiographs. Approximately 17% of patients in our cohort had PT of over 10° and may have benefited from tilt-adjustment of component position. Previous studies have examined the effect of pelvic tilt on acetabular component anteversion and reported findings consistent with our results. Lembeck et. al. demonstrated that acetabular component anteversion changed with variation in pelvic tilt and expressed concern that failure to correct for this would make navigation inaccurate [11]. Babisch et. al. provided a nomogram for conversion of cup alignment values into familiar target values based on changes in sagittal pelvic tilt, and the authors suggested that navigation systems incorporate measurement of pelvic tilt to allow for intraoperative adjustment of alignment values[5]. Increased acetabular inclination is a recognized risk factor for accelerated bear surface wear and liner fractures [20,21]. Although the influence of acetabular anteversion on the wear of various bearing surfaces is largely unknown, evidence suggests that acetabular orientation in the axial plane also likely affects bearing wear [22]. Tilt-adjusted component position may have significant benefits for surface materials such as ceramic on ceramic and metal on metal, which are less forgiving to edge-loading found with increased functional inclination [23,24].

There are limitations to our study. We were only able to assess post-operative pelvic tilt in one functional position (standing) at one follow-up interval. However, at six weeks following surgery, patients ambulate and stand for radiographs without assistance, and studies have shown preoperative pelvic tilt is predictive of postoperative pelvic tilt in both the standing and supine positions [25]. In our model we did not assess the combined effects of coronal and/or axial plane rotation of the pelvis on tilt-adjusted acetabular component position. Another limitation inherent to our radiographic definition of functional component position is that it was defined in only one position with the patient standing. PT may change substantially during different activities such as walking or sitting that could be considered in a dynamic analysis of component position[7,12].

In conclusion, PT can significantly affect the functional positional of acetabular components. Based on the prevalence and variability of PT found in this study population and the relatively small change in PT following THA, tilt-adjustment of the acetabular component position based on standing pre-operative imaging is likely to be of benefit in the majority of patients undergoing navigated THA. Pre-operative dynamic imaging of the pelvis and hip joint may help surgeons individualize and optimize component position to protect against impingement, dislocation and early failure [22,26].

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Figure 1.

A line representing the anterior pelvic plane (APP) is drawn in relation to the line representing the coronal plane in a pelvis with 15° of posterior pelvic tilt (PT).

Figure 2.

Figure demonstrating position of acetabular shell with 30° anterior pelvic plane (APP) anteversion and 40° APP inclination with a) 0° of sagittal pelvic tilt and b) 20° of posterior pelvic tilt changing the functional anteversion to 44.2° and the functional inclination to 50.9°.

Figure 3.

Plot of pre-operative versus post-operative pelvic tilt (PT). Pre-operative PT was strongly correlated with post-operative PT ($r^2 = 0.88$, $p = 0.0001$).

Figure 4.

Plot of pelvic incidence versus change in pelvic tilt. Pelvic incidence does not appear to correlate with change in pelvic tilt ($r^2 = -0.16$, $p = 0.06$).

Figure 5.

a) Plot of pelvic tilt versus anterior pelvic plane (APP) anteversion versus functional anteversion showing a relatively linear relationship throughout the range of tilt and acetabular component positions. b) Plot of pelvic tilt versus APP anteversion versus functional inclination showing a dramatic increase in effect of pelvic tilt on functional inclination as the APP anteversion is increased.

Table 1

Definitions of Terms, modified from Wan et al.[12]

Term	Definition
Anterior pelvic plane (APP)	Plane defined by the two anterior iliac spines and pubic tubercle
APP Inclination	The angle between the pelvic longitudinal axis and the acetabular axis when this is projected onto the APP (radiographic definition)
Functional Inclination	The angle between the pelvic longitudinal axis and the acetabular axis when this is projected onto the coronal plane (radiographic definition)
APP Anteversion	The angle between the acetabular axis and the APP (radiographic definition)
Functional Anteversion	The angle between the acetabular axis and the coronal plane (radiographic definition)
Pelvic Tilt	The angle between the APP and the coronal plane

Table 2

Frequency pre-operative pelvic tilt and change in pelvic tilt following total hip arthroplasty.

Degrees	Pre-operative Pelvic Tilt	Change in Pelvic Tilt
≤ -10.0	9 (6.5%)	1 (0.7%)
-9.9 to -5.0	27 (19.6%)	10 (7.2%)
-4.9 to -0.1	27 (19.6%)	60 (43.5%)
0	1 (0.7%)	2 (1.4%)
0.1 to 4.9	36 (26.1%)	57 (41.3%)
5.0 to 9.9	24 (17.4%)	8 (5.8%)
≥ 10.0	14 (10.1%)	0 (0%)
Total	138 (100)	138 (100.0%)

Table 3

Functional acetabular component position for given values of APP anteversion and sagittal pelvic tilt.*

APP α (°)	0 (°)		10 (°)		20 (°)		30 (°)		40 (°)	
	α (°)	θ (°)	α (°)	θ (°)	α (°)	θ (°)	α (°)	θ (°)	α (°)	θ (°)
Pelvic Tilt (°)										
-25	18.9	43.0	28.4	46.4	37.9	50.5	47.2	55.9	56.2	63.5
-20	15.2	41.8	24.9	44.3	34.6	47.2	44.2	50.9	53.6	56.0
-15	11.4	41.0	21.3	42.8	31.1	44.9	40.9	47.4	50.6	50.9
-10	7.6	40.4	17.6	41.6	27.5	42.9	37.4	44.5	47.3	46.6
-5	3.8	40.1	13.8	40.7	23.8	41.3	33.8	42.0	43.7	43.0
0	0.0	40.0	10.0	40.0	20.0	40.0	30.0	40.0	40.0	40.0
5	-3.8	40.1	6.2	39.5	16.1	39.0	26.1	38.3	36.1	37.5
10	-7.6	40.4	2.3	39.3	12.2	38.2	22.2	36.9	32.1	35.5
15	-11.4	41.0	-1.6	39.3	8.3	37.6	18.1	35.9	28.0	33.9
20	-15.2	41.8	-5.4	39.5	4.3	37.3	14.1	35.0	23.8	32.6
25	-18.9	42.8	-9.3	39.9	0.3	37.2	9.9	34.4	19.5	31.5

* Anterior pelvic plane (APP) inclination was fixed at 40°. α = anteversion; θ = inclination