Pelvic tilt between supine and standing after total hip arthroplasty an RSA up to seven years after the operation

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Abstract
The pose of the prosthetic components after total hip arthroplasty (THA) is commonly evaluated on conventional radiographs. Any change of the pelvic position after the operation in supine and between supine and standing position with time will influence validity of the measurements. We evaluated the changed pelvic tilt angle (PTA) in supine and standing position up to 7 years after operation. The aims of our study were (a) to evaluate if the PTA change over time after THA, (b) to assess any difference in PTA between supine and standing positions, and (c) to investigate whether factors such as gender, the condition of the opposite hip or low-back pain have any influence on PTA after THA. Repeated radiostereophotogrammetric radiographs of 106 patients were studied. Patients had been examined in the supine position postoperatively, and in both supine and standing positions at 6 months and 7-year follow-up. Measurements of supine patients showed an increasing mean posterior pelvic tilt over time. From supine to standing, the pelvis tilted in the opposite direction. At 6 months, the mean anterior tilt was 3.6° ± 3.8° (confidence interval [CI]: 2.8° to 4.3°) which increased to 6.4° ± 3.9° (CI: 5.7° to 7.2°) at 7 years. The mean changes in pelvic rotations around the longitudinal and sagittal axis were less than 1 degree, in both positions. In individual patients, this change reached about 11.0 degrees in supine and 18.0 degrees when standing.

KEYWORDS
acetabular cup orientation, dislocation, pelvic tilt, RSA, standing, supine, total hip arthroplasty (THA)

1 | INTRODUCTION

Orientation of the acetabular component during total hip arthroplasty (THA) is essential to avoid complications such as dislocation, impingement and accelerated bearing wear, which can lead to osteolysis around the implant and cause loosening.1-4

Dislocations are one of the most frequent complications after THA, leading to revision surgery.5,6 Posterior dislocations are reported to occur more often, however, anterior dislocations account for about 20% of all dislocations.7-10 Despite proper positioning of the acetabular component, the risk of dislocation may vary due to factors such as patient’s characteristics, implant design, and surgical technique.11,12

This manuscript is part of my thesis with the title "Wear and migration in total hip arthroplasty measured with Radiostereometric Analysis," which was defended in February 2018.

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Implant instability and asymmetrical loading of the acetabular component may also be an effect of excessive pelvic tilt. Pelvic tilt is defined as the angle between the anterior pelvic plane and a vertical line in the standing position. The rotation of the pelvis leads to anterior tilt (the upper portion of the pelvis tips forward) and posterior tilt (upper portion of the pelvis tips backward). There is an increasing interest in the relation between the pelvic position and presence of spinal deformities or disease since such disorders might influence the risk of dislocation after THA.

The orientation of the cup after operation with THA is commonly evaluated on standard pelvic radiographs, which routinely are exposed in the supine position. However, most activities of daily living are performed in the upright position. The orientation of the cup relative to the pelvis is set during the operation, but the pelvic tilt might change when the patient is mobilized, partly because of release of contractures during the operation and partly because of subsequent stretching of the soft tissues with time. Such changes might influence the validity of determination of cup orientation based on supine radiographs. Radiostereometric analysis (RSA) enables accurate evaluations of changes in the pelvic orientation, such as supine and standing and over time. Detailed studies of changes in pelvic tilt between supine and standing and over time may be of value when interpreting the cup orientation after THA using conventional radiography. Increased knowledge in this field may be of value to optimize the outcome of hip arthroplasty and may also facilitate our understanding of issues related to impingement and instability after THA.

We aimed to use RSA to evaluate if PTA changes over time in patients with total hip prosthesis and if the pelvic tilt differs between supine and standing positions at 6 months and 7 years after the operation. We also evaluated whether factors such as gender, the status of the opposite hip, or presence of any low-back disability influence the PTA after THA. To our knowledge, this is the first report on changes of pelvic tilt using RSA in patients operated with THA.

2 | PATIENTS AND METHODS

2.1 | Level of evidence: level II, diagnostic study

One hundred and six patients (106 hips) were selected from four different studies. All the patients underwent THA and were included in prospective clinical RSA trials evaluating cup migration and femoral head penetration at Sahlgrenska University Hospital between 1998 and 2005 (Figure 1). During the operation, tantalum markers had been inserted into the bone and the polyethylene liner or the cup. The selection criteria were patients who underwent cemented or uncemented THA for primary or secondary osteoarthritis (OA) of the hip and who were scheduled for follow-up including supine and standing

![Flow chart of all patients included in the study. The four studies included (a) 61 cemented THAs in an evaluation of polyethylene quality (Digas et al, 2003); (b) 32 patients operated bilaterally with uncemented cups with a different types of polyethylene quality on the two sides (Digas et al, 2004); (c) 52 cemented THAs in an evaluation of two types of bone cement (not published previously); (d) 84 cemented THAs in a study aimed to study different types of stem design (Thien et al, 2010). THA, total hip arthroplasty. [Color figure can be viewed at wileyonlinelibrary.com]
examination on at least two occasions (at 6 months and 7 years after surgery), in addition to the supine postoperative RSA examination. The purpose of examining patients in supine and standing positions was to evaluate any potential differences in femoral head penetration between these two positions.\(^{20}\) Only hips marked in the segment of interest, that is, the acetabular bone with at least three tantalum markers or more and with a scatter corresponding to a condition number less than 125 and a mean error of rigid body fitting corresponding to at most 0.35 mm were included.\(^{21,22}\) One hundred and six patients (106 hips) fulfilled the inclusion criteria (Figure 1). All patients had provided informed consent for the insertion of tantalum markers during the operation and the subsequent RSA examinations. Approval was obtained through the Regional Ethics Committee, S 257-00, R312-98, Ö449-00, and Ö450-00. Patient demographic data are presented in Table 1.

The primary outcome parameter was the pelvic rotations about the transverse axis (anterior or forward tilt [+] and posterior or backward [-] tilt) (Table 2A). Pelvic rotations about the other two axes (longitudinal, y-axis, and sagittal, z-axis) are also presented (Tables 2B and 2C).

Of 106 patients, 42 had a unilateral hip prosthesis throughout the study period, 16 patients underwent surgery with a hip prosthesis on the contralateral side during the follow-up period of 7 years and 48 patients had bilateral hip prosthesis when the study was initiated. In this latter group, and in those patients with both hips followed with RSA, the hip with the optimum scatter and visibility on stereoradiographs of tantalum markers in the pelvis was selected. To determine the condition of the contralateral hip in patients with a unilateral prosthesis at the last follow-up (n = 42), conventional radiographs were reviewed. They revealed that 14 patients had a normal hip and 28 suffered from OA on the contralateral side.

We also reviewed the medical records of all patients regarding the incidence of low-back pain. A history of low-back pain was considered to be or to have been present if the patients had visited our department because of this condition during the follow-up or had complained of low-back pain at any follow-up visits after the hip operation. In 28 of the 106 patients, low-back problems had been documented. None of the patients had undergone spinal fusion. We also reviewed the medical records of all patients regarding the incidence of hip dislocation corresponding to a mean follow-up period of 12 years (range: 7-16 years) after operation. None of the patients had undergone revision surgery due to hip dislocation.

### 2.2 Radiostereometric analysis

For the purpose of this study, we calculated the motions of tantalum markers inserted into the pelvis (the pelvic bone segment) in relation to the head. The primary outcome parameter was the pelvic rotations about the transverse axis (anterior or forward tilt [+] and posterior or backward [-] tilt) (Table 2A). Pelvic rotations about the other two axes (longitudinal, y-axis, and sagittal, z-axis) are also presented (Tables 2B and 2C).

### Table 1 Baseline demographic data. Mean (range) or numbers

| Gender    |       |   |
|-----------|-------|---|
| Male      | 39    |   |
| Female    | 67    |   |
| Age, y    | 59 (30-78) |   |
| Weight, kg| 75 (51-112) |   |
| Height, cm| 170 (155-195) |   |
| BMI, kg/m²| 26 (19-35) |   |
| Bilateral THA |       |   |
| No        | 42    |   |
| Yes       | 48    |   |
| During the follow-up | 16 |   |
| Low-back pain |       |   |
| No        | 78    |   |
| Yes       | 28    |   |
| Contralateral hip at 7 y |       |   |
| Normal    | 14    |   |
| Osteoarthritis | 28 |   |
| THA       | 64    |   |

**Abbreviation:** THA, total hip arthroplasty.

### Table 2A Anterior (+)/posterior tilt (−) in the supine and standing positions in 106 patients up to 7 years after THA

|          | n  | Mean (SD) | 95% CI          | P value |
|----------|----|-----------|-----------------|---------|
| Supine   |    |           |                 |         |
| Postoperative –6 mo | 106 | -2.0° (3.0°) | -2.6° to -1.4° | <.001   |
| Postoperative –7 y | 106 | -2.7° (2.9°) | -3.3° to -2.2° | <.001   |
| Supine to standing |    |           |                 |         |
| 6 mo     | 106 | 3.6° (3.8°) | 2.8° to 4.3°    | <.001   |
| 7 y      | 106 | 6.4° (3.9°) | 5.7° to 7.2°    | <.001   |

**Abbreviations:** CI, confidence interval; SD, standard deviation; THA, total hip arthroplasty.

\(^*\)The Student t test.
Stereoradiographic measurements and analysis were performed with UmRSA Digital measure and UmRSA Analysis software 6.0 (RSA Biomedical, Umeå, Sweden). Statistical analysis was performed using IBM SPSS, version 20.0.0.

### TABLE 2C

| Supine                  | n  | Mean (SD) | 95% CI      | P value* |
|-------------------------|----|-----------|-------------|----------|
| Postoperative           |    |           |             |          |
| −6 mo                   | 106| −0.86° (3.5°) | −1.5° to 0.17° |          |
| Postoperative           |    |           |             |          |
| −7 y                    | 106| −0.59° (3.7°) | −1.3° to 0.13° | .39      |

Abbreviations: CI, confidence interval; SD, standard deviation; THA, total hip arthroplasty.

*The Student t test.

to the coordinate system defined by the calibration cage. These motions are by convention labeled absolute motions of the pelvic bone or segment. In this way, true positional changes of the pelvis represented by markers in the acetabulum can be determined between different positions such as supine and standing or over time with the patient examined in the same or at varying positions.

During the operation, spherical tantalum markers with a diameter of 0.8 mm or 1.0 mm diameter were inserted into the bone and into the polyethylene of the cup. Although only three visible and well-defined markers in each segment of interest are necessary for a complete radiosterometric evaluation, five to nine markers were inserted into the acetabular region of the pelvis to optimize marker spread and compensate for loose or invisible markers.

To ensure alignment of the laboratory coordinate axes to the pelvis, the orientation of the patient in relation to the cage was standardized in the reference position (supine position), so that the transverse axis should pass through the two anterior iliac spines. When examined standing the patient had the arms crossed on the chest at a standard position.

To evaluate the reproducibility of the RSA measurements, two sets of RSA images (double examinations) of 20 patients in the supine position at the same visit were performed. The patients were repositioned between the examinations, without moving the calibration cage and X-ray tubes. All patients were examined using a uniplanar technique.

Stereoradiographic measurements and analysis were performed with UmRSA Digital measure and UmRSA Analysis software 6.0 (RSA Biomedical, Umeå, Sweden).

### 2.3 | Statistical analysis

Statistical analysis was performed using IBM SPSS, version 20.0.0. All RSA data were normally or close to normally distributed (Shapiro-Wilk; P < .05). The data are presented as the mean ± standard deviation (SD) at a confidence interval (CI) level at 95%. Paired-samples t tests were used to evaluate any differences between two repeated observations from the same patients and an independent sample t test or one-way analysis of variance was used for comparison between different groups. Statistical significance was assumed at P values less than .05.

Generalized linear models were constructed in which pelvic tilt in supine position and from the supine to the standing position at 6 months and 7 years were used as dependent variables, with gender, the status of the contralateral side (only at the 7-year follow-up) and low-back pain (only at 7-year follow-up) as predictors. Age was used as a covariate.

The precision of pelvic position was calculated as 95% CI using the SD of the difference measured between two examinations multiplied by the critical value (t) obtained from the T-table. The precision was calculated from zero by assuming that the pelvic tilt between the two examinations had no specific direction. Precision of the double examination measurements was found to be ±3.3° for rotations about the transverse axis, ±1.3° for the longitudinal and ±4.5° for the sagittal axis (± describes the 95% CI of individual patients).

### 3 | RESULTS

#### 3.1 | Changes in PTA in supine position

The pelvis tended to show an increased posterior tilt with increasing follow-up. Between the postoperative and the follow-up examination at 6 months the posterior tilt reached a mean of −2.0° ± 3.0° (CI: −2.6° to −1.4°), which increased to −2.7° ± 2.9° (CI: −3.3° to −2.2°) at 7 years (P = .01) (Table 2A). The mean changes around the longitudinal and sagittal axes were less than 1 degree, in both supine and standing positions (Tables 2A and 2B).

#### 3.2 | Changes in PTA between supine and standing position

From supine to standing, the mean change was 3.6° ± 3.8° (CI: 2.8° to 4.3°) at 6 months which increased to 6.4° ± 3.9° (CI: 5.7° to 7.2°) at 7 years (P < .001) (Table 2A). At 6 months, five patients demonstrated anterior tilt changes above 10 degrees reaching a maximum of 18 degrees (Figure 2A). Nineteen patients demonstrated an anterior tilt above 10 degrees at the 7-year follow-up (Figure 2B).

#### 3.3 | Influence of different factors on PTA

##### 3.3.1 | Gender

At 6 months, the mean change in posterior pelvic tilt was greater (P = .02) in females (−2.5° ± 3.0°) than in males (−1.1° ± 2.6°) in the supine position. At 7 years this posterior tilt had increased in both females and males to −3.1° ± 3.0° and −2.1° ± 2.8°, respectively (females vs males: P = .08). Between supine and standing, there
was no difference between the genders at 6 months. Compared to the male participants, females showed a significant larger anterior tilt from supine to standing at 7 years (7.2° ± 4.1° vs 5.1° ± 3.2°; *P* = .01) (Table 3).

### 3.3.2 Low-back pain

In the supine position, no significant differences in PTA were observed between the patients with or without low-back pain at any of the two follow-up occasions (*P* > .05). From supine to standing, a weak and insignificant tendency toward larger anterior tilt was observed in patients with no low-back pain on both occasions.

### 3.3.3 Linear regression analysis

For females measured in the supine position at 6 months, regression analysis of rotations about the transverse axis (dependent value)
showed an increased posterior tilt \((P = .01)\) and a tendency toward increasing posterior tilt with age \((P = .06)\) (Table 4A). From the supine position postoperatively to supine at 7 years, a moderate association between female gender and posterior pelvic tilt was observed \((P = .06)\), but no association with age \((P = .56)\) or back pain \((P = .35)\) (Table 4A).

At 6 months, changes in pelvic tilt from supine to standing positions were not significantly correlated with gender \((0.90)\) or age \((0.40)\). Significant increases in anterior pelvic tilt from supine to standing positions at 7 years (Table 4B) were associated with female gender \((P = .004)\) and patient age \((P = .02)\).

Any influence of the status of the opposite hip was only studied for supine to standing at 7 years, because the exact time frame for the development of OA on the nonoperated side could not be established. Analysis of supine to standing results at 7 years did not reveal any influence of the opposite side (normal, OA, or THA) on the recorded PTA (Table 4B).

### DISCUSSION

A steep acetabular cup inclination increases the risk of dislocation and is also considered as an important reason for increased wear regardless of the material used.\(^{23-25}\) Routinely, the inclination of the cup is determined postoperatively on radiographs exposed in the supine position. The patient will, however, perform numerous activities when upright and, between supine and standing, the rotation of the pelvis about the transverse axis might change. Any change in pelvic orientation after the operation in the supine position and between the supine and standing position during the postoperative period will influence validity of cup orientation measurements.

A limitation of our study is that we were unable to evaluate pelvic orientation prior to THA, because the RSA technique requires maker beads to be inserted into the bone. However, several studies have found no significant difference between preoperative and postoperative PTA.\(^{26-28}\) Another possible limitation is that double examinations in the standing position were not performed. We had no ethical approval to repeat both the supine and standing examinations and since we hypothesized that the supine examination would have the largest variability, we chose to perform double examinations in this position.

We found that, when the patient is measured in the supine position, the PTA changes over a period of 7 years. This change in terms of increasing posterior tilting was comparatively small and more pronounced in females than in males. After operation, extension defect caused by the hip disease can be expected to decrease and even disappear. Our observation of increasing posterior

### TABLE 3

|                | Female |          | Male |          | \(P\) value^a |
|----------------|--------|----------|------|----------|--------------|
|                | \(n\)  | Mean (SD) | 95% CI | Mean (SD) | 95% CI       |
| Supine         |        |           |       |          |              |
| Postoperative—6 mo | 67/39  | -2.5° (3.0°) | -3.2° to -1.7° | -1.1° (2.6°) | -2.0° to -0.29° | .02 |
| Postoperative—7 y | 67/39  | -3.1° (3.0°) | -3.8° to 2.4° | -2.1° (2.8°) | -3.0° to -1.2° | .08 |
| Supine to standing |        |           |       |          |              |
| 6 mo           | 67/39  | 3.6° (4.2°) | 2.6° to 4.6° | 3.5° (3.0°) | 2.5° to 4.5° | .84 |
| 7 y            | 67/39  | 7.2° (4.1°) | 6.2° to 8.2° | 5.1° (3.2°) | 4.1° to 6.2° | .01 |

Abbreviations: CI, confidence interval; SD, standard deviation; THA, total hip arthroplasty.

^aThe Student t test.

### TABLE 4A

|                | \(\beta\) | 95% CI     | \(P\) value |
|----------------|----------|------------|-------------|
| Supine-supine  |          |            |             |
| Postoperative—6 mo |        |           |             |
| Gender          |          |            |             |
| Female          | -1.4     | -2.60 to -0.32 | 0.01       |
| Male^a          | 0\(^*$\) |            |             |
| Age             | .05      | -0.00 to 0.10 | 0.06       |
| Low-back pain   |          |            |             |
| Yes             | -0.58    | 0.63 to -1.80 | .35        |
| No^a            | 0\(^*$\) | ...        | ...         |

Abbreviation: CI, confidence interval.

^aReference
TABLE 4B Linear regression analysis: gender, age, opposite hip, and low-back pain with pelvic tilt from supine to standing

| Supine to standing | 6 mo | 7 y |
|--------------------|------|-----|
|                    | β    | 95% CI | P value | β    | 95% CI | P value |
| Gender             |      |       |         |      |       |         |
| Female             | .09  | −1.40 to 1.60 | .90 | 2.10 | 0.69 to 3.60 | .004 |
| Male <sup>a</sup>  |      |       |         |      |       |         |
| Age                | .03  | −0.04 to 0.09 | .40 | .07  | 0.01 to 0.13 | .02 |
| Opposite hip       |      |       |         |      |       |         |
| Normal             | −0.01 | −2.10 to 2.10 | .99 |      |       |         |
| OA                 | 1.30 | −0.36 to 2.90 | .13 | 1.50 | −3.10 to 0.05 | .06 |
| THA                |      |       |         |      |       |         |
| Low-back pain      |      |       |         |      |       |         |
| Yes                | −1.50 | −3.10 to 0.05 | .06 |      |       |         |
| No <sup>b</sup>    |      |       |         |      |       |         |

Abbreviations: CI, confidence interval; OA, osteoarthritis; THA, total hip arthroplasty.

*aReference

Tilt over time could reflect that the soft-tissue distraction continues up to at least 6 months after the operation and even during longer in some patients. In changing from a supine to standing position, the pelvis tilted in the opposite (ie, anterior) direction. This anterior tilt increased with time and became significant at 7-year follow-up especially in women. The increased pelvic tilt in woman may be associated with age-related changes of the spine due to osteoporosis, which increases with age and especially in females. Female gender and increasing age have previously been found to be consistent with larger variations of PTA, which is consistent with our findings. Those authors evaluated changes in PTA in 86 patients in the supine and standing positions 2 to 4 years after operation and reported a significant difference in PTA between those positions. In addition, they found that the amount of pelvic tilt prior to surgery was a contributory factor. Ishida et al. <sup>27</sup> reported that patients with large preoperative anterior tilt demonstrated greater changes of this parameter after operation. However, there seems to be some disagreement in the literature regarding the impact of preoperative pelvic tilt on the extent of postoperative tilting of the pelvis in the standing position. <sup>26,28,34</sup> We found that the status of the contralateral hip had no effect on the PTA. One could speculate that untreated OA on the opposite side in these patients would result in more anterior pelvic tilt than in those with a normal hip on the opposite side, due to soft-tissue contracture.

Similar to our observations, Tamura et al. <sup>35</sup> observed a posterior pelvic tilt supine at the 1-year follow-up, which tended to level out at the following examinations. Contrary to our observations, however, these authors observed a posterior tilt in an increasing number of patients with time and especially between the 5- and 10-year follow-up. The reason for this difference is not known but could be perhaps related to differences in demographic and especially different diagnoses of hip diseases. We think that the precision of our measurements mainly was related to the ability of the patient and the examiner to obtain a standardized alignment at the reference position, to randomly occurring changes of the pelvic tilt supine and standing and, to a relatively much smaller degree, the resolution of RSA itself. Previous studies seem to have focused their error analysis on the measurement methodology and not to individual variations in pelvic positioning. Several studies (Nishihara et al. <sup>36</sup> Pierrepont et al. <sup>27</sup> Tamura et al. <sup>35</sup> Uemara et al. <sup>38</sup>) matched three-dimensional measurements or reconstructions from computed tomography images to conventional radiographic images. They found a high correlation between these measurements and in one of these studies, a median absolute error of 1.5 degrees was reported, but none of these calculations seem to be based on repetition of the examination procedure. In our study, we only repeated examination supine to study precision. Further studies with repeated examinations of the standing position in one and the same patient could also be of interest, but at the time period for this study, we had no ethical allowance for expansion of the double examinations.

In the previous studies quoted above, the pelvic positions were determined based on anatomical landmarks and the change of pelvic tilt between these positions were computed. We measured change of pelvic tilt corresponding to rotations about the transverse axis of the RSA calibration cage by determination of position changes of clusters of markers inside the pelvic bone. We were therefore unable to account for any differences between the groups at the starting or reference supine position which is a limitation.

Patients with low-back problems might be expected to have reduced mobility of the spine and the pelvis. The evaluation of low-back pain in our study was retrospective and could, therefore, be regarded as suboptimal. However, the differences between patients with or without low-back pain were small and amounted to only one to two degrees on average. These findings were consistent with a meta-analysis comparing pelvic kinematics in patients with and without...
low-back pain, which reported no difference between these patient
groups.\textsuperscript{39,42} According to our findings and in patients without spinal
fusion, the influence of low-back problems on the stability of a hip
prosthesis seems to be small.

5  |  CONCLUSION

Up to 7 years after insertion of a THA, the pelvis tilts slightly pos-
teriorly in the supine position. When rising to standing, we found
that the pelvis tilts in the opposite direction. This tilt increased with time
and reached an average of about 7 degrees in females and 5 degrees
in males. For many patients, the individual changes are small and
most probably have minor effects on the outcome of the procedure.
In individual cases, this tilt might be high as much as 15 to 20 degrees.
Female patients displayed larger changes in pelvic tilt in both supine and
standing positions. A large PTA after THA may cause dislocation or
influence the rate of wear of the articular surface. If possible, identifi-
cation of these patients before the operation could be beneficial to
obtain guidelines for optimum cup positioning or choice of implants with
built-in increased resistance to dislocation.\textsuperscript{43} Increased knowledge of
postoperative changes of pelvic tilt may contribute to the understanding of
adverse outcomes after THA and how to reduce the risk of their
occurrence.

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CONFLICT OF INTERESTS
One of the authors of this paper is a board member of RSA Biome-
dical and has a financial relationship with the organization that could
influence or bias the content of the paper.

AUTHOR CONTRIBUTION
JKÄ was responsible for the study conception and design. BSH col-
lected the data and performed the analysis and drafted the manu-
script. JKÄ and MM critically reviewed and contributed to the paper.
All authors read and approved the final manuscript.

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REFERENCES
1. Lewineke GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dis-
locations after total hip-replacement arthroplasties. J Bone Joint Surg
Am. 1978;60(2):217-220.
2. Wan Z, Boutary M, Dorr LD. The influence of acetabular component
position on wear in total hip arthroplasty. J Arthroplasty. 2008;23(1):51-56.
3. Gandhi R, Marchie A, Farrokhyar F, Mahomed N. Computer naviga-
tion in total hip replacement: a meta-analysis. Int Orthop. 2009;33(3):
593-597.
4. Wera GD, Ting NT, Moric M, Paprosky WG, Sporer SM, Della Valle CJ.
Classification and management of the unstable total hip arthroplasty.
J Arthroplasty. 2012;27(5):710-715.
5. Woo RY, Morrey BF. Dislocations after total hip arthroplasty. J Bone
Joint Surg Am. 1982;64(9):1295-1306.
6. Hedlundh U, Ahnfelt L, Hybbinette CH, Wallinder L, Weckstrom J,
Fredin H. Dislocations and the femoral head size in primary total hip
arthroplasty. Clin Orthop Relat Res. 1996;333(333):226-233.
7. Dorr LD, Wolf AW, Chandler R, Conaty JP. Classification and treat-
ment of dislocations of total hip arthroplasty. Clin Orthop Relat Res.
1983;(173):151-158.
8. Di Schino M, Baudart F, Zilber S, Poignant A, Allain J. Anterior dis-
location of a total hip replacement. Radiographic and CT-scan as-
essment. Behavior following conservative management. Orthop Trauma
Surg Res. 2009;95(8):573-578.
9. Ng FY, Wang Q, Chiu KY, Yan CH. Anterior dislocation after total hip
replacement—effects of pelvic rotation and femoral head size. Hip Int.
2013;23(4):386-390.
10. Kobayashi H, Nakashima Y, Yamamoto T, et al. Late anterior dis-
location due to posterior pelvic tilt in total hip arthroplasty. Open
Orthop J. 2016;10:206-212.
11. Amstutz HC, Ludwig RM, Schurman DJ, Hodgson AG. Range of mo-
tion studies for total hip replacements. A comparative study with a
new experimental apparatus. Clin Orthop Relat Res. 1975;111:
124-130.
12. Matsushita A, Nakashima Y, Jingushi S, Yamamoto T, Kuraoka A,
Iwamoto Y. Effects of the femoral offset and the head size on the safe
range of motion in total hip arthroplasty. J Arthroplasty. 2009;24(4):
646-651.
13. Gorin M, Roger B, Lazennec JY, et al. Hip-spine relationship: a radio-
anatomical study for optimization in acetabular cup positioning. Surg
Radiol Anat. 2004;26(2):136-144.
14. Bradson CR, Malchau H, Yuan X, et al. Experimental assessment of
precision and accuracy of radiostereometric analysis for the de-
termination of polyethylene wear in a total hip replacement model.
J Orthop Res. 2002;20(4):688-695.
15. Onsten I, Berzins A, Shott S, Sumner DR. Accuracy and precision of
radiostereometric analysis in the measurement of THR femoral
component translations: human and canine in vitro models. J Orthop
Res. 2001;19(6):1162-1167.
16. Madanat R, Makinen TJ, Moritz N, Mattila KT, Aro HT. Accuracy and
precision of radiostereometric analysis in the measurement of three-
dimensional micromotion in a fracture model of the distal radius.
J Orthop Res. 2005;23(2):481-488.
17. Digas G, Karrholm J, Thanner J, Malchau H, Herberts P. Highly
cross-linked polyethylene in cemented THA: randomized study of 61 hips.
Clin Orthop Relat Res. 2003;417:126-138. https://doi.org/10.1097/01.blo.000096802.78689.45
18. Digas G, Karrholm J, Thanner J, Malchau H, Herberts P. The Otto
Auftranc Award. Highly cross-linked polyethylene in total hip ar-
throplasty: randomized evaluation of penetration rate in cemented
and uncemented sockets using radiostereometric analysis. Clin Orthop
Relat Res. 2004;(429):6-16.
19. Thien TM, Thanner J, Karrholm J. Randomized comparison between 3
surface treatments of a single anteverted stem design: 84 hips followed
for 5 years [published online ahead of print February 20, 2009].
J Arthroplasty. 2010;25(3):437-444. https://doi.org/10.1016/j.arth.2009.01.015
20. Bradson CR, Thanner J, Greene ME, et al. Standing versus supine
radiographs in RSA evaluation of femoral head penetration. Clin Or-
thop Relat Res. 2006;448:46-51.
21. Valstar ER, Gill R, Ryd L, Flivik G, Borlin N, Karrholm J. Guidelines for
standardization of radiostereometry (RSA) of implants. Acta Orthop.
2005;76(4):563-572.
22. Ryd L, Yuan X, Lofgren H. Methods for determining the accuracy of radiostereometric analysis (RSA). Acta Orthop Scand. 2000;71(4):403-408.

23. Jeffers JR, Roques A, Taylor A, Tuke MA. The problem with large diameter metal-on-metal acetabular cup inclination. Bull NYU Hosp Jt Dis. 2009;67(2):189-192.

24. Kennedy JG, Rogers WB, Soffe KE, Sullivan RJ, Griffen DG, Sheehan LJ. Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. J Arthroplasty. 1998;13(5):530-534.

25. Callanan MC, Jarrett B, Bragdon CR, et al. The John Charnley Award: risk factors for cup malpositioning: quality improvement through a joint registry at a tertiary hospital. Clin Orthop Relat Res. 2011;469(2):319-329.

26. Blondel B, Parratte S, Tropiano P, Pauly V, Aubaniac JM, Argenson JN. Pelvic tilt measurement before and after total hip arthroplasty. Orthop Traumatol Sur. 2009;95(8):568-572.

27. Ishida T, Inaba Y, Kobayashi N, et al. Changes in pelvic tilt following total hip arthroplasty. J Orthop Sci. 2011;16(6):682-688.

28. Maratt JD, Esposito CI, McLawhorn AS, Jerabek SA, Padgett DE, Mayman DJ. Pelvic tilt in patients undergoing total hip arthroplasty: when does it matter? J Arthroplasty. 2015;30(3):387-391.

29. Fon GT, Pitt MJ, Thies AC Jr. Thoracic kyphosis: range in normal subjects. AJR Am J Roentgenol. 1980;134(5):979-983.

30. Ensrud KE, Black DM, Harris F, Ettinger B, Cummings SR. Correlates of kyphosis in older women. The Fracture Intervention Trial Research Group. J Am Geriatr Soc. 1997;45(6):682-687.

31. Boyle JJ, Milne N, Singer KP. Influence of age on cervicothoracic spinal curvature: an ex vivo radiographic survey. Clin Biomech (Bristol, Avon). 2002;17(5):361-367.

32. Allon T, Shaffrey CI, Lenke LG, Harrop JS, Smith JS. Progressive spinal kyphosis in the aging population. Neurosurgery. 2015;77(suppl 4):S164-172.

33. Taki N, Mitsugi N, Mochida Y, Akamatsu Y, Saito T. Change in pelvic tilt angle 2 to 4 years after total hip arthroplasty. J Arthroplasty. 2012;27(6):940-944.

34. Kanto M, Maruo K, Tachibana T, et al. Influence of spinopelvic alignment on pelvic tilt after total hip arthroplasty. Orthop Surg. 2019;11(3):438-442.

35. Tamura S, Nishihara S, Takao M, Sakai T, Miki H, Sugano N. Does pelvic sagittal inclination in the supine and standing positions change over 10 years of follow-up after total hip arthroplasty? J Arthroplasty. 2017;32(3):877-882.

36. Nishihara S, Sugano N, Nishii T, Ohzono K, Yoshikawa H. Measurements of pelvic flexion angle using three-dimensional computed tomography. Clin Orthop Relat Res. 2003;411(411):140-151.

37. Pierrepont J, Hawdon G, Miles BP, et al. Variation in functional pelvic tilt in patients undergoing total hip arthroplasty. Bone Joint J. 2017;99-B(2):184-191.

38. Uemura K, Takao M, Otake Y, et al. Reproducibility of pelvic sagittal inclination while acquiring radiographs in supine and standing postures. J Orthop Surg (Hong Kong). 2019;27(1):2309499019828515.

39. Day JW, Smidt GL, Lehmann T. Effect of pelvic tilt on standing posture. Phys Ther. 1984;64(4):510-516.

40. Christie HJ, Kumar S, Warren SA. Postural aberrations in low back pain. Arch Phys Med Rehabil. 1995;76(3):218-224.

41. Youdas JW, Garrett TR, Egan KS, Therneau TM. Lumbar lordosis and pelvic inclination in adults with chronic low back pain. Phys Ther. 2000;80(3):261-275.

42. Laird RA, Gilbert J, Kent P, Keating JL. Comparing lumbo-pelvic kinematics in people with and without back pain: a systematic review and meta-analysis. Bmc Musculoskel Dis. 2014:15229.

43. Kreipke R, Rogmark C, Pedersen AB, et al. Dual mobility cups: effect on risk of revision of primary total hip arthroplasty due to osteoarthritis: a matched population-based study using the Nordic Arthroplasty Register Association Database. J Bone Joint Surg Am. 2019;101(2):169-176.

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