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Does Standing Affect Acetabular Component Inclination and Version After THA?

Gregory G. Polkowski MD, Ryan M. Nunley MD,
Erin L. Ruh MS, Brandon M. Williams DC,
Robert L. Barrack MD

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Abstract

Background Avoiding complications after hip arthroplasty with hard-on-hard bearings, especially metal-on-metal, correlates with the position of the acetabular component. Supine imaging with conventional radiography has traditionally been utilized to assess component inclination (abduction), as well as anteversion, after THA and surface replacement arthroplasty (SRA). However, most adverse events with hard bearings (excessive wear and squeaking) have occurred with loading. Standing imaging, therefore, should provide more appropriate measurements.

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All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained. This work was performed at Washington University School of Medicine, St Louis, MO, USA.

G. G. Polkowski
Department of Orthopedic Surgery, New England
Musculoskeletal Institute, University of Connecticut
Health Center, Farmington, CT, USA

R. M. Nunley, E. L. Ruh, B. M. Williams, R. L. Barrack (✉)
Department of Orthopaedic Surgery, Washington University
School of Medicine, One Barnes-Jewish Hospital Plaza, 11300
West Pavilion, Campus Box 8233, St Louis, MO 63110, USA
e-mail: pouchera@wustl.edu; barrackr@wustl.edu

Questions/purposes We determined whether standing changed standard measurements of acetabular component position using a novel biplanar imaging system compared to traditional supine imaging.

Methods We performed simultaneous biplanar standing imaging of the lower extremity with a novel imaging system using low radiation collimated beam on 46 patients who underwent THA (23) or SRA (23). Patients who had previously undergone THA had standard CT scans performed. For patients who underwent SRA, we compared acetabular inclination in the supine versus double-limb and single-limb standing.

Results Standing anteversion differed from supine anteversion by greater than 5° for 12 of 23 patients who underwent THA (range, 5°–16°). For patients who underwent SRA, 13 of 23 patients exhibited a difference of greater than 3° in inclination between supine and double-limb standing images, and six of 23 patients exhibited a difference of greater than 3° in inclination between supine and single-limb standing images.

Conclusions Standing changed the acetabular inclination and version in a substantial percentage of patients undergoing hip arthroplasty.

Introduction

The function and durability of THA have been directly related to component positioning [24]. Accurate, reproducible positioning of the acetabular component has been the greatest challenge of acceptable component positioning in the routinely accepted safe zone [19], demonstrated in only about 50% of cases in one recent study [5]. Complications of acetabular component malposition have included instability and wear [19, 24]. Hard bearings have been

more dependent on accurate positioning to avoid edge loading, increased metal ion levels, and unique phenomena, such as squeaking [3, 10]. The association between acetabular position and numerous complications has been extremely variable. The complications noted were related to the position of the component [11], but many of these complications occurred in apparently normally positioned components and may have been absent in apparently malpositioned components [22]. There have been a number of possible explanations including impingement, soft tissue laxity, and microseparation [23].

An additional possible explanation is the influence of standing on the position of the acetabular component. Traditional total hip imaging has been performed in the supine position [9]. Most adverse events attributed to malposition occur in functional positions, and there is evidence that the orientation of the pelvis changes from the supine to the standing position [1, 4, 13, 17, 25].

We determined the impact of standing on the position of the acetabular component measured using a novel biplanar imaging system after THA compared to traditional supine positioning of the patient during conventional radiography.

Patients and Methods

To investigate the impact of standing on the position of the acetabular component after THA, we evaluated the standing acetabular component position in two cohorts of patients who underwent hip arthroplasty. The first group consisted of 23 patients who had previously undergone unilateral cementless THA and were already enrolled in a prospective study evaluating the extent of osteolysis after THA with conventional or highly crosslinked polyethylene. As part of this protocol, a CT scan was obtained that could be used as a standard for comparison for sagittal-plane acetabular anteversion. The second group consisted of 23 patients who were part of a prospective study tracking the whole-blood metal ion levels after metal-on-metal unilateral surface replacement arthroplasty (SRA). Serial pre- and postoperative supine radiographs were available for this cohort. We selected patients based on the following criteria: enrollment in one of the prospective THA or SRA studies, unilateral THA, and a willingness to undergo standing imaging of their arthroplasty components. Our research coordinator (ELR) contacted a convenience sample of candidates from a pool of 46 study participants with THA or 31 study participants with SRA and asked them to participate in this research study. We were able to recruit 23 patients with THA and 23 patients with SRA to participate. We received IRB approved for this study.

We subjected each patient to a novel radiographic technique that provided simultaneous biplanar AP and lateral

imaging of the pelvis and lower extremities to measure acetabular component position. The EOS[®] X-Ray Imaging Acquisition System (EOS Imaging Inc, Paris, France) was used to acquire the standing images (Fig. 1). The EOS[®] system used two radiographic imaging acquisition systems mounted at right angles to each other within the apparatus, allowing simultaneous orthogonal imaging of the patient while standing. This system incorporated a novel x-ray detector signal technique based on the principle of a multi-wire proportional chamber, which allowed for a substantial amplification of x-ray signal, generating high-quality images. The combination of the highly collimated source x-ray beam and the substantial signal amplification at the detector allowed the system to generate high-quality images with a fraction of radiation exposure compared with conventional radiography techniques: 800 to 1000 times less than CT imaging and six to nine times less than conventional radiography [8]. This imaging system recently gained FDA approval in the United States for imaging of the spine and lower extremities, and several studies have described and validated this imaging system as a useful tool for the measurement of the spine, pelvis, and hip arthroplasty acetabular component position [6, 17]. An embedded software program (SterEOS[®]; EOS Imaging Inc) allowed for direct measurement of angles and distances on the two-dimensional images. Using the simultaneity and orthogonality of the frontal and lateral plane images, the software could also

Fig. 1 A photograph shows the EOS[®] X-Ray Imaging Acquisition System (EOS Imaging Inc, Paris, France).

generate a three-dimensional (3D) model of the underlying bony structures. Bony landmarks were identified, and a basic model projected onto the simultaneous AP and lateral images. The contour of the model was adjusted to match the underlying osseous structures, and the software automatically calculated a variety of 3D parameters of the modeled bone. The acetabular component after THA could be incorporated into the modeling so that component position could be measured in relation to user-defined parameters or classic bony landmarks.

We acquired simultaneous AP and lateral radiographs using the EOS imaging system for all patients. All patients in the THA cohort were imaged from their shoulders to their feet while standing with both feet pointed directly forward and the front of the left foot in line with the heel of the right foot, such that the right and left legs could be easily distinguishable on the lateral radiographs. The floor of the EOS® imaging booth had a grid on which the patients stood so that their feet were positioned consistently. For the patients in the SRA cohort, we obtained standing AP and lateral radiographs in double-limb stance in an identical manner. Because this study was the first using this imaging system to measure standing hip arthroplasty acetabular component position, we also chose to acquire single-limb stance images in the SRA cohort to determine the feasibility of obtaining such images with this imaging system and to see whether there was a difference in coronal plane cup inclination between supine and standing imaging. We obtained single-limb standing radiographs of patients with SRA on their operative side with the nonoperative limb held in a position of 30° of hip and knee flexion to bring the contralateral foot off the floor. The digital images were stored, and the embedded SterEOS® imaging processing software program measured the angles of acetabular component position.

We used the SterEOS® imaging software to measure the functional acetabular inclination in the coronal plane on AP radiographs. Previous studies focusing on the validation of these measurement techniques on metal-backed THA components and using this software demonstrated inter- and intraobserver reproducibility for cup inclination and anteversion of $\pm 1.64^\circ$ and $\pm 1.44^\circ$, respectively [12]. For cup anteversion, the inter- and intraobserver reproducibility was $\pm 2.55^\circ$ and $\pm 2.33^\circ$, respectively [12]. A single observer (BMW), specially trained by the manufacturer's representatives on the use of the imaging software, made all of the measurements. To measure functional acetabular inclination in the coronal plane, BMW measured the angle between a line drawn parallel to the floor and a second line drawn through the superior lateral and inferior medial border of the acetabular component (Fig. 2). The functional acetabular inclination was measured in all patients who underwent SRA (double- and single-limb stance).

Fig. 2 A supine AP radiograph of the pelvis of a patient after SRA shows an acetabular inclination of 43° . The standing pelvis radiograph of this patient is shown (Fig. 5).

We defined functional acetabular anteversion as the anterior opening of the acetabular component in the pure sagittal plane, when viewed from the direct lateral position. The term anteversion could have been misleading as it was inherently nonspecific. There have been several definitions of anteversion, as described by Murray [21], with anatomic and surgical anteversion being the most commonly used by practicing orthopedists. Anatomic anteversion referred to the opening of the acetabular component as measured in the axial or transverse plane, which could be directly measured from the axial images obtained from a CT scan. Surgical anteversion referred to the opening of the acetabular component in the sagittal plane. It was this anteversion that was approximated with a conventional alignment guide during implantation of the acetabular component with the patient in a lateral position during THA, and it was this pure sagittal plain anteversion that we measured with the reconstructed sagittal CT and direct lateral EOS® images. We measured the functional acetabular anteversion in the sagittal plane on the patients with THA on the lateral radiographs and determined it using the angle between a horizontal line and a line drawn connecting the anterior superior and posterior inferior borders of the acetabular component. In patients who had undergone THA, the presence of a smaller femoral head and the polyethylene liner allowed for easy visualization of the appropriate component landmarks for these angles to be measured (Fig. 3). In patients who had undergone SRA, the larger metal head and monoblock metal cup obscured the appropriate component contours, making the functional anteversion measurement in this cohort unfeasible.

To compare the functional standing inclination and anteversion angles of acetabular component position in the

Fig. 3 A reconstructed sagittal CT image depicts a sagittal plane acetabular component anteversion of 42° . The standing lateral radiograph of this patient is shown (Fig. 4).

Fig. 4 An EOS® standing lateral radiograph shows a sagittal anteversion of 59° , a 17° difference in anteversion compared to this patient's supine lateral anteversion measurement (Fig. 3).

THA and SRA cohorts, we measured an additional series of values for acetabular component position in these same 23 patients with THA and 23 patients with SRA using data collected during the other prospective studies in which this same cohort of patients had already been enrolled [20]. Each of the 23 patients with THA had undergone a CT scan of their pelvis to assess for periacetabular osteolysis. The imaging protocol called for the patients to be positioned supine on the CT gantry with the radiation source and detector perpendicular to the gantry during data acquisition. We reviewed these CT data and measured acetabular anteversion in the sagittal plane as the angle formed between the line drawn between the apexes of acetabular component and a line parallel to the CT gantry table on the reconstructed sagittal images (Fig. 4). We also reviewed

Fig. 5 An EOS® standing AP pelvis radiograph shows an acetabular inclination of 54° , 11° more vertical than the corresponding supine measurement for this patient (Fig. 2).

supine AP pelvis radiographs of the 23 patients who underwent SRA and measured the values of acetabular component inclination. These AP pelvis radiographs were obtained with the patients lying supine, legs internally rotated 15° , with the x-ray beam centered at the symphysis pubis, and with the radiation source at a height of 40 cm off the x-ray table. We used the angle between a line drawn parallel to the ischial tuberosities and through the superior lateral and inferior medial border of the acetabular component to measure acetabular component inclination (Fig. 5). We then compared the CT values for supine sagittal plane acetabular anteversion for the patients who had undergone THA and the conventional radiographic supine measurements of acetabular component inclination in the coronal plane in the patient who underwent SRA with the standing values obtained using the EOS® imaging system.

We used a paired Student's t-test to compare supine inclination and anteversion values with the corresponding measurements in the standing position (Microsoft® Excel®; Microsoft Corp, Redmond, WA, USA).

Results

The data acquired using the EOS® imaging system allowed for straightforward measurement of coronal and sagittal plane acetabular component position in patients who had undergone THA and SRA. For the 23 patients with THA, the mean difference in sagittal plane acetabular component anteversion measured from supine CT images and the standing EOS® images was 7° (range, -2° to 18°) (Table 1). In 20 of 23 (87%) patients, there was an increase

Table 1. Sagittal plane anteversion in patients with THA

Variable	Value
Supine CT anteversion (°)*	28 (4–43)
EOS® standing anteversion (°)*	34 (14–60)
p value	< 0.0001
Difference in anteversion (°)*	7 (–2 to 18)
Number patients with > 5° difference	12/23 (52%)

* Values are expressed as mean, with range in parentheses.

Table 2. Acetabular inclination in SRA patients

Variable	Value	
	Double limb	Single limb
Conventional (supine) radiograph cup inclination (°)*	43 (33–56)	
EOS® standing radiograph cup inclination (°)*	45 (30–57)	43 (31–57)
p value	0.017	0.489
Number patients with > 3° difference	13/23 (56%)	6/23 (26%)

* Values are expressed as mean, with range in parentheses.

in sagittal plane anteversion when the acetabular component position was assessed with the patient in a standing position compared with supine measurements. Twelve of the 23 (52%) patients who underwent THA had an increase greater than a 5° in anteversion when measured in a standing position compared with supine measurements.

For the 23 patients who underwent SRA, the mean double- and single-limb coronal plane acetabular component inclination was 45° (range, 30°–57°) and 43° (range, 31°–57°), respectively, compared with 43° (range, 33°–56°) using conventional supine imaging (Table 2). In 13 of 23 (56%) patients, there was a greater than 3° change in acetabular component inclination between supine and standing imaging during double-limb stance, and in six of 23 (26%) patients, there was a greater than 3° change in inclination during single-limb stance.

Discussion

The position in which the acetabular component was implanted during THA and SRA surgery have had important implications for function, longevity, and potential complications after these procedures [2, 3, 10, 19, 24]. In spite of the advances in technology, wear and dislocation have continued to be major issues after THA, and component position has been reported to affect wear and stability [11, 14, 24]. In spite of these advances in technology and bearing surfaces, the traditional techniques for imaging the

pelvis have remained static and supine. We attempted to demonstrate, in a small cohort of patients who underwent THA or SRA, the differences in some aspects of component positioning when supine and standing imaging techniques were compared using a novel radiographic instrument.

There were several limitations in this study. First, the total number of patients in each cohort was relatively small. This study was intended to generate pilot data regarding the feasibility of using this imaging acquisition system to measure the standing acetabular component position after THA, and the numbers were limited by the willingness and availability of the patients we recruited to participate in the ongoing study. All of these patients were previously enrolled in another longitudinal cohort study, and many were not interested in being subjected to additional imaging tests. We were restricted to this pool of patients; however, they all had prior CT scans and standardized postoperative conventional radiographic images. Since these cohorts of patients were available, we did not think it wise to unnecessarily subject a new set of patients to CT scan radiation doses. Second, our analysis did not include a preoperative standing assessment of pelvic and acetabular parameters, such as pelvic tilt, sacral slope, and pelvic incidence. Accounting for these variables in a larger number of patients may have allowed for a more meaningful interpretation and assessment of functional acetabular component positioning. Third, a more comprehensive evaluation of the pelvic parameters previously mentioned in a larger number of patients may have allowed for a correlation between the magnitude of change in acetabular component position and individual morphologic characteristics of a patient's spinopelvic alignment. This study was underpowered to detect such trends and relationships. One of the more dramatic changes in pelvic position occurred when a person sat, which had implications for joint stability after THA, but we did not measure acetabular component position with patients in a seated position. Recent reports indicated such measurements have been possible with this imaging system [15, 16], and future studies relating the functional effects of sitting on component position and how this may relate to joint stability and the wear characteristics of the bearing surface represent topics of future research endeavors.

Our observations suggested a substantial degree of change occurred in functional acetabular component position when the patient moved from the supine to a standing position, and the novel biplanar EOS® imaging system provided a reliable method to measure acetabular component positioning in multiple planes simultaneously. Changes in the sagittal position of the acetabular component (functional acetabular anteversion) were affected to a greater degree than was the coronal plane alignment when the patient assumed an erect posture. In our study, 52% of the patients who underwent THA had a difference of greater than 5° in their supine versus

standing sagittal plane anteversion, and our findings were consistent with multiple reports in the literature documenting the effect that postural changes could have on acetabular component position [1, 4, 7, 13, 15–17, 25]. For every 1° of change in pelvic tilt in the sagittal plane, a corresponding 0.7° change in acetabular component anteversion occurred [18], and a nomogram was devised to help the surgeon account for pelvic tilt in attempting to position acetabular component in the so-called safe zone of 40° ± 10° inclination and 15° ± 10° of anteversion in relation to the functional standing axis of the pelvis [18, 19]. For example, a patient with 15° posterior pelvic tilt needed to have his/her acetabular component inserted with only 3° of anteversion in relation to the anterior pelvic plain to account for the effect that the pelvic tilt had on the functional position of the acetabular component when he/she assumed an erect posture [1]. The fact that close to ½ of our patients who underwent THA did not have greater than 5° change in the sagittal plane anteversion likely reflected differences in the spinal pelvic alignment that we did not measure.

The presence of safe acetabular component position determined by supine imaging did not exclude a patient from experiencing a complication after THA. The fact that substantial changes in the functional position of the acetabular component occurred when a patient assumed a nonsupine posture may have helped explain why some patients with apparently acceptable acetabular component position measured on supine radiographs or with CT imaging still experienced complications, such as instability, wear, and squeaking. The technologic advances present in the EOS® imaging system allowed for a relatively low-radiation orthogonal assessment of acetabular component position after THA in positions of functional importance. Additional features of the system allow for 3D modeling, correction for rotation, and more comprehensive assessment of the balance between the spine and the pelvic structures that all contributed to the functional orientation of the acetabular component after THA. These technologic advances will likely play a key role in future studies focusing on identifying new targets for acetabular component position based on individualized functional assessment of a patient's pelvic anatomy.

In summary, we demonstrated standing changed the acetabular inclination and version in a substantial percentage of patients who underwent THA.

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