■ HIP

Functional acetabular component position with supine total hip replacement

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Orientation of the acetabular component influences wear, range of movement and the incidence of dislocation after total hip replacement (THR). During surgery, such orientation is often referenced to the anterior pelvic plane (APP), but APP inclination relative to the coronal plane (pelvic tilt) varies substantially between individuals. In contrast, the change in pelvic tilt from supine to standing (dPT) is small for nearly all individuals. Therefore, in THR performed with the patient supine and the patient's coronal plane parallel to the operating table, we propose that freehand placement of the acetabular component placement is reliable and reflects standing (functional) implant position. We examined this hypothesis in 56 hips in 56 patients (19 men) with a mean age of 61 years (29 to 80) using three-dimensional CT pelvic reconstructions and standing lateral pelvic radiographs. We found a low variability of acetabular component placement, with 46 implants (82%) placed within a combined range of 30° to 50° inclination and 5° to 25° anteversion. Changing from the supine to the standing position (analysed in 47 patients) was associated with an anteversion change < 10° in 45 patients (96%). dPT was < 10° in 41 patients (87%). In conclusion, supine THR appears to provide reliable freehand acetabular component placement. In most patients a small reclination of the pelvis going from supine to standing causes a small increase in anteversion of the acetabular component.

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Orientation of the acetabular component influences wear,[1] range of movement,[2] and the likelihood of dislocation after total hip replacement (THR).[3] In particular, a high acetabular component inclination angle may increase wear and loosening.[4] In simulator studies, ceramic-on-ceramic (CoC) bearings appear less sensitive to high inclination of the acetabular component[5] than to laxity, leading to lateral displacement with rim loading.[6] Although the clinical consequences appear small, in retrieval studies high anteversion angles in CoC implants have been associated with anterior rim loading, and low anteversion to posterior rim loading.[7] In addition, in CoC bearings the orientation of the acetabular component has a relationship with the incidence of squeaking[8] and psoas tendinitis.[9]

The anterior pelvic plane (APP), defined as the triangular plane formed by the two anterosuperior iliac spines (SIAS) and the symphysis pubis,[10] has become the standard reference plane for positioning of the acetabular component.[11] Although the APP can be reliably reconstructed from CT scans, inaccurate identification of the APP during navigation itself can create substantial errors in acetabular component positioning.[12]

Most studies measuring acetabular component position from CT scans do not report the position of the APP relative to the coronal plane. This is important, because pelvic tilt is relatively constant for one individual but, as reported by several authors, varies up to 30°[13-16] or even 60°[17,18] between individuals. Thus, the APP is not very useful to reference acetabular component position, when it is not used in conjunction with pelvic tilt.

In contrast, the small mean differences of 4° to 7° between lying and standing pelvic tilt reported by the same authors indicates that acetabular component implantation relative to the coronal plane in the supine position is a satisfactory reference for standing component position in most patients. Ultimately, as the highest bearing loads occur in walking, the standing acetabular component position is likely to determine wear.[19] We term this implant position relative to the coronal plane as the functional acetabular component position.

THR in the supine position creates a stable pelvic position and places the coronal plane of the patient parallel to the operating table. Therefore, we put forward the hypothesis that supine THR will provide reliable functional

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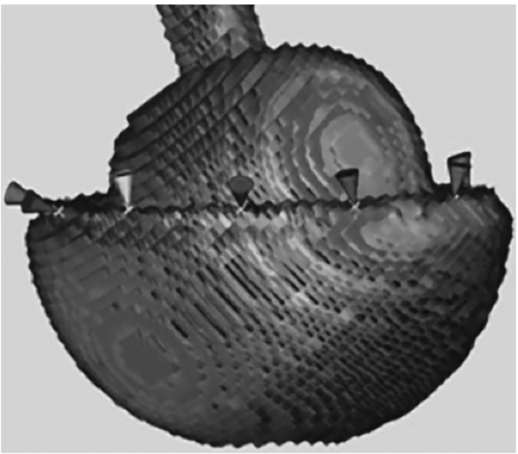

Fig. 1a

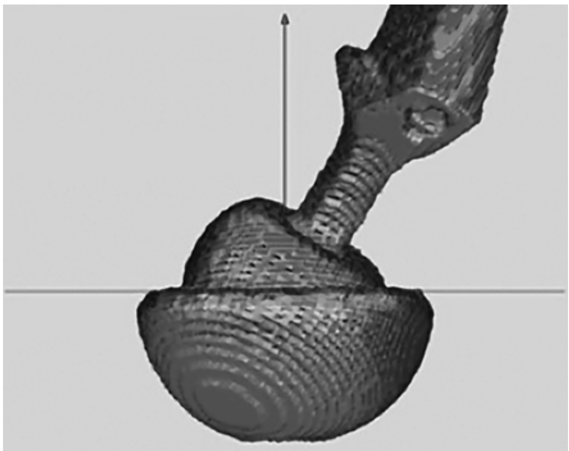

Fig. 1b

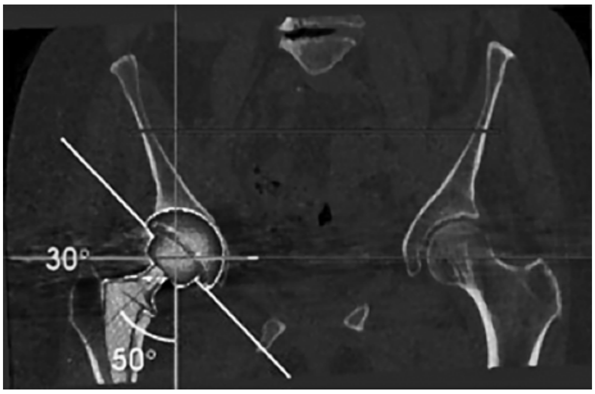

Fig. 1c

Images showing a) the points placed manually on the rim of the acetabular component, reflecting the face of the implant (b). Subsequently, anatomical inclination and anteversion with reference to the anterior pelvic plane are given (c) (and converted to radiological values).

placement of the acetabular component that reflects the standing position of the cup.

Patients and Methods

A total of 56 patients (19 men) with a mean age of 61 years (SD 9.9; 29 to 80) scheduled for unilateral primary THR were enrolled in this prospective study. All patients underwent CT scanning within a few days after surgery, and in 47 of them pre-operative standing lateral pelvic radiographs were obtained. The local medical ethical board approved the study protocol, and informed consent was obtained from each patient.

Two specialist hip surgeons (TH, HEH) performed all operations using the supine direct anterior approach (DAA) with standard instruments and without a traction table. Cementless implants were used in all cases (Corail stem, Pinnacle Duofix acetabular component; DePuy Inc., Warsaw, Indiana). In 54 patients a 36 mm diameter CoC bearing couple (Biolox; Ceramtec, Plöchingen, Germany) was used. Two patients required an acetabular shell < 52 mm and received a 28 mm diameter bearing couple.

Surgical procedure. The patient was placed supine on a regular operating table. Each leg was draped separately. An incision was made over the midline of the muscle belly of tensor fascia lata, with the tip of the greater trochanter as the midpoint of the incision. The intermuscular interval between the tensor fascia lata and sartorius muscles was used to enter the hip joint. The lateral femoral circumflex vessels were dissected and cauterised. After osteotomy of the femoral neck, the head could be removed. Subsequently the acetabulum was reamed and the acetabular component inserted freehand, without the use of navigation or other alignment tools, using a straight acetabular component inserter handle. The position of this straight implant inserter handle relative to the operating table and the patient's body axis reflects the acetabular component anteversion and inclination, respectively. In order to prepare the femur, a blunt-tipped hook, to deliver the femur anteriorly and laterally from the wound, was combined with double-bent Homan retractors and double-offset broach handles.[20] After sizing the femoral cavity, a trial reduction was carried out before inserting the definitive stem. The wound was closed in layers.

Measurements. These measurements were performed by one author (WE). The 56 CT scans were reconstructed to 3D images using dedicated software (Department of Orthopaedics, Imperial College, London, United Kingdom) to assess acetabular component position with reference to the APP. A total of ten points were manually placed on the rim of the acetabular component (Fig. 1a). The mean value of these points formed a plane reflecting the face of the implant

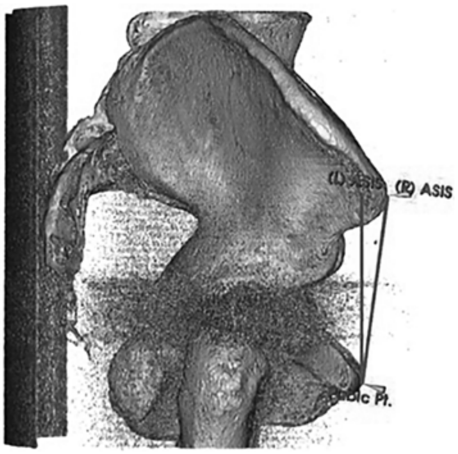

Fig. 2a

Fig. 2b

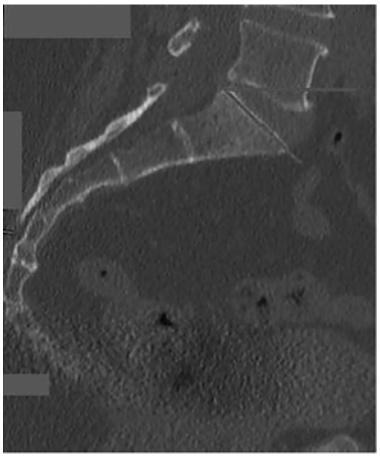

Fig. 2c

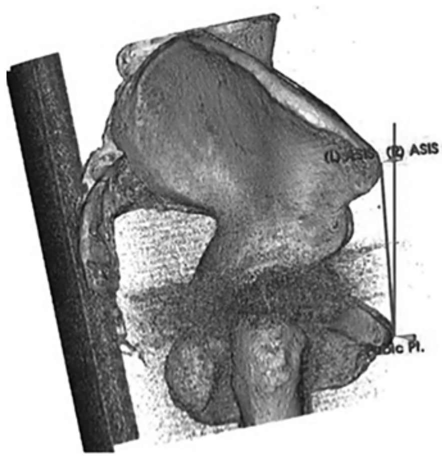

Fig. 2d

Three-dimensional (3D) CT reconstructions showing the angle between the anterior pelvic plane (APP) and the vertical (coronal) plane used to assess functional acetabular component position (a). Sacral slope was determined in a pre-operative standing lateral pelvic radiograph (b) and in the (supine) pelvic CT (c). Subsequently, the 3D pelvic CT reconstruction was tilted into the standing sacral slope (d) to calculate standing functional acetabular component position.

(Fig 1b). The angles between this plane and the transverse and sagittal plane perpendicular to the APP were calculated, representing the inclination and anteversion of the anatomical component (Fig. 1c). In addition, both were converted to radiological component inclination and anteversion.[21]

Using another 3D-CT program (Department of Orthopaedics, Imperial College, London) we determined the standing and supine functional acetabular component position. First, the APP was determined semi-automatically. Second, supine pelvic tilt was determined as the angle between the APP and the coronal plane with pelvic position as it was scanned (Fig. 2a). Anterior sagittal pelvic rotation (tilt) was represented as a positive angle, and posterior tilt, or reclination, as a negative angle. Third, we manually rotated the pelvis until the sacral slope, defined as the angle between a horizontal line and the S1 endplate,[22] was similar to the sacral slope as measured on pre-operative standing lateral pelvic radiographs (Figs 2b and 2c). Thus, the standing pelvic position was displayed and APP tilt was calculated (Fig. 2d). Finally, using pelvic tilt, the acetabular component inclination and anteversion relative to APP were converted to functional inclination and anteversion,[11,13] that is, relative to the floor/horizontal plane when supine and relative to the vertical plane when standing.

Sacral slope as measured in sagittal CT reconstructions with the pelvis in the scanned position was compared to sacral slope as measured in standing lateral pelvic radiographs to determine the difference between supine and standing pelvic tilt. In order to examine whether THR influences pelvic tilt, SS measurements were repeated in standing lateral pelvic radiographs made six months after surgery.

Statistical analysis. Interobserver reliability was determined using an intra-class correlation coefficient (ICC). Mean values were compared using a dependent paired samples *t*-test. All angular measurements were rounded to whole degrees. A p-value < 0.05 was considered significant.

Table I. Orientation of the acetabular component

Mean orientation (°) (SD; range)	Referenced supine (n = 56)	Referenced standing (n = 47)
Inclination	37 (6.5; 21 to 53)	37 (6.4; 20 to 51)
Anteversion	19 (4.6; 10 to 29)	21 (5.8; 4 to 31)
Pelvic tilt	4 (6.3; -9 to 18)	1 (7.8; -16 to 20)
Sacral slope		
Pre-operative	42 (8.5; 18 to 60)	40 (9.0; 12 to 60)
Post-operative	-	40 (8.7; 10 to 57) [n = 34]

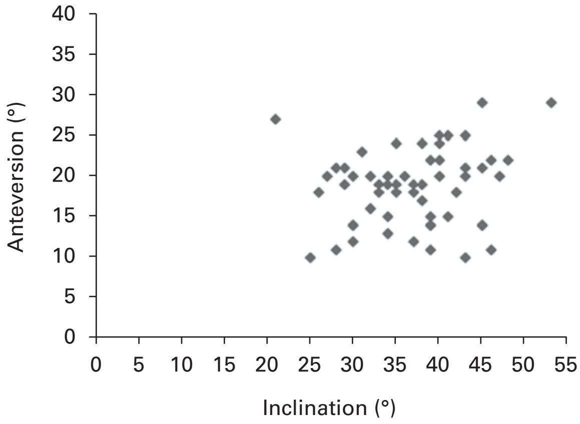

Fig. 3a

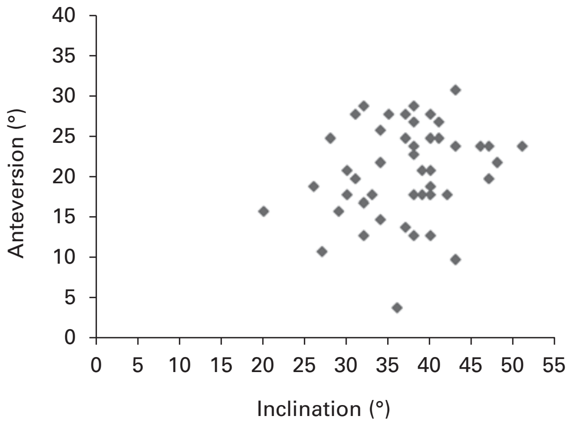

Fig. 3b

Scatter plots showing the functional orientation of each acetabular component as measured a) supine (n = 56) and b) standing (n = 47).

Statistical testing was performed using IMB SPSS v17.0 (SPSS Inc., Chicago, Illinois).

Reliability study. In order to study the interobserver reliability, a second observer (SJH) repeated 20 measurements of acetabular component position with reference to APP, and a third observer (HEH) repeated measurements of 20 sacral slope angles on standing lateral pelvic radiographs. Good interobserver reliability was found for both acetabular component inclination and anteversion, with an ICC of 0.967 and 0.983 (p < 0.001), respectively. For sacral slope the ICC was 0.941 (p < 0.001).

Results

Freehand functional acetabular component placement. The mean acetabular component inclination was 37° (SD 6.5; 21° to 53°; 95% confidence interval (CI) 35° to 39°), and mean anteversion was 19° (SD 4.6; 10° to 29°; 95% CI 18° to 20°) (Table I). The CI and SD were relatively small, indicating low variability of component placement.

There was a tendency towards relatively low acetabular component inclination angles, with eight (14%) placed with inclination < 30°. None of the implants had excessive (> 60°) inclination, or remarkably low or high anteversion angles (Fig. 3a).

When referenced to Lewinnek's safe zone[3] of 30° to 50° inclination and 5° to 25° anteversion, we found an accuracy of 95% (53 of 56) for implant anteversion and 84% (47 of 56) for inclination. The combined accuracy was 82% (46 of 56).

Table II. Distribution of the change in pelvic tilt from supine to standing (dPT), with the corresponding mean difference (Δ) of functional acetabular component anteversion between supine and standing

dPT (°)	n	Δ mean cup anteversion (SD)
< -10	3	10 (1.5)
-6 to -10	13	7 (1.7)
-5 to 5	24	1 (2.0)
6 to 10	4	-6 (1.4)
> 10	3	-10 (1.0)

Standing acetabular component position. In the 47 patients with both views available, there was a very small mean difference between supine and standing for acetabular component anteversion (mean 2° (SD 5.4°; -11° to 12°); p = 0.02), and no significant difference for inclination (mean 1° (SD 1.8°; -6° to 5°); p = 0.054). Individual differences in acetabular component anteversion between supine and standing were < 10° in 96% (n = 45), < 5° in 64% (n = 30), between 6° to 10° in 32% (n = 15) and > 10° in 4% (n = 2).

Pelvic tilt from supine to standing. In 24 of 47 patients (51%) there was no or a small dPT (≤ 5°), 16 (34%) had posterior tilt, seven (15%) had anterior tilt > 5° (Table II). In 41 patients (87%) a dPT < 10° was present. Posterior tilt increased (standing) acetabular component anteversion (Table II) (Fig. 3b) and also decreased accuracy from 82% (46 of 56) to 64% (30 of 47) according to Lewinnek et al.[3]

Influence of THR on pelvic tilt. In 34 of 47 patients who consented to a second standing lateral pelvic radiograph six months after THR, 29 (85%) had no or only a small change (≤ 5°) in sacral slope after THR, three (9%) had an increase (anterior tilt) of 7° and two (6%) had a decrease (posterior tilt) of 11°.

Discussion

According to the safe zone of Lewinnek et al,[3] acetabular component placement decreased from 82% (46 of 56) to 64% (30 of 47) from supine to standing, owing to an increase in outliers with implant anteversion > 25°. However, we feel that assessing implant position using a box-shaped 'safe zone' only is outdated. We agree with Murphy et al[23] that optimal positioning may differ for wear, range of movement and likelihood of dislocation.[23]

For wear, it may be that the zone for optimal placement is an ellipsoid rather than a box. Esposito et al[24] found a correlation between acetabular component anteversion and wear in CoC bearings, but concluded that high implant anteversion may not produce anterosuperior edge loading if combined with a low inclination angle. Similarly, low acetabular component anteversion may not produce a high wear rate when combined with a high inclination angle.[24] This reciprocal interaction between inclination and anteversion negates the use of a square box or 'safe zone' to assess the accuracy of acetabular component placement regarding wear. An ellipsoid shape would better reflect this inclination–anteversion interaction.

In 1978, the Lewinnek 'safe zone' was intended to address stability (although based on only nine dislocations in 300 patients, three of which were inside the safe zone).[3] For dislocation, its rate in contemporary arthroplasty is now markedly reduced when using 32 mm or 36 mm heads and a muscle-sparing approach, to a level that makes dislocation no longer the main factor guiding decision making.[25] Further, the applicability of the safe zone in CT-based studies is questionable because Lewinnek et al[3] used anteroposterior radiographs to measure the acetabular component anteversion angles.[26,27] With CoC bearings, measuring anteversion on anteroposterior radiographs is difficult because an ellipse cannot be reliably determined because of over-projection of the radio-opaque component. Finally, Lewinnek et al[3] used a jig with bubble level to position patients for supine anteroposterior pelvic radiographs, so that the anterior pelvic plane could be made parallel to the coronal plane. Thus, as Wan et al[11] summarised, the safe zone is not truly applicable when the coronal plane is not parallel to the APP. Particularly for range of movement, we feel further studies are needed to identify a CT-based 'functional safe zone' related to the coronal plane.

Freehand functional acetabular component placement in the DAA without a traction table has, to our knowledge, not previously been evaluated. Matta, Shahrdar and Ferguson[28] inserted the acetabular component under fluoroscopic guidance and on a traction table in 437 patients. Their results were similar to ours, with 96% of all implants having an inclination angle between 30° and 50° and 93% with anteversion between 10° and 25°. However, measurements were done using radiographs, making the anteversion measurements not truly comparable.[26,27]

Most studies on freehand acetabular component placement in the lateral decubitus position also use radiographic measurements. Minoda, Kadowaki and Kim[29] reported one of the highest levels of accuracy for lateral decubitus positioning, with 72% of implants within Lewinnek's safe zone.[3] Callanan et al[30] found that 59% of the acetabular components were placed within 5° to 25° anteversion and 30° to 45° inclination. Although based on a smaller sample size, we found a higher accuracy than these two studies.

We could not compare our data meaningfully with other CT-based studies because these studies reference the acetabular component position relative to the APP without assessing pelvic tilt.

Inaccuracy of freehand placement in the lateral decubitus position may be explained by axial rolling of the patient influencing implant version, but also by adduction of the hemipelvis influencing inclination.[31,32] Further, variability of patient positioning in the lateral decubitus restricts correct identification of the coronal plane. Supine patient positioning for THR with a stable pelvic position and the coronal plane positioned parallel to the operating table and the floor reduces these problems.

In accordance with several other studies,[14,17,18] dPT was < 10° for the majority of patients (41 of 47). Similarly, change in the standing pelvic tilt after THR was small for 32 of 34 patients (94%). Murphy et al[23] found that all patients had a post-operative pelvic tilt change < 10°. In other studies this applied to approximately 85% of patients.[16,17,33] Thus, supine implant positioning may accurately represent the post-operative standing acetabular component position for most patients.

Lembeck et al[13] concluded that every degree of pelvic tilt influences implant anteversion by 0.7°. Thus, a 10° reduction in pelvic tilt (dPT 10°) can increase acetabular component anteversion by 7° when going from supine to standing. Further improvement of acetabular component placement may be obtained by pre-operatively identifying the patients with a large dPT.

Uncertainties remain, however, on the long-term effect of THR on dPT, as changes have been reported to occur up to four years after THR.[33] In addition, severe pelvic tilt seems to be associated with larger dPT post-operatively.[33] Also, it appears that a pronounced lordosis reduces towards the mean after THR[16] and therefore, it is suggested that the implant should be placed with less anteversion in patients with a high degree of pelvic tilt.[16,33]

We acknowledge several limitations of our study. First, in nine patients a pre-operative standing lateral pelvic radiograph was not obtained owing to logistical difficulties at the hospital ward, particularly at the inception of the study. Secondly, only 34 of 47 patients consented to a standing lateral pelvic radiograph post-operatively. Moreover, they were made six months after surgery, whereas change in standing pelvic tilt seems to reach a plateau after one year.[33] However, as Ishida et al[16] noted, the largest dPT occurs within three months after surgery.

Third, we only took acetabular component position into account, ignoring stem version or head–neck ratio as influential factors for stability, wear and range of movement. As several studies have reported, acetabular component anteversion should be correlated with femoral component version.[2,34] In the DAA when placing a cementless stem, version follows the anatomy of the metaphysis, but some studies suggest this results in an increase in femoral anteversion.[34,35] Future investigations should therefore also incorporate CT measurement of femoral version.

Supine DAA appears to provide reliable freehand acetabular component placement compared with studies of the lateral decubitus position.[29,30] However, especially regarding wear, there is room for improvement in component positioning. We opt for a simple mechanical alignment tool to assess the position of the straight-shafted acetabular component impactor with reference to the patient and operating table to further reduce the range of implant anteversion. Aiming for a lower acetabular component anteversion may be considered for improving standing acetabular anteversion in patients with increased pelvic tilt. Finally, individual attention based on pelvic tilt seen on lateral radiographs may further improve implant position when standing.

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