Pelvic position and movement during hip replacement

The orientation of the acetabular component is influenced not only by the orientation at which the surgeon implants the component, but also the orientation of the pelvis at the time of implantation. Hence, the orientation of the pelvis at set-up and its movement during the operation, are important. During 67 hip replacements, using a validated photogrammetric technique, we measured how three surgeons orientated the patient’s pelvis, how much the pelvis moved during surgery, and what effect these had on the final orientation of the acetabular component. Pelvic orientation at set-up, varied widely (mean ±2 standard deviation (SD)): tilt 8° (2SD ±32), obliquity –4° (2SD ±12), rotation –8° (2SD ±14). Significant differences in pelvic positioning were detected between surgeons (p < 0.001).

The mean angular movement of the pelvis between set-up and component implantation was 9° (SD 6). Factors influencing pelvic movement included surgeon, approach (posterior > lateral), procedure (hip resurfacing > total hip replacement) and type of support (p < 0.001).

Although, on average, surgeons achieved their desired acetabular component orientation, there was considerable variability (2SD ±16) in component orientation. We conclude that inconsistency in positioning the patient at set-up and movement of the pelvis during the operation account for much of the variation in acetabular component orientation. Improved methods of positioning and holding the pelvis are required.

Cite this article: Bone Joint J 2014; 96-B:876–83.

Wide variations in the orientation of the acetabular component in total hip replacement (THR) are invariably reported, with measurements of inclination and anteversion having standard deviations (SD) of up to 10° and ranges of up to 60°, even in high-volume centres.1-3 The quantification of variability is difficult, as range includes extreme outliers and standard deviation includes only about 68% of cases. To address this, we have defined variability as ±2 SD, which includes about 95% of cases. With this definition, the reported variability in acetabular component orientation is about ±20°. This variability is the result of many factors such as the position of the pelvis at the time of implantation, the orientation the surgeon wants to achieve and the way that orientation is assessed post-operatively.

The position of the pelvis at implantation depends on the position the pelvis is placed at the beginning of the operation and the amount of intra-operative movement. In general before commencing surgery, surgeons aim to position the pelvis in a ‘neutral’ orientation relative to the operating table, so that the axes of the pelvis are parallel to those of the operating table. The patient supports are then supposed to maintain the pelvis in this position during the procedure. At the time of implantation, the surgeon assumes the pelvis is still in a ‘neutral’ position. During non-navigated procedures, the precise orientation of the pelvis at implantation is not known and any deviation from ‘neutral’ will affect the orientation of the component that is assessed post-operatively. If the pelvis is tilted (rotation around transverse axis) or rotated (rotation around longitudinal axis) this will primarily influence the anteversion of the component, whereas if the pelvis is oblique (rotation around antero-posterior axis), this will mainly influence its inclination.4 Pelvic orientation is known to vary widely both in different patients and situations. For example, in the physiologically supine position, the pre-operative pelvic tilt has been reported to have a range from –24° to 10° among arthritic patients.5

Our aims were to determine the variation in pelvic orientation as the surgeon positions the patient on the operating table, and to ascertain the amount of pelvic movement that takes place between set-up and introduction of the acetabular component.
Patients and Methods
Between October 2010 and November 2011, we prospectively recruited 67 patients to this study which had received ethical approval from two centres (Nuffield Orthopaedic Centre, Oxford, United Kingdom and ANCA Medical Centre, Ghent, Belgium). Inclusion criteria were primary surgery for osteoarthritis (OA), absence of fixed deformities of the hip and an American Society of Anaesthesiologist (ASA) grade I or II.6 Patient demographics and anthropometric parameters (weight, height and body mass index (BMI)) are detailed in Table I. The majority of patients (n = 52, 78%) underwent THR, whereas the remaining 15 (22%) underwent hip resurfacing (HR). All patients were operated on in the lateral decubitus position. The procedures were performed by three surgeons (KADS, PMS and RdA). Surgeon A was a senior clinical fellow who had performed 300 THRs via the posterior approach and his target orientation of the acetabular component (inclination/anteversion) was 40°/20°. Surgeon B had performed over 7000 hip replacements, including over 3500 HRs via the posterior approach, and his target inclination/anteversion was 45°/20°. Surgeon C had performed over 13 000 hip replacements via the lateral approach and his target inclination/anteversion was 40°/15°.

The surgeons used the same support posteriorly over the sacrum (Fig. 1) but different supports anteriorly. Surgeon B routinely used a single support over the pubic symphysis (pubis only), surgeons A and C used a single support over the operated anterior superior iliac spine (ASIS) (ASISx1). For the last 12 operations (six each) enrolled in the study (ASISx2) surgeons A and C were invited to place an additional support over the contralateral ASIS. Details of surgical practice, including prostheses used and size of acetabular component, are included in Table I.

Intra-operative measurements. Stereophotogrammetry (SPG) allows the spatial measurement of three-dimensional (3D) objects from a pair of images.7 Common points are identified on each image, and if the location of each camera relative to the image plane is known, the 3D co-ordinates and thus the location, can be determined. The 3D locations of specific pelvic landmarks and of a guide wire drilled into the pelvis, were captured. The position of the landmarks were used to determine the pelvic orientation at set-up, and the movement of the wire during surgery was used to assess subsequent pelvic movement.

Two Logitech Webcam Pro 9000 HD cameras (Logitech, Romanel-sur-Morges, Switzerland) were mounted on the theatre’s laminar air-flow hoods orientated at approximately 90° to each other and arranged so that the operating field was fully captured. All three surgeons positioned patients on the operating table in the manner routine to their practice, aiming to orientate the pelvis neutrally relative to the table using the frontal plane defined by the two ASISs and the pubis. The table was positioned in the middle of the operating theatre space, as defined by the laminar-flow hood. A calibration object, consisting of 12 spherical markers, was placed over the patient and aligned with the operating table. Stereoscopic images were captured using the cameras; this initial stereo-pair of images was used to calibrate the measurement volume. All subsequent measurements were made in a coordinate frame aligned to the operating table. A custom software application, Fotop, written in Matlab (R2011, The MathWorks, Natick, Massachusetts) was developed to perform the measurements.

Surgeons were then asked to locate, using a wand, the specific anatomical landmarks that they had used to align the pelvis and a stereo-pair of images were captured. The
landmarks captured were the two ASISs, the pubic symphysis (PS) and the lumbosacral junction (LSJ) (Fig. 2). The wand was manufactured with such specifications (pointed end and length) as to allow its placement between patient’s supports/bony landmarks and capture, even when pointing at the non-operated side. The orientation of the pelvis was determined from the positions of the landmarks. In three cases, surgeons were asked to identify the pelvic landmarks twice, with an interval of five minutes between measurements. Good repeatability was found with the difference in measurement of tilt, obliquity and rotation being 1° (SD 3°), 1° (SD 2°) and 1° (SD 3°) respectively.

Patients were prepared and draped. Prior to skin incision, a wire was inserted into the iliac wing of the operated hemipelvis and a pair of images was captured, from which the location of the wire at the beginning of the operation (t0) could be determined. Surgery was carried out and a pair of images was captured following implantation of the acetabular component, with the introducer still attached and the retractors in place, in order to measure the location of the wire at the time of implantation (t1).

Radiographic orientation measurements. Radiographic measurements of the orientation of the acetabular component were made from standardised post-operative, supine antero-posterior (AP) pelvic and lateral hip radiographs. The Ein-Bild-Roentgen-Analysis (EBRA) software, a validated method of estimating radiographic orientation, was used to calculate radiographic inclination (RI) and anteversion (RA) of the acetabular component from the AP radiographs. Measurements were performed independently by two observers (GG, HGP) blinded to other parameters, with excellent intra- and inter-observer correlations (inter-class correlation coefficients > 0.95, p < 0.001, 95% confidence interval (CI); 95.6 to 98.1). The mean differences in the measurements of inclination and anteversion were 0.1° (SD 1) and 0.3° (SD 2) respectively. Analysis of a second set of radiographs obtained at follow-up for 20 patients revealed an intra-subject difference of 1° (SD 1) (-1 to 3°)/2° (SD 2) (-5 to 7) for inclination and anteversion of the acetabular component, respectively.

Data analysis. From the position of the pelvic landmarks measured after the patient was positioned, we calculated the orientation of the pelvis relative to the operating theatre table. From this we determined the variability (defined as 2SD) in pelvic orientation at set-up in all three planes (tilt/obliquity/rotation).

We calculated the angular pelvic movement that takes place during the operation between set-up and implantation of the orientation by capturing the wire’s orientation at
set-up (t₀, prior to skin incision), and at implant impaction (t₁) (Fig. 3). In addition, we investigated the effect of type of support (pubis only versus ASISx1 versus ASISx2), procedure (HR versus THR), approach (posterior versus lateral) and surgeon on the amount of pelvic movement.

In order to determine how accurately surgeons achieved their desired target, we calculated Δinclination and Δanteversion for each patient as defined below:

\[\text{Δinclination} = \text{Surgeon-specific inclination target} - \text{RI achieved}\]

\[\text{Δanteversion} = \text{Surgeon-specific anteversion target} - \text{RA achieved}\]

In addition, we determined whether surgeons had achieved orientation within their target zone (personal orientation target ± 10°).

**Statistical analysis.** Variability was defined as two standard deviations (SD). Non-parametric statistical tests (Mann-Whitney U, Kruskal-Wallis, Spearman’s rho) were used. The chi-squared test was used for cross-tabulated data. Correlation was characterised as poor (0.00 to 0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), good (0.61 to 0.80), or excellent (0.81 to 1.00). Statistical significance was defined as p < 0.05. Statistical analyses were performed with IBM SPSS Statistics version 19, (IBM, Chicago, Illinois).

**Results**

A wide scatter of pelvic orientations at set-up was detected for the whole cohort, as detailed in Table II and Figure 4. The variability was much greater for pelvic tilt (2SD ±32°) than pelvic rotation (2SD ±14°) and obliquity (2SD ±12°). There were significant differences between surgeons in the positioning of the pelvis at set-up for pelvic tilt and rotation (p < 0.001), but not for pelvic obliquity. For example the mean tilt for surgeon B was 5° (2SD ±18), whereas for surgeon C it was -21° (2SD ±30).

The mean amount of movement of the wire and thus of the pelvis that took place between set-up and implantation was 9° (2SD ±12°, (0° to 28°)). Wire movement was not influenced by anthropometric factors. The following surgical factors had a significant effect on wire movement: surgeon (p < 0.001, Kruskal–Wallis) (Fig. 5), pelvic supports (p = 0.004, Kruskal–Wallis), approach (p < 0.001, Mann–Whitney U test) and procedure type (p = 0.02, Mann–Whitney U test) (Fig. 5). Wire movement had a moderate correlation (rho = 0.45, p < 0.001) with pelvic tilt at set-up.
The mean RI inclination of the acetabular component was 43° (2SD ±12, (28° to 55°)), and the mean RA was 19° (2SD ±14, (4° to 35°)). The mean difference between where the surgeon aimed to place the acetabular component and where it ended up was 1° (2SD ±12, (–10° to 17°)) for Δinclination and 0° (2 SD ±14, (–15° to 12°)) for Δanteversion. None of the anthropometric or surgical factors influenced Δinclination. No anthropometric factor influenced Δanteversion. However, two surgical factors influenced Δanteversion: type of pelvic support (p = 0.03, Kruskal–Wallis) and procedure (p = 0.006, Mann–Whitney U test) (Tables II, III and IV). In 80% of cases, the orientation of the acetabular component ended up within the surgeon’s target zone.

To date, at a mean follow-up of 58 months (37 to 71), none of the patients have had any complications; none have returned nor are due to return to theatre for any reason.

**Discussion**

We have demonstrated a wide variation in both pelvic positioning at set-up (2SD between ±12° and ±32° in different directions) and pelvic movement (2SD ±12°) during hip replacement. This would lead to great variability in pelvic orientation at implantation, and therefore variability in final orientation of the acetabular component. Although the desired target zone orientation was achieved in 80% (n = 57) of cases, there was considerable variability in both inclination (2SD ±12°) and anteversion (2SD ±14°).

The wide variation in pelvic orientation is due to both patient and surgical factors. The greatest variability in pelvic orientation was in tilt (rotation around the transverse axis). Our measured pelvic tilt angles were higher than have been previously reported.5,11,12,13 This may be because tilt angles have typically been measured with the patient in physiological positions such as supine, standing or sitting. Surgeon B positioned the pelvis closest to neutral, with the least amount of pelvic tilt and had the least variability. This is probably because he was the only surgeon who assessed the position of the pubic symphysis as well as both ASISs, all of which have to be identified to determine pelvic tilt. He did this as he was the only surgeon to use a support over the pubis symphysis. We therefore recommend that during set-up, surgeons should routinely assess for pelvic tilt by palpating both ASISs and the symphysis pubis. The position of the posterior support in the cranio-caudal direction along the lumbosacral spine varies amongst surgeons, and influ-
ences pelvic tilt. By adjusting its position, surgeons should be able to minimise pelvic tilt.

The operated hemipelves tended to be externally rotated at set-up. This was most pronounced with the single ASIS support (–11°, 2SD ±12°) compared with the double ASIS (–7°, 2SD ±14°) or the pubis only (–5°, 2SD ±10°) supports (p = 0.02). This is not surprising, as a single support over the operated ASIS used in combination with a posterior support over the lumbosacral spine would tend to externally rotate the pelvis. It is therefore recommended that a single ASIS support is not used.

A considerable change in pelvic position intra-operatively was detected, similar to previous findings of Asayama et al,14 who reported that internal rotation is the primary movement that takes place during THR. Although patient factors did not influence pelvic movement, surgical factors did, in particular pelvic support, approach and type of procedure. Although these factors are interrelated and surgeon dependent, significant differences were identified even when these factors were uncoupled. The support with the least constraint anteriorly, i.e. the pubis-only support, demonstrated the greatest amount of pelvic movement amongst THRs. In contrast, the use of supports over both the ASISs anteriorly significantly reduced the amount of movement that takes place. We therefore recommend that surgeons consider having at least two supports anteriorly, thereby achieving three-point stabilisation and increasing pelvic constraint. Like Ezoe et al.,15 we identified significantly more intra-operative movement with the posterior approach (mean 9°) than with the lateral approach (mean 4°) in THR. During the posterior approach, the intact strong anterior capsule and iliofemoral ligament, coupled

![Box plots showing the scatter of pelvic orientations for pelvic tilt, obliquity and rotation for the whole cohort (a), and analysis of each orientation according to surgeon (b, c and d).](image-url)
with the strong retraction and the leg-twisting manoeuvre, probably apply an increased torque to the pelvis.

We also found that the type of procedure influenced the amount of intra-operative pelvic movement. Analysing the procedures of surgeon B only, (hence eliminating factors relating to surgeon, approach and supports), we found a significantly greater amount of intra-operative pelvic movement for HRs than for THRs (means, 16° versus 10°) (p = 0.02). This is not surprising, as in HRs the intact femoral head and neck obscure the acetabulum, and hence greater retraction is needed for an adequate view.

The variability in orientation of the acetabular component (±12° to ±14°) was similar to the variability in pelvic rotation and obliquity at set-up (±12° to ±13°), but was much less than the variability in tilt (±32°). This consistency in terms of tilt is an encouraging finding, demonstrating that surgeons are able to account in part for pelvic tilt during the operation. It is not clear how they do this. Surgeons tend to set the pelvis up with different amounts of tilt, presumably because they position their supports differently. By reviewing their post-operative radiographs, they probably learn how to implant the components so as to optimise the orientation for their setup. They may also use intra-operative landmarks such as the transverse acetabular ligament (TAL) to aid component positioning.

This study has certain limitations. First, the pelvic orientation was determined by surgeons identifying landmarks, which may not be accurate. However the repeatability study suggests that the errors introduced by this amounted to about ±5°, which is much less than the variability in pelvic position. Second, although the software (Fotop) was able to calculate the angular movement of the pelvis, it was not able to determine the 3D direction of movement based on measurements from a single wire.
In conclusion, this study demonstrated wide variations in pelvic orientation, particularly tilt, at set-up for any given surgeon and between surgeons. Also substantial amounts of pelvic movement occurred during surgery. These findings explain, at least in part, the variation seen in post-operative orientations of acetabular components. In order to minimise this variability, we recommend that surgeons carefully position the pelvis at set-up, taking particular note of tilt assessed by the relative position of the symphysis pubis and ASISs. We also recommend the use of improved supports and increased care with retraction and leg twisting during the posterior approach and hip resurfacing, in order to minimise pelvic movement during surgery.

### Supplementary material

A detailed explanation of planes defined, calculations made, validation of technique, and a mathematical analysis quantifying possible inaccuracies due to wand misplacement, is available with the electronic version of the article at www.bjj.boneandjoint.org.uk.

### Table III. The effect of different surgical factors on pelvic movement intra-operatively and inclination/anteversion (I and A) (ASIS, anterior superior iliac spine; SD, standard deviation)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>THR (n = 16) mean/SD (range)</th>
<th>HR (n = 15) mean/SD (range)</th>
<th>p-value&lt;br&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire movement (°)</td>
<td>10/1 (5 to 17)</td>
<td>16/7 (7 to 28)</td>
<td>0.02</td>
</tr>
<tr>
<td>Radiographic inclination (°)</td>
<td>46/5 (36° to 55)</td>
<td>46/4 (40 to 52)</td>
<td>0.91</td>
</tr>
<tr>
<td>Radiographic anteversion (°)</td>
<td>22/6.0 (12 to 35)</td>
<td>16/4 (8 to 21)</td>
<td>0.002</td>
</tr>
<tr>
<td>ΔInclination (°)</td>
<td>–1/5 (–10 to 10)</td>
<td>–1/4 (–7 to 5)</td>
<td>0.9</td>
</tr>
<tr>
<td>ΔAnteverision (°)</td>
<td>–2/6 (–15 to 8)</td>
<td>4/4 (–1 to 12)</td>
<td>0.003</td>
</tr>
<tr>
<td>Within individual target zone n (%)</td>
<td>15 (94)</td>
<td>14 (93)</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### Table IV. Pelvic measurements and those of orientation of the component for total hip replacements (THRs) and hip resurfacings (HRs) performed by surgeon B (so, standard deviation)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>THR (n = 16) mean/SD (range)</th>
<th>HR (n = 15) mean/SD (range)</th>
<th>p-value&lt;br&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire movement (°)</td>
<td>4/3 (0 to 11)</td>
<td>1/6 (–7 to 17)</td>
<td>0.54</td>
</tr>
<tr>
<td>Radiographic inclination (°)</td>
<td>11/6 (2 to 28)</td>
<td>0/6 (–15 to 12)</td>
<td>0.59</td>
</tr>
<tr>
<td>Radiographic anteversion (°)</td>
<td>7/5 (0 to 22)</td>
<td>0/6 (–15 to 12)</td>
<td>0.59</td>
</tr>
<tr>
<td>ΔInclination (°)</td>
<td>1/6 (–8 to 17)</td>
<td>1/6 (–15 to 12)</td>
<td>0.03</td>
</tr>
<tr>
<td>ΔAnteverision (°)</td>
<td>13/6 (5 to 28)</td>
<td>3/6 (–15 to 10)</td>
<td>0.03</td>
</tr>
<tr>
<td>Within individual target zone n (%)</td>
<td>5/3.0 (0 to 12)</td>
<td>3/6 (–10 to 11)</td>
<td>0.03</td>
</tr>
</tbody>
</table>

### References


