Photographic measurement of the inclination of the acetabular component in total hip replacement using the posterior approach

J. C. Hill,
D. P. Gibson,
R. Pagoti,
D. E. Beverland

From the Musgrave Park Hospital, Belfast, United Kingdom

The angle of inclination of the acetabular component in total hip replacement is a recognised contributing factor in dislocation and early wear. During non-navigated surgery, insertion of the acetabular component has traditionally been performed at an angle of 45° relative to the sagittal plane as judged by the surgeon’s eye, the operative inclination. Typically, the method used to assess inclination is the measurement made on the post-operative anteroposterior radiograph, the radiological inclination.

The aim of this study was to measure the intra-operative angle of inclination of the acetabular component on 60 consecutive patients in the lateral decubitus position when using a posterior approach during total hip replacement. This was achieved by taking intra-operative photographs of the acetabular inserter, representing the acetabular axis, and a horizontal reference. The results were compared with the post-operative radiological inclination.

The mean post-operative radiological inclination was 13° greater than the photographed operative inclination, which was unexpectedly high. It appears that in the lateral decubitus position with a posterior approach, the uppermost hemipelvis adducts, thus reducing the apparent operative inclination. Surgeons using the posterior approach in lateral decubitus need to aim for a lower operative inclination than when operating with the patient supine in order to achieve an acceptable radiological inclination.

A common complication of total hip replacement (THR) is dislocation,1-3 and more recently, with the increasing use of metal-on-metal bearings, wear due to edge loading has become a major issue.4 The angle of inclination of the acetabular component is a recognised factor in both dislocation and wear.1-8 Therefore, achieving correct orientation of the component is of great importance.

The inclination and anteversion of the acetabular component was defined by Murray9 with respect to three different perspectives: radiological, operative and anatomical. The radiological inclination is the “angle between the longitudinal axis and the acetabular axis when projected on to the coronal plane”, the operative inclination is the “angle between the acetabular axis and the sagittal plane” and the anatomical inclination is the “angle between the acetabular axis and the sagittal plane”. This study looks only at the radiological and operative inclinations. Due to the effects of operative anteversion, which rotates the component in the mediolateral axis, radiological inclination is higher than operative inclination.9,10 Several papers have reported a safe zone for inclination and anteversion. However, different measurement techniques and definitions have been used, making them difficult to compare.10

Traditionally during surgery, insertion of the acetabular component has been at an angle of 45°. This assumes that the patient is correctly positioned and does not take account of any effect that their size and shape may have on their position. With the patient in the lateral decubitus position the sagittal plane and the floor should be parallel. The acetabular component inserter becomes the acetabular axis and hence the angle between the inserter (acetabular axis) and the floor (sagittal plane) is the operative inclination. It assumes that the transverse plane is vertical so that the pelvis is neither abducted nor adducted.

In a study completed by Hassan et al,11 when using an alignment guide and aiming for 30° to 50° of inclination and 5° to 25° of anteversion, the surgeons were only able to achieve this for 58% of the time when the orientation was reviewed radiologically, and compared with the safe zones reported by Lewinnek et al.3 This study did not mention whether they
had taken account of the difference between operative and radiological inclination and anteversion.

Previous studies have used CT, trigonometry and protractors to measure the orientation of the acetabular component. More recently techniques of image-free intra-operative computer-aided navigation have been developed that can measure orientation of the acetabular component, although these are not considered to be as accurate as CT-based navigation systems due to the difficulty in locating anatomical landmarks. Partially due to cost constraints, hip navigation has not been widely used and typically post-operative anteroposterior radiographs are used to assess inclination of the component. This is the radiological inclination.

There is now extensive literature that both highlights the importance of achieving appropriate inclination and anteversion and also how to measure it, but are surgeons achieving their goals? Surgeons using navigation can obviously check their results from the navigation software but others place the component using alignment guides or their own judgement. The surgeon involved in this present study (DEB) uses the transverse acetabular ligament to control version of the component, but inclination is estimated and based on the angle between the acetabular component inserter (acetabular axis) and the theatre floor (sagittal plane). This is the operative inclination. As an initial audit the radiographs of 50 consecutive THRs, taken on the day after operation, were measured to determine the radiological angle of inclination. The surgeon was aiming for 40° of operative inclination in theatre. The mean radiological inclination was 46.16° (34° to 57°). However, 11 of these inclinations were over 50° and two were over 55°. It was therefore decided to measure the intra-operative radiological and operative angles of inclination using a camera and compare these with the radiological inclination after operation.

None of the previous studies discussed have attempted to use digital photography to obtain the peri-operative inclination angles of the acetabular component.

The aim of this study was to record photographically and then measure the angles of inclination of the acetabular inserter at the time when the component is introduced into the acetabulum during THR in 60 consecutive patients. Using image analysis software the angles from the photographs were calculated. These results were then compared with the radiological inclination as measured on the anteroposterior radiographs taken on the day following operation.

Patients and Methods
A total of 67 THR patients (67 hips) were investigated. However, the photographs of seven of the patients were not of adequate quality. The study was classified as an audit by the research governance committee and as such ethical approval was deemed unnecessary, but written consent for intra-operative photographs was obtained before operation. All procedures were performed via the posterior approach by a single surgeon (DEB) with the patient held in the lateral decubitus position using patient supports. During preparation of the acetabulum the upper and lower limbs are positioned as shown in Figure 1. As can be seen the upper limb lies in adduction. The Pinnacle Acetabular System (DePuy, Leeds, United Kingdom) was used for all patients. The surgeon sets the version of the acetabular component with reference to the transverse acetabular ligament. This ligament is exposed using an inferior ‘tear-drop’ retractor which is held in place by a chain attached to the theatre table. For each patient the wound depth is recorded by measuring the distance (cm) from the lateral surface of the greater trochanter to the skin. This is called the fat depth. A mean value was obtained for the fat depth for all the patients in the study.

The operating table is positioned in the laminar air flow and a spirit level is used to ensure that it is level in both planes. Photograph 1 is taken freehand from the end of the operating table (Fig. 2). The camera and the tripod are then set up at a distance of 1.75 m from the greater trochanter, perpendicular to the coronal plane, in preparation for photograph 2 (Fig. 2). The central camera position is marked on the floor. The height of the camera is set to the same level as the greater trochanter (approximately 1.2 m). A sonic laser level with tripod (Argos Ltd, Milton Keynes, United Kingdom), accurate to 0.5 mm/m is placed 0.75 m in front of the camera in line with the greater trochanter and levelled. This provides a horizontal reference to use when measuring the angle of inclination of the acetabular component. Two tape measures are then safely secured to the theatre floor in the x and y directions with the x-axis passing through the central camera position (red dashed line, Fig. 2). When the surgeon inserts the acetabular component photograph 2 is taken. This creates the simulated radiological inclination. The camera is then moved along the x-axis to the point where the acetabular component inserter appears perpendicular to the horizontal and photograph 3 is taken with the sonic laser level in the same position relative to the camera as before. This is the plane of inclination view.
The position to take photograph 4 is then calculated on Microsoft Office Excel (Microsoft Corp., Redmond, Washington) using equation 1, knowing the distance between photographs 2 and 3 on the x-axis. The camera and sonic laser level are re-positioned and photograph 4 is taken. This creates the operative inclination. Photograph 5 is then taken freehand from the end of the operating table. When the surgeon closes the wound and the drapes are removed, photograph 6 is taken freehand from the end of the operating table. Then (Fig. 2):

\[
Y = 2.75 \tan x^0 + 1.75
\]

\[
\text{where } \tan x^0 = \frac{X}{1.75}
\]

Photographs 1 and 6 were taken to determine whether the patient had moved during surgery. Photographs 2 and 4 were analysed to determine the angle between the acetabular component inserter and the sonic laser level to calculate the photographic simulated radiological and operative inclinations. Photograph 3 was analysed to ensure the angle between the component inserter and sonic laser level was 90°, therefore ensuring that photograph 4 was taken in the correct position. Photograph 5 was taken as a visual record of the level of anteversion of the acetabular component but was not formally measured. A total of 57 patients had this series of photographs taken, of which seven were not of adequate quality.

The other ten patients were photographed as described but after photographs 1 to 5 had been taken the surgeon removed the inferior teardrop retractor and a second set of photographs was taken. This was to determine whether the insertion of this retractor caused a change in the angles of inclination photographed.

The image analysis of the photographs was performed using Lucia G software (Nikon UK Ltd, Kingston-upon-Thames, United Kingdom). Each photograph was analysed three times and a mean angle obtained. The post-operative radiographs were then measured to determine the radiological inclination using the teardrop method. Each radiograph was measured by two authors (DPG, RP) to ensure inter-observer reliability. Statistical analysis of the operative inclination, simulated radiological inclination and post-operative radiological inclination was carried out on SPSS Statistics 17.0 (SPSS Inc., Chicago, Illinois) using repeated measures analysis of variance (ANOVA). Statistical significance was set as \( p < 0.05 \).

**Validation.** In order to determine the level of accuracy of the method the procedure was repeated in theatre with an artificial pelvis. The acetabular component inserter was inserted into the pelvis and held in position using a retort stand and clamp. It was photographed with three different levels of inclination at 30°, 40° and 50° and the same level of anteversion at 25°. The position of the pelvis did not move during the experiment. Only photographs 2 (simulated radiological inclination), 3 (plane of inclination) and 4 (operative inclination) were taken for this experiment. For photographs 2 and 3, five photographs were taken with the camera in different positions: in the zero position (0) as described in the above method, 5 cm to the right of the zero position along the x-axis (+5), 10 cm to the right of the zero position along the x-axis (+10), 5 cm to the left of the zero position along the x-axis (-5) and 10 cm to the left of the zero position along the x-axis (-10). Five photographs were also taken for the operative inclination view and these positions were determined using equation 1 and knowing the positions of the five photographs taken for photograph 3. These photographs were analysed in the same way as the original experiment.

**Results**

The results of the validation study are shown in Figure 3. From this it is clear that the results were valid and that small discrepancies in camera position did not impair them. The change in the angles of inclination varies from +1.3° to -2.1° when the distance from the zero position changes from +10 cm to -10 cm. The greatest change in angle with changing position occurred at 30° of inclination. It should be noted that ±10 cm is an exaggerated case and during experimentation, while it is difficult to ensure that photographs 3 and 4 are taken in the correct position due to time constraints in theatre, the camera position was never as much as 10 cm out, as this would have been obviously incorrect. Also, as the position of photograph 2 is set up first in preparation for the acetabular component insertion, its positioning was always accurate.

Figure 4 shows examples of the angle analysis of the photographs using Lucia G software. The overall results are displayed in Figure 5, which is a comparison of the angles calculated for the operative, simulated radiological and the
post-operative radiological inclinations for all 50 patients. Table I shows the mean value of these results.

From Figure 5 it can be seen that there is a clear trend with the highest angle being the post-operative radiological
inclination (mean value 46.9°) followed by the simulated radiological inclination (mean 40.0°) and finally the operative inclination (mean 33.9°). Statistical analysis showed that there were highly significant differences between all three definitions of inclination using repeated measures ANOVA (p < 0.001).

A second set of photographs was taken in ten further patients after the surgeon removed the inferior teardrop retractor. The mean difference for photograph 2 with and without the retractor was 1.05° (SD 0.51) and for photograph 4 was 1.18° (SD 0.49), with photographs taken without a retractor having a higher angle than with a retractor.

The mean fat depth in the whole series of 60 patients was 2.84 cm (0.5 to 6.1).

**Table II. Six patients of opposing trend with fat depths at the hip**

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Operative inclination Mean (°)</th>
<th>SD</th>
<th>Simulated radiological inclination Mean (°)</th>
<th>SD</th>
<th>Post-operative radiological inclination Mean (°)</th>
<th>SD</th>
<th>Fat depth at hip (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>38.4</td>
<td>0.5</td>
<td>45.3</td>
<td>0.3</td>
<td>47</td>
<td>0.5</td>
<td>6.2</td>
</tr>
<tr>
<td>18</td>
<td>31.6</td>
<td>0.4</td>
<td>37.5</td>
<td>0.5</td>
<td>38</td>
<td>0.5</td>
<td>3.7</td>
</tr>
<tr>
<td>22</td>
<td>33.3</td>
<td>0.2</td>
<td>46.4</td>
<td>0.3</td>
<td>44</td>
<td>0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>23</td>
<td>35.9</td>
<td>0.2</td>
<td>43.1</td>
<td>0.3</td>
<td>42</td>
<td>0.3</td>
<td>2.5</td>
</tr>
<tr>
<td>42</td>
<td>29.6</td>
<td>0.3</td>
<td>38.5</td>
<td>0.2</td>
<td>35</td>
<td>0.2</td>
<td>4.5</td>
</tr>
<tr>
<td>45</td>
<td>28.3</td>
<td>0.2</td>
<td>33.0</td>
<td>0.4</td>
<td>29</td>
<td>0.4</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**Discussion**

Although a general trend was found in that the post-operative radiological inclination was largest, followed by the simulated radiological inclination and then the operative inclination, there were six results that did not follow this (Table II). In these cases the intra-operative radiological inclination was almost the same as or greater than the post-operative radiological inclination, by up to 4.0°. This trend appears to be explained by the obesity of the patient. A large depth of fat can influence the angle of the acetabular component inserter if it is forced against a deep wound edge. This causes an increase in the angle of the two intra-operative measurements of inclination. The mean fat depth in the series was 2.84 cm (0.5 to 6.1). The mean depth for the six patients opposing the trend was 4.17 cm (2.5 to 6.2). The individual fat depths are shown in Table II along with their respective inclinations. Apart from patient 23, all these patients had an above average fat depth.

From inspection of the photographs for these six patients it was clear that the acetabular component inserter had impinged on the edge of the wound. For patient 23, where the fat depth was only 2.5 cm the handle was still in contact with the edge of the wound. However, from photograph 5 it was obvious this was due to increased anteversion.

As mathematically predicted, due to anteversion, the operative inclination was lower than both the simulated radiological inclination as determined photographically and the post-operative radiological inclination measurements in all patients. However what was not expected was the discrepancy between the simulated and the post-operative radiological inclination which had a difference of 6.9°. We hypothesised that when the inferior teardrop retractor is inserted the position of the pelvis within the soft-tissue envelope may be altered thus changing the...
angle of the acetabular inserter. However, having photographed ten extra patients after removal of the inferior tear drop retractor it was found that it may account for around 1° of difference, but not 6.9°.

We consider that the most likely explanation is a change in pelvic orientation between the lateral decubitus position in theatre and the supine positions for the radiographs. Before each operation it was ensured, by using a spirit level, that the operating table was level in both planes. An error in ensuring that the patient’s coronal plane was vertical could have affected version, but should have a minimal effect on inclination. It would therefore seem that when the patient is in lateral decubitus the uppermost hemipelvis appears to adduct. Such movement must occur in the lumbar spine. This would explain why the simulated radiological inclination was on average 6.9° less than the post-operative radiological inclination. Clearly pelvic orientation in the lateral decubitus position requires further investigation.

These results agree with others in that the operative inclination was constantly less than the radiological inclination. We found that the surgeon’s mean operative inclination was 33.9° (27.0° to 41.4°) which is lower than the 40° the surgeon was aiming for. However in 17 cases (34%) the post-operative radiological inclination was found to be > 50° and in five (10%) of these cases the inclination was > 55°. However, but interestingly in these cases the operative inclination still only averaged 37.3°. While we knew that the radiological inclination would be higher than the operative inclination aimed for in theatre, the extent of this difference, which was 13°, was unexpectedly high.

This study measured the operative and simulated radiological inclination intra-operatively using digital photography and compared it with the post-operative radiological inclination. Predictably post-operative radiological inclination was greater than the operative inclination. However, of more concern was the difference between the simulated radiological inclination as measured photographically and the post-operative radiological inclination. The most likely explanation is that when the patient is positioned in lateral decubitus the uppermost hemipelvis adducts. Based on these findings the senior author (DEB) now aims for a maximum of 35° of operative inclination to achieve a post-operative radiological inclination that is consistently less than 50°. Clearly patient positioning remains critical.

Supplementary material

A photograph showing the component inserter handle impinging against the edge of a deep wound is available with the electronic version of this article on our website at www.jbjs.org.uk

The authors would like to acknowledge The School of Mechanical & Aerospace Engineering at Queen’s University Belfast for the use of their equipment and M. Parker at the Clinical Research Support Centre for his statistical advice. No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References