JOINT MOTION AND SURFACE CONTACT AREA RELATED TO COMPONENT POSITION IN TOTAL HIP ARTHROPLASTY

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A three-dimensional computer model of a total hip replacement was used to examine the relationship between the position of the components, the range of motion and the prosthetic joint contact area. Horizontal acetabular positions with small amounts of acetabular and femoral anteversion provide the largest contact areas, but result in limited joint movement.

These data will allow surgeons to select implant positions that will provide the largest possible joint contact area for a given joint range of motion although these are conflicting goals. In some component positions a truncated spherical prosthetic head resulted in smaller contact areas than a completely spherical head.

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Many different femoral and acetabular component positions have been recommended in total hip arthroplasty surgery: 30° to 50° of acetabular abduction, 0° to 30° of acetabular anteversion, and 0° to 20° of femoral anteversion have all been suggested.1-7 Charnley advocated 45° of acetabular abduction, 0° of acetabular anteversion, and a maximum of 5° of femoral anteversion.8 Muller has proposed that the combined acetabular and femoral anteversion should not exceed 25° to 30°.9 Ranawat has recommended 20° to 30° of combined anteversion in males and closer to 45° in females.10 Operative difficulties can result in additional variations.11 Many different implant position combinations provide acceptable clinical results, but variations in component positions lead to differences in available joint motion, joint stability and implant survival.12-14 Schmalzried et al has reported a statistically significant correlation between osteolysis and acetabular abduction greater than 50°.15

Differences in prosthetic joint motion related to implant position have been reported6,12 as has the effect of implant design and head/neck diameter ratios.12,16,17 The data in this study help to predict the prosthetic joint motion and contact areas resulting from acetabular and femoral position.

MATERIALS AND METHODS
The radiograph and CT scan of a normal hip were selected. Digital CT images were used to create three-dimensional computer models of both the hemipelvis and proximal femur. The models were manipulated using a personal computer (Quadra 840, Apple Computer Inc, Cupertino, California) and Form Z (Autodesys Inc, Columbus, Ohio) software. A Spectron EF (Smith & Nephew Richards, Memphis) stem and a long neck 28 mm diameter ball were selected by radiographic templating. The Spectron stem has a 131° neck-shaft angle (personal communication, Jeff Schryver, Smith and Nephew, Memphis) and for this study the neck was modified to a 12 mm diameter cylinder. The head to neck diameter ratio was 2.3 (Fig. 1). A 3-D model of the femoral component was formed and implanted into the femur recreating the same femoral offset and head height as the natural femur. An hemispherical acetabular component was selected by templating with a 52 mm outside diameter and a 28 mm inside diameter. A 3-D solid model was generated and placed into the model reproducing the centre of rotation of the natural socket (Fig. 1). An inner edge chamfer was avoided. The tolerance between the prosthetic femoral head and the inside surface of the prosthetic acetabulum was 0.5 mm.

The centre of rotation of the acetabulum and femoral head were placed at the origin of the three Cartesian coordinates x, y and z. The pelvis was kept fixed while
the femur was rotated about the centre of rotation of the hip. The computer software was capable of detecting overlap (interference) between elements of the model. Maximum motion was defined as the number of degrees of movement before overlap of either bone or components.

The femoral component was placed in 0°, 10° and 25° of anteversion. The acetabular component was placed in 0°, 10°, 20° and 30° of anteversion and 30°, 40°, 45° and 50° of abduction. These 48 combinations of implant position were examined for maximum joint motion in five directions associated with prosthetic hip dislocation (Table I). Maximum flexion with the hip in 10° adduction and 10° internal rotation was used to mimic the function of getting up from a low seat without keeping the knees apart.

The hip was put through a range of motion until the neck of the femoral component impinged on the edge of the acetabular component. The origin of the x, y and z axes was then moved to the point of contact. The femoral component was rotated further about the new origin rotating the ball out of the socket until dislocation was simulated (Fig. 2). The difference between component impingement and dislocation was recorded.

Prosthetic joint contact area was studied in two additional models, both had 28 mm diameter spherical balls. One had a flat area at the point of attachment between the

Table I. The five implant positions examined for maximum range of motion before dislocation

<table>
<thead>
<tr>
<th>Position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>Maximum external rotation in 0° of flexion and 0° of abduction</td>
</tr>
<tr>
<td>10°</td>
<td>Maximum flexion in neutral rotation and neutral abduction</td>
</tr>
<tr>
<td>20°</td>
<td>Maximum flexion in 10° of adduction and 10° internal rotation</td>
</tr>
<tr>
<td>30°</td>
<td>Maximum internal rotation in 90° of flexion and neutral abduction</td>
</tr>
<tr>
<td>40°</td>
<td>Maximum internal rotation in 90° of flexion and 10° of adduction</td>
</tr>
<tr>
<td>45°</td>
<td>Maximum internal rotation in 90° of flexion and 10° of adduction</td>
</tr>
<tr>
<td>50°</td>
<td>Maximum internal rotation in 90° of flexion and 10° of adduction</td>
</tr>
</tbody>
</table>

Fig. 1

A three-dimensional computer model of a male hip with an implanted THR. The acetabulum is in 40° abduction and 10° anteversion. The femoral component is in 10° anteversion.
ball and the neck of the prosthesis (Fig. 3), the other was a truncated ball. This geometry was modelled after the femoral heads of retrieved Triad (Johnson and Johnson, Rutherford, New Jersey) and TR-28 (Zimmer USA, Wausau, Indiana) prostheses. Both of these new models were created with a 0.1 mm tolerance between the femoral head and the inside diameter of the socket (Fig. 3). Polyethylene wear was mimicked by advancing the prosthetic femoral head 1 mm into the acetabular component in each position. The direction of femoral head advancement was selected from the prosthetic retrieval data reported by Kabo et al. After the femoral head was moved, overlap of the joint surfaces was determined and the contact area between the two components calculated.

RESULTS

Maximum joint motions in the prosthetic hip model for each of the combinations studied are shown in Figures 4 to 8. The model showed that external rotation in 0° flexion increased as femoral anteversion decreased. External rotation also increased as acetabular anteversion decreased until
Figure 4 - Maximum joint external rotation with the hip in 0° flexion and 0° abduction for each of the component position choices. (P = prosthetic impingement, B = bone impingement). Figure 5 – Maximum joint flexion with the hip in 0° rotation and 0° abduction for each of the component position choices. (P = prosthetic impingement, B = bone impingement). Figure 6 – Maximum joint flexion with the hip in 10° adduction and 10° internal rotation for each of the component position choices (P = prosthetic impingement, B = bone impingement). Figure 7 – Maximum joint internal rotation with the hip in 90° flexion and 0° abduction for each of the component position choices (P = prosthetic impingement, B = bone impingement).
bone impingement occurs. Acetabular abduction had little effect on maximum external rotation.

Joint flexion in 0° abduction and 0° rotation increased as acetabular abduction, acetabular anteversion, and femoral anteversion increased. When the acetabulum was placed in 30° to 45° of abduction and anteverted 0° while the femoral component was in 0° of anteversion the components allowed less than 110° of flexion. The same relationships are seen in flexion when the femur was internally rotated 10° and adducted 10°. Less than 110° of flexion occurred in this situation even when the acetabulum was anteverted 25°. Placing the femur in 10° of adduction did not change this relationship greatly.

When motion was continued after impingement the 28 mm ball with a 12 mm diameter cylindrical femoral neck rotated 12° more before an equator of the femoral head reached the edge of the acetabulum (see Fig. 2).

Prosthetic joint contact area is presented in Figures 9 and 10. With a spherical femoral head, anteversion of the femur had no effect on joint contact area. Prosthetic joint contact area increased as acetabular abduction decreased and also as acetabular anteversion decreased. With the truncated model, joint contact area at times increased less as acetabular abduction, acetabular anteversion, and femoral anteversion decreased. The disadvantage of the truncated design results from the truncated portion of the femoral head rotating into the acetabulum. The greatest differences in contact area between the two head geometries was seen when both femoral and acetabular anteversion were high.

**DISCUSSION**

Our computer model has been used to examine the relationship between the position of the femoral and acetabular components and the potential joint motion associated with both dislocation and joint contact area. Specific implant designs and patient anatomies could be substituted to provide information for specific patient groups or even individual patients. An unlimited number of implant position choices and joint motions can be examined using this technique.

There are several deficiencies of the present study; motion estimates do not take into account soft-tissue structures which could influence joint range of motion by causing impingement before bone or prosthetic component contact. This study also does not consider joint reaction forces or soft-tissue tension. The model presented was developed using images of a hip from a normal male; differences in gender and variations in anatomy may modify the results.

The range of joint motion, in directions commonly associated with dislocation, varies considerably as both acetabular and femoral component positions change. In general, prosthetic hip flexion increased as acetabular abduction, acetabular anteversion and femoral anteversion increased. Internal rotation with the hip in 90° flexion increased as these same three parameters increased. External rotation in 0° flexion decreased as acetabular anteversion and femoral anteversion increased.

Joint contact area also varies with implant position. The most important choice of component position with respect to joint contact area is acetabular abduction. As acetabular abduction became more horizontal, joint contact area increased. As acetabular abduction decreased from 50° to 30°, with a spherical 28 mm diameter femoral head, joint contact area increased from 7.7 to 9.1 cm². Prosthetic joint contact area decreased as acetabular
The information provided in this study can help to decide how much hip motion is desired in a specific patient and then select the component position that will allow such motion and also provide the largest possible joint contact area. Maximising joint contact area might be expected to result in less polyethylene stress and a potential reduction in polyethylene wear.

Joint contact area is also affected by femoral head design. Femoral anteversion does not change the contact area of the prosthetic joint when a spherical head design is used. If a femoral head with a truncated spherical design is used, the truncated portion of the prosthetic head rotates into the acetabular component as femoral and acetabular anteversion increase. This results in a decrease in prosthetic joint contact area.

During total hip arthroplasty, surgeons may wish to increase joint contact area in a young, active or obese patient. They may wish to increase potential hip flexion, adduction and internal rotation in an impulsive or forgetful patient. During revision of one component with a well-fixed accompanying component, the surgeon may wish to determine in what position the revised component should be placed to maximise joint range of motion and joint contact area. If no satisfactory joint motion and contact area options can be found the surgeon may wish to consider revision of the fixed component.

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REFERENCES


