Three-dimensional anatomy of the hip in osteoarthritis after developmental dysplasia


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Using radiography and computer tomography (CT) we studied the morphology of 83 hips in 69 Caucasian adults with osteoarthritis secondary to developmental dysplasia of the hip (DDH). A previously published series of 310 hips with primary osteoarthritis was used as a control group. According to the Crowe classification, 33 of the dysplastic hips were graded as class I, 27 as class II and 23 as class III or class IV.

The intramedullary femoral canal had reduced mediolateral and anteroposterior dimensions in all groups compared with the control group. Only in Crowe class II hips was the femoral neck-shaft angle increased. The proximal femur had more anteversion in all the developmental dysplasia of the hip groups, ranging from 2° to 80°. Templated measurement of acetabular dimensions for plain radiography closely matched measurements taken by CT.

The results of our study confirm the observations previously confined to the Japanese population.

Osteoarthritis secondary to developmental dysplasia of the hip (DDH) may lead to some technical difficulties when performing total hip arthroplasty. This may be the result of the abnormal proximal femoral anatomy and the attempted implantation of the cup at the level of the true acetabulum.

Several authors have noted that the proximal femoral morphology is challenging for implantation of a stem in the presence of a narrow intramedullary canal and increased anteversion. The extramedullary portion of the prosthesis must accommodate not only this increased anteversion but also the modified head offset in order to restore the appropriate abductor lever arm and joint kinematics.

Previous studies of the three-dimensional morphology of the dysplastic femur have been limited to the Japanese population. The combination of computer tomography (CT) and plain radiography allows evaluation to be made of the three-dimensional morphology of the proximal femur.

The anteroposterior size of the acetabulum itself as measured by CT is often different from the supero-inferior size evaluated on plain radiography. No study, however, has reported the CT-based anteroposterior dimensional evaluation of the dysplastic acetabulum related to the degree of subluxation of the hip.

Our aim was to evaluate the three-dimensional femoral anatomy of patients from a European (Caucasian) population with osteoarthritis secondary to DDH and to compare this work with a control group of hips with primary osteoarthritis using the same CT protocol, and to provide an anteroposterior dimensional evaluation of the acetabulum according to the various degrees of subluxation of the hip.

Patients and Methods

We studied the CT scans and radiographs of 83 hips (35 right and 48 left) in 69 adult patients (57 women and 12 men) with DDH who were scheduled for total hip arthroplasty. According to the classification of Crowe et al., 33 dysplastic hips (40%) were in class I (less than 50% subluxation), 27 (32%) in class II (50% to 75% subluxation) and 23 (28%) in class III and class IV (respectively, 75% to 100% subluxation and more than 100% subluxation).

Women made up most of the study group: 92% in class I, 65% in class II, and 90% in class III and class IV.

The overall mean age of the patients was 52 years (SD 13; 17 to 82). Their mean weight was 64 kg (SD 14.5; 40 to 118) and their mean height was 161 cm (SD 7.8; 150 to 185). There was no significant difference in the age, weight and height between the three groups (Table I).

As a control group, we used a previously published series of 310 primary osteoarthritic hips which had been identically studied.
Radiological analysis. The leg-length discrepancy was evaluated on a full view of both legs, with the patient supine and with a minimum source-distance of 3 m. The leg length was defined as the distance from the axis of the iliac crest to the bimalleolar arch. The femoral length was determined by the vertical distance of the segment joining the top of the femoral head to the middle of the condylar axis of the knee.

Measurements were also performed on the frontal view of the femur according to the method of Noble et al.\(^{11}\) and Sugano et al.\(^{7}\) in order to calculate the following variables: centre, diameter and height of the femoral head from the centre of the lesser trochanter, the neck-shaft angle (angle formed by the diaphyseal axis and the axis of the femoral neck) and the medial offset (perpendicular distance from the diaphyseal axis to the centre of the femoral head) (Fig. 1).

Computer tomography scan analysis. For the CT examination, scout views confirmed the position with the legs in extension parallel to the table and with fixed rotation. A CT reconstruction of the femur was performed with slices 2 to 3 mm thick using the following set of transverse scans: slices at 5 mm intervals from 10 mm above the acetabular roof to 10 mm below the lesser trochanter, slices at 10 mm intervals from 10 mm below the lesser trochanter to the femoral isthmus and three slices at 5 mm intervals through the femoral condyles for definition of the posterior bicondylar axis.

Dicom format images (512 x 512 pixels) were obtained using dedicated software (Contouring and Osiris; Symbios, Yverdon, Switzerland) to create a three-dimensional reconstruction of the internal and external geometry of the femur with its underlined endosteal and periosteal contours. Values obtained were automatically corrected for magnification.

Mediolateral and anteroposterior widths of the medullary canal were measured at three levels within the canal: 20 mm above the centre of the lesser trochanter, 40 mm below the centre of the lesser trochanter and at the isthmus according to the method of Husmann et al.\(^{12}\)

The anteroposterior diameter of the acetabulum was measured using the level of the radiological teardrop on the

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### Table I. The mean (SD) age, weight and height for each group of patients with developmental dysplasia of the hip (DDH) and those with primary osteoarthritis (control group)

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDH I</td>
<td>49.8 (13.8)</td>
<td>63.1 (12.1)</td>
<td>165.2 (9.0)</td>
</tr>
<tr>
<td>DDH II</td>
<td>59.8 (14.4)</td>
<td>48.3 (11.5)</td>
<td>165.3 (6.8)</td>
</tr>
<tr>
<td>DDH III + IV</td>
<td>56.3 (12.4)</td>
<td>68.9 (16.0)</td>
<td>162.9 (6.2)</td>
</tr>
<tr>
<td>Control hip</td>
<td>62.0</td>
<td>nd*</td>
<td>nd</td>
</tr>
</tbody>
</table>

* nd, not determined
The proximal femoral anteversion (so-called helotorsion angle, He) is the angle formed by the mediolateral width 20 mm above the centre of the lesser trochanter and the translated posterior bicondylar axis.

The proximal femoral anteversion was defined by the angle between the posterior bicondylar axis and the mediolateral dimension of the medullary canal at 20 mm above the lesser trochanter (Fig. 3).

The canal flare index measured on the CT scan was defined as the ratio between the intracortical width of the femur 20 mm proximal to the lesser trochanter and at the isthmus of the canal.

**Accuracy of measurement.** One operator made all the measurements and in order to evaluate the intraobserver error the measurements were repeated four times on 25 randomly chosen femora at an interval of at least one day. The radiological measurements had a precision value of less than 2.5 mm and of less than 3° for angles. The CT measurements had a precision value equal to 0.4 mm and less than 2.5°.

**Statistical analysis.** Distribution of variables for each group was tested for normality using the Kolmogorov-Smirnov test. For normally distributed variables, when there were more than two groups to compare with the same variances, differences between groups were analysed by one-way analysis of variance (ANOVA) without repetition followed by an unpaired t-test (multiple pair-wise comparisons) for all significant variables. For abnormally distributed variables or normally distributed variables with different variances, a Kruskal-Wallis ANOVA was performed followed by Dunn’s test for all pair-wise comparisons. The results of each group were compared with those of the control group of hips with primary osteoarthritis by using Student’s t-test. A p value of less than 0.05 was considered to be significant.

**Results**

The measurements (mean and SD) of the morphological parameters obtained from radiographs and CT scans are given in Tables II and III.

![Fig. 3](image-url) 
CT slice with superimposed slices performed at the centre of lesser trochanter + 20 mm level and knee level for the definition of anteversion. The proximal femoral anteversion is the angle formed by the mediolateral width 20 mm above the lesser trochanter and the translated posterior bicondylar axis.

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**Table II.** Mean (SD) values of dimensional parameters in each group of patients with developmental dysplasia of the hip (DDH) and those with primary osteoarthritis (POA; control group)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DDH I</th>
<th>DDH II</th>
<th>DDH III-IV</th>
<th>POA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral length (mm)</td>
<td>51.1</td>
<td>50.6</td>
<td>45.8</td>
<td>nd</td>
</tr>
<tr>
<td>Leg-length discrepancy (mm)</td>
<td>16.43</td>
<td>34.42</td>
<td>35.37</td>
<td>nd</td>
</tr>
<tr>
<td>Position of the isthmus (mm)</td>
<td>124</td>
<td>129.8</td>
<td>116.4</td>
<td>nd</td>
</tr>
<tr>
<td>Height of the centre of the femoral head (mm)</td>
<td>48.6</td>
<td>48.4</td>
<td>44.5</td>
<td>57</td>
</tr>
<tr>
<td>Medial head offset (mm)</td>
<td>25.1</td>
<td>23.2</td>
<td>21.6</td>
<td>40.5</td>
</tr>
<tr>
<td>Neck-shaft angle (°)</td>
<td>131.9</td>
<td>136.8</td>
<td>127.4</td>
<td>129.8</td>
</tr>
<tr>
<td>Anteversion angle (°)</td>
<td>36.4</td>
<td>43.6</td>
<td>38.4</td>
<td>22.9</td>
</tr>
<tr>
<td>Canal flare index</td>
<td>4.8</td>
<td>4.6</td>
<td>4.8</td>
<td>4.3</td>
</tr>
</tbody>
</table>

* nd, not determined

**Table III.** Mean (SD) mediolateral and anteroposterior dimensions (mm) of the femoral canal measured by CT at three different levels: the isthmus, 40 mm under the centre of the lesser trochanter (CLT - 40 mm) and 20 mm above the centre of the lesser trochanter (CLT + 20 mm) in the groups with developmental dysplasia of the hip (DDH) and the control group

<table>
<thead>
<tr>
<th>Mediolateral dimension</th>
<th>Isthmus</th>
<th>CLT - 40 mm</th>
<th>CLT + 20 mm</th>
<th>Anteroposterior dimension</th>
<th>Isthmus</th>
<th>CLT - 40 mm</th>
<th>CLT + 20 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDH I</td>
<td>9.3 (2.7)</td>
<td>13.2 (3.0)</td>
<td>42.3 (7.4)</td>
<td>12.6 (3.5)</td>
<td>15.8 (4.7)</td>
<td>30.8 (5.1)</td>
<td>30.8 (5.1)</td>
</tr>
<tr>
<td>DDH II</td>
<td>9.4 (2.1)</td>
<td>12.9 (2.4)</td>
<td>41.2 (6.4)</td>
<td>12.7 (2.5)</td>
<td>16.1 (3.4)</td>
<td>27.6 (5.4)</td>
<td>27.6 (5.4)</td>
</tr>
<tr>
<td>DDH III + IV</td>
<td>9.7 (3.4)</td>
<td>12.7 (3.5)</td>
<td>42.6 (8.7)</td>
<td>13.6 (3.6)</td>
<td>15.8 (3.3)</td>
<td>30.4 (8.7)</td>
<td>30.4 (8.7)</td>
</tr>
<tr>
<td>Control group</td>
<td>11.2 (2.3)</td>
<td>19.3 (2.9)</td>
<td>46.3 (6.9)</td>
<td>14.2 (2.9)</td>
<td>19.7 (3.0)</td>
<td>38.2 (7.3)</td>
<td>38.2 (7.3)</td>
</tr>
</tbody>
</table>
The mean shape of the femur was similar for all the DDH groups with a position of the femoral isthmus located at a mean of 127 mm (SD 20) below the lesser trochanter. The internal dimensions of the femoral canal were also comparable and significantly smaller than those of the control group. The canal flare index was very similar for all groups except between DDH group I and the control group (respectively, 4.8 (SD 0.3) and 4.3 (SD 0.1, p = 0.06) showing a more tapered medullary canal in this class of femur.

No difference in the diameter of the femoral head was found between the different groups. The height of the centre of the femoral head was significantly lower in the DDH groups compared with the control group 48 mm (SD 13) vs 57 mm (SD 0.5).

The neck-shaft angle in class II was significantly higher than that in class III and class IV (p = 0.01) and in the control group (p < 0.0002). For all DDH groups the incidence of coxa valga was 46.5% and the incidence of coxa vara was 11.3%.

The anteversion was comparable for all DDH groups and exceeded that of the control groups but had no correlation with any other morphological parameter such as leg-length discrepancy, neck-shaft angle or canal flare index.

Irrespective of the Crowe class the dysplastic hips had no marked difference in their anteroposterior diameters as measured by CT and were similar to the templated measurements from plain radiography. No comparison figures were available for the control group of primary osteoarthritic hips (Table IV).

Discussion

The anatomical abnormalities caused by DDH make total hip arthroplasty particularly difficult to perform. Previous studies using CT and three-dimensional reconstruction to analyse these abnormalities have been confined to Japanese patients. Robertson et al provided a mean model of the developmental dysplastic femur based on 24 Japanese adult patients with DDH. There was no control group of an equivalent population and the sample size was limited for each degree of subluxation. Sugano et al also studied a Japanese population which included 35 female patients with DDH and was compared with an age-matched group of 15 patients serving as a normal anatomical control group for Japanese women. Noble et al studied a group of 154 Japanese women aged from 18 to 82 years with DDH and compared it with a healthy non-arthritic control group of 53 female patients.

The weakness of our study is the absence of morphological femoral measurements before the onset of osteoarthritis, but the main goal of the study was to provide morphological data available at the time of hip arthroplasty.

We have studied a Caucasian population of 83 hips scheduled for total hip arthroplasty. This series included all the degrees of hip subluxation as described by Crowe et al. However, classes III and IV have been studied together because of limited numbers in each group and because the surgical problems were very similar in these groups with distinct false and true acetabula.

Our findings confirmed in a European population some of the features which have been described previously both by two-dimensional and three-dimensional analysis. Our study also showed that the dysplastic femur had a narrower diaphysis and intramedullary canal. This difference was significant for DDH groups when compared with the group of hips with primary osteoarthritic. Although the stature of the patients, reflected in height, femoral length, femoral head and position of the isthmus, were different from those of the Japanese population described by Sugano et al, the anteroposterior and mediolateral widths of the canal above the lesser trochanter and at the isthmus were remarkably comparable.

Consistent with the findings of Robertson et al, our data demonstrate a progressive decrease in medial head offset from DDH class I to class IV, and when compared with the primary osteoarthritic control group. The decrease in the femoral neck-shaft angle with increased severity of subluxation noted both by Robertson et al and Sugano et al was only found in our study for the high subluxation classes III and IV. On the contrary we found a significant increase in femoral neck-shaft angle for classes I and II in a larger sample than those studied by these authors. A constant finding in femoral anatomical studies in DDH is a significant increase in anteversion of the femoral neck compared with that in primary osteoarthritides, and the values found in our study were comparable with those found for the Japanese population. The value of 22° found by Sugano et al for the 15 patients used as a control group of the normal Japanese population was similar to that found in the study of 310 femora with primary osteoarthritides. Probably the most important finding for the surgeon performing THA for DDH is the large individual variability for anteversion values, ranging in our study from 2° to 80° with no correlation with the severity of subluxation. The surgeon may need to address this matter at operation using one of the described methods.

Although the use of CT for measuring the anteroposterior diameter of the true acetabulum pre-operatively in patients with DDH has been described previously, no study has reported this evaluation for each degree of subluxation. The anteroposterior radiograph provides only a two-dimensional representation of a three-dimensional reconstruction and can lead to either an under- or overestimation of the amount of cover of the socket. However, in

| Table IV. Comparison of templated plain radiographic and CT measurements (mean, SD; mm) by Crowe classification* of the anteroposterior dimensions of the acetabulum |
|-----------------|-----------------|-----------------|
| Crowe classification | Templated plain radiography | CT |
| DDH I | 51.6 (6.6) | 51.2 (5.1) |
| DDH II | 52.6 (4.6) | 53.1 (5.6) |
| DDH III + IV | 50.8 (4.3) | 49.6 (5.8) |

* DDH, developmental dysplasia of the hip
Our study has shown important morphological differences between 83 arthritic hips with DDH compared with 310 hips with primary osteoarthritis in a Caucasian population. This provides additional three-dimensional information to that already available for a Japanese population. The results in both racial groups with DDH have revealed similar femoral intramedullary features. However, at joint replacement the surgeon needs to be prepared to adapt the surgical technique or the design of the neck of the prosthesis to the degree of anteversion of each individual femur.

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References