Analysis of cover of the femoral head in normal and dysplastic hips

NEW CT-BASED TECHNIQUE

We present a new CT-based method which measures cover of the femoral head in both normal and dysplastic hips and allows assessment of acetabular inclination and anteversion. A clear topographical image of the head with its covered area is generated. We studied 36 normal and 39 dysplastic hips. In the normal hips the mean cover was 73% (66% to 81%), whereas in the dysplastic group it was 51% (38% to 64%). The significant advantage of this technique is that it allows the measurements to be standardised with reference to a specific anatomical plane. When this is applied to assessing cover in surgery for dysplasia of the hip it gives a clearer understanding of where the corrected hip stands in relation to normal and allows accurate assessment of inclination and anteversion.

Assessment of the degree of cover of the femoral head by the acetabulum is a critical element in surgery for dysplasia of the hip. The main objectives of corrective surgery are to increase the cover of the femoral head by the available acetabulum and to optimise the orientation of the weight-bearing zone. There is evidence in the literature that rotating the acetabulum laterally in the frontal plane and anteriorly in the sagittal plane reduces the joint contact pressures, and as a result a reduction in the risk of the development of osteoarthritis may be anticipated. It is also clear that dysplastic hips have less available acetabulum to cover the femoral head, and an understanding of how the amount and location of the cover differ from normal hips may well be significant in terms of prognosis.

In order to assess cover of the femoral head several plain radiological indices have been in common use, including the centre-edge angle of Wiberg from anteroposterior (AP) and false-profile views, the acetabular index of the weight-bearing zone, and the lateral subluxation index. All these are based on a two-dimensional representation of the hip and give rather limited information. Additionally, equations for calculating cover based on plain radiographs are cumbersome, complex and involve many assumptions.

CT has proven to be a more accurate, practical and informative way of analysing the geometry of the hip. Klaue et al first used a computer-assisted model indirectly to derive representations of cover of the femoral head. Janzen et al then described a CT-based method for measuring the centre-edge angle of Wiberg at ten rotational increments. Later, the same group used that method to examine dysplastic hips before and after acetabular osteotomy. These described methods are all subject to the introduction of errors because of the difficulty of assessing and standardising the degree of pelvic tilt which has a considerable effect on the measurement of the acetabular angle.

We present a new CT-based method which provides a topographical image of the femoral head with the covered area clearly represented. In this study we used this technique to measure the percentage cover of the femoral head by the weight-bearing zone in patients with normal hips, with the position of the pelvis standardised in relation to a specific anatomical plane. As a demonstration of the applicability of the technique, we also applied it to demonstrate and measure the cover in a group of patients with dysplasia of the hip. Dysplasia was defined as the presence of a centre-edge angle of 20° or less. Acetabular inclination and anteversion were also measured in both groups.

Patients and Methods

In order to determine normal cover of the femoral head, we studied 27 patients (11 men, 16 women) with a mean age of 31 years (15 to 61). Of these, 13 had contralateral acetabular fractures which had been reconstructed before a further post-operative pelvic CT scan was obtained. Another nine had pelvic CT scans to
investigate other conditions and were found to have normal hips bilaterally. The remaining five had unilateral hip dysplasia and therefore had five normal hips. In total 36 normal hips were available for study.

In the dysplastic group, there were 27 patients (4 men, 23 women) with a mean age of 27 years (14 to 41). Of these, 12 had bilateral disease, giving a total of 39 dysplastic hips of varying degrees of severity.

CT was carried out using a Siemens Sensation 64 scanner (Siemens, Erlangen, Germany) with convolution kernel B60s. The pelvis was scanned in two separate segments, with 1.5 mm slices at the level of the anterior superior iliac spine and 1 mm slices across the acetabula. The radiation dose was 1.7 mSv, as opposed to 10 mSv for a traditional pelvic CT scan. The dose of 1.7 mSv is equivalent to that of background radiation for eight months or that of exposure for three months in Radon-rich areas such as Cornwall, United Kingdom. By comparison, the radiation doses from plain AP and lateral pelvic radiographs are 0.7 mSv and 0.8 mSv, respectively. Positioning of patients in the scanner was standardised with the legs in neutral abduction/adduction and with the patellae pointing directly upwards.

Using a custom-made software program developed by one of the authors (RR), sets of anatomical landmarks were acquired on the three-dimensional (3D) reconstructed images. The analysis was based entirely on the location of these landmarks. Some were used to define the orientation for the pelvis which affected the final cover. The pelvis was rotated so that the anterior pelvic plane, defined by the anterior superior iliac spines and the pubic tubercles, was vertical. The pelvis was then rotated in this plane so that the anterior superior iliac spines were at the same level, approximating to the frontal plane in the standing position.

A set of 20 points was assigned over the surface of the femoral head. An algorithm was used to fit the best sphere to these points with an associated root mean square error. This found the estimated centre and radius of the femoral head. Another set of 20 points was placed around the superior half of the acetabular rim (Fig. 1). These points were projected on to the sphere representing the femoral head in the direction of its centre (Fig. 2). The sphere and markers were then projected on to the horizontal plane to produce a circle and a curved line cutting across it. The percentage cover was calculated from the resulting areas. An image was also generated which represented the femoral head with its covered part clearly shown. Acetabular inclination and anteversion were also measured using a best-fit plane for the landmarks on the superior half of the acetabular rim (Fig. 3).

Acetabular inclination was determined by measuring the angle between the plane of the superior half of the acetabular rim and the horizontal plane perpendicular to the anterior pelvic plane. With the same orientation, acetabular anteversion was determined by measuring the angle between the transverse axis and the acetabular axis as defined by Murray (Fig. 4).

In order to test the reliability of the method, all the measurements were repeated by an independent observer (VK) and the interobserver agreement was measured by calculating the intraclass correlation coefficient and using...
the Bland-Altman plots, which plot the difference between two observers’ measurements against their mean.\textsuperscript{25}

**Statistical analysis.** Cover of the femoral head, inclination and anteversion were compared between the normal and dysplastic groups using the independent samples \( t \)-test assuming an unequal variance.

Correlation analysis was then carried out on the dysplastic group between the cover of the femoral head and the lateral centre-edge angle, and between the cover and the acetabular index of the weight-bearing zone using SPSS statistical software version 14.0 (SPSS Inc., Chicago, Illinois). A value of \( p \leq 0.05 \) was considered significant.

**Results**

The root mean square error associated with the assumption that the femoral head is a sphere was calculated for 24 dysplastic hips. The mean error was 0.5 mm (SD 0.2).

In the normal hips the mean cover of the femoral head was 73\% (95\% confidence interval (CI) 71 to 74), whereas in the dysplastic group it was 51\% (independent \( t \)-test, \( p < 0.001 \); 95\% CI 49 to 54; Fig. 5). The mean inclination was 45\° (37\° to 54\°) for the normal hips and 51\° (38\° to 63\°) for the dysplastic hips (independent \( t \)-test, \( p < 0.001 \)). The mean acetabular anteversion was 17\° (1\° to 31\°) in the normal hips and 19\° (-7\° to 39\°) in those with dysplasia which was not significantly different (independent \( t \)-test, \( p = 0.25 \)). Table I gives a summary of the results.

In regard to gender differences in cover, inclination and anteversion for both the normal and the dysplastic groups, no statistically significant differences were found (Table II).

Inter-observer agreement for cover, inclination and anteversion in both the normal and dysplastic groups showed a mean intraclass correlation coefficient of 0.96 according to reliability analysis. Bland-Altman analysis also showed good agreement between the observers for each of the six parameters. The mean difference between the observers’ measurements of cover was 0.3\° (SD 2.5) for both the normal and dysplastic groups (Fig. 6).
Pearson’s correlation coefficient for the dysplastic group showed that cover correlated with the centre-edge angle ($r = 0.51$) and the acetabular index of the weight-bearing zone ($r = 0.58$), both of which were significant ($p = 0.01$).

**Discussion**

One of the main aims of acetabular surgery for dysplasia of the hip is to increase the cover of the femoral head by the acetabulum and thereby reduce the joint contact pressures. Traditionally, planning such surgery relies on plain radiological assessment. The difficulty of controlling for pelvic tilt, which can significantly affect the results of acetabular measurements, has been recognised in the literature.\textsuperscript{11,14,16,26} Our technique uses a method of CT which allows standardisation of these measurements against an anatomical reference plane and thus avoids discrepancies that arise from inaccurate assessment of the pelvic tilt. A clear representation of the amount of cover is produced, and the location of deficiencies or excessive cover are well visualised.

Attempts at using plain radiological methods to perform a 3D evaluation of cover have been made in the past. Mieno et al\textsuperscript{11} and Konishi and Mieno\textsuperscript{26} used a computer program to obtain such data from plain pelvic radiographs, and measured cover in normal hips using this method. Both groups of authors\textsuperscript{11,26} stated that the technique was not suitable for the analysis of dysplastic hips because of the assumption that the surfaces of the acetabulum were spherical and congruent. In cases in which the joint surface was distorted or incongruent they felt that a CT method was more appropriate. They also thought that the angle of pelvic tilt introduced a significant variable and acknowledged that it was difficult to measure pelvic tilt precisely. They observed a range of variation of pelvic tilt of 21°.

Several investigators have used CT for the analysis of dysplastic hips. Klaue et al\textsuperscript{14} described a technique in which the contours of the joint were plotted from the axial cuts of a CT scan. These were then superimposed on each other. An advantage of this method was that it was able to show the position of the fossa acetabuli in relation to the cover of the femoral head. They acknowledged the difficulty of controlling for tilt of the pelvis in the sagittal plane and felt that functional pelvic tilt could not be reproduced.

Janzen et al\textsuperscript{16} described a technique which used 3D to define the centre of the femoral head and then measured the centre-edge angle at rotational increments of 10° around the acetabular rim. This provided a graphical display of the relationship of the edge of the acetabulum to the centre of...
the femoral head and in dysplasia showed the areas of the major deficiency. They acknowledged that their method did not allow for control of the vertical tilt of the pelvis which may have affected the measurements.

Our results have shown that the mean cover of the femoral head in a group of normal hips was 73% with a 95% CI of 71 to 74. By comparison, the mean in the group of dysplastic hips was 51% (95% CI 49 to 54). In the normal hips using the plain AP radiological technique of Konishi and Mieno, cover was 77% in women and 79% in men. Kojima, Nakagawa and Tohkura used two AP radiographs (supine and erect) for analysis of acetabular cover using a technique based on the method of Konishi and Mieno. Their results for cover were somewhat higher: for normal hips the mean was 87% and for dysplastic hips 63%. The technique developed by Konishi and Mieno was also used by de Kleuver et al to calculate acetabular cover on pre- and post-operative radiographs after triple osteotomy. They found that the mean acetabular cover was 53% pre-operatively which improved to a mean of 70% after operation. The authors did not address the issue of pelvic tilt. They recognised that their technique did not take into consideration the fossa acetabuli which may certainly have had a bearing on the actual contact area of the hip. The study by Klaue et al did demonstrate the position of the fossa acetabuli. The mean cover in 30 normal hips was 70% and in a series of 25 hips with acetabular dysplasia the total cover varied between 30% and 50%, which is in quite close agreement with our findings.

As well as providing accurate information relating to cover our technique also provided accurate data with regard to other acetabular indices, in particular acetabular inclination and anteversion. Dysplastic hips are known to have ‘open’ acetabula, indicated in our study by the highly significant difference in inclination between the normal and the dysplastic hips. On the other hand, regarding acetabular anteversion, there was no significant difference between the two groups. This finding is in agreement with that of other studies which have examined acetabular anteversion using CT-based techniques comparing normal and dysplastic hips.

With regard to gender differences, it was not possible to make any conclusions for the dysplastic group due to the sample size of only five male hips. However, in the normal group, there was no statistically significant difference in cover, inclination or anteversion between men and women. The mean anteversion in this group was 17° (SD 8) as opposed to 20° (SD 7) observed by Maruyama et al. For women the mean anteversion was 18° (SD 8) whereas for men it was 15° (SD 7). When compared with the gender-specific values reported by Maruyama et al of 21° (SD 7) for women and 19° (SD 6) for men, it can be seen that our values are 3% to 4% less. This may be related to the method of measurement since Maruyama et al directly measured anteversion on historical pelvic specimens using a line joining the anterior and the posterior ridges. Our method on the other hand fits a plane to the superior half of the acetabular rim and uses this for measuring anteversion and inclination.

The degree of pelvic tilt alters the apparent version of the acetabulum in a similar way to cover of the femoral head. The assessment of acetabular retroversion from plain radiographs and the visualisation of a cross-over sign may vary significantly depending on the degree of pelvic tilt. Our technique allowed for an accurate assessment of acetabular version with reference to a standardised anatomical plane. When analysing an individual case an assessment could then be made as to whether anatomical retroversion exists or whether it is essentially a functional retroversion related to posture and pelvic tilt. This may have considerable therapeutic implications.

The reliability and robustness of our method were tested by both the intraclass correlation coefficient and the Bland-Altman method. Both showed highly reproducible results with intraclass correlation coefficients above 0.9 and only one or two outliers beyond 2 SD on the Bland-Altman plots. The mean difference between the observers’ results was 0.3° for cover of the femoral head in both the normal and dysplastic groups.

The main limitation of this technique was the assumption that the femoral head is spherical. This is common to many of the techniques. In normal hips the assumption is valid since the femoral head is spherical or nearly so. The figure of 73% should therefore stand as a mean cover. In dysplastic hips, the femoral head may be elliptical or deformed. However, in most cases in which an acetabular re-orientation procedure is performed, the hip is congruent since incongruent hips are considered to be a relative con-
traindication to such a procedure. We were able to measure the degree to which our estimation of sphericity of the femoral head was accurate by producing a root mean square error. This represented the mean deviation of the points used from the sphere generated, and for the dysplastic group this value was 0.5 mm. The other limitation of our technique was that it did not identify the position of the fossa acetabuli. This may be of significance when assessing dysplastic hips in which the fossa would potentially make the actual amount of acetabulum available for articulation less than that which would be apparent from measuring the projected cover.

Our technique appeared to be relatively less cumbersome than others reported, and the analysis took approximately 15 minutes. This could perhaps be considered the equivalent of templating a procedure, as in the preparation for joint replacement. The applicability of the technique is clear when it is applied to assessing cover in surgery to address dysplasia of the hip since it provides a better understanding of where the corrected hip stands in relation to a normal hip. Its major advantages over those methods previously reported are that the measurements can be made in relation to a fixed anatomical plane, a measurement of acetabular inclination and anteverision is automatically provided and there is an opportunity for assessing the effect of surgery on these parameters.

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Table I. The values for cover of the femoral head, acetabular inclination and anteverision for the normal and dysplastic groups

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Dysplastic</th>
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<tbody>
<tr>
<td><strong>Cover of the femoral head</strong></td>
<td>Mean (SD; range)</td>
<td>73 (4; 66 to 81)</td>
</tr>
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<td></td>
<td></td>
<td>45 (4; 37 to 54)</td>
</tr>
<tr>
<td><strong>p-value</strong></td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
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Table II. The mean (SD, range) values for cover of the femoral head, inclination and anteverision according to gender

<table>
<thead>
<tr>
<th>Gender</th>
<th>Normal</th>
<th>Dysplastic</th>
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<tbody>
<tr>
<td></td>
<td>Cover of the femoral head (%)</td>
<td>Inclination (°)</td>
</tr>
<tr>
<td>Male</td>
<td>73 (4; 67 to 79)</td>
<td>44 (4; 37° to 53°)</td>
</tr>
<tr>
<td>Female</td>
<td>73 (4; 66 to 81)</td>
<td>45 (4; 38° to 63°)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.72</td>
<td>0.88</td>
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Fig. 6a

Bland-Altman plots for cover of the femoral head in a) normal and b) dysplastic hips.
References