MEASUREMENT OF ACETABULAR EROSION

THE EFFECT OF PELVIC ROTATION ON COMMON LANDMARKS

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Using dried bones which could be tilted and rotated, we assessed the accuracy of published radiographic methods for measuring the migration of prosthetic acetabular components and compared the results with a new method. The new line linking acetabular margins was significantly more accurate for proximal migration than the teardrop, the sacroiliac line or the sacroiliac-symphysis line. For medial migration, a new line tangential to the brim and through the horizontal mid-point of the obturator foramen was more accurate than Köhler's line, the ilio-ischial line or the ilio-pubic line. In combination, the two new lines can give a more accurate assessment of acetabular erosion than previous methods, since they are less affected by the differences in rotation commonly found in a series of radiographs.

The reported incidence of erosion of the acetabulum after hemiarthroplasty varies widely. With single component prostheses it varies from zero (Johnston et al. 1982) to 64\% (Whittaker et al. 1972), and with biarticular prostheses, from zero (Langan 1979; Long and Knight 1980; Devas and Hines 1983) to 9\% (Leyshon and Matthews 1984). Objective comparison within or between these groups is impossible, since neither the radiological criteria for erosion nor exact measurements are given in these papers. The current debate regarding the benefits of biarticular over single component hemiarthroplasty creates a need for a standard method of measurement of known accuracy by which studies can be compared. A number of radiological landmarks have been described by other authors interested in the diagnosis of protrusio acetabuli and the detection of migration of arthroplasties (Figs 1 and 2):

1) the sacroiliac line, which joins the inferior margins of the sacroiliac joints (Sutherland et al. 1982).
2) a line passing through two points each midway between the inferior margin of a sacroiliac joint and the

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Landmarks previously described for measurement of proximal (Fig. 1) and medial (Fig. 2) migration.
symphysis pubis (H. G. Davies, personal communication).
3) the inferior margin of the teardrop (Sutherland et al. 1982).
4) the brim of the true pelvis (Sotelo-Garza and Charnley 1978).
5) Köhler’s line, which passes tangential to the lateral margin of the pelvic brim and the obturator foramen (Sutherland et al. 1982).
6) the inner margin of the teardrop (Sotelo-Garza and Charnley 1978).
7) the ilio-ischial line, a radiodense line which passes from the pelvic brim to the lateral border of the obturator foramen (Armbuster et al. 1978).

The accuracy of measurement from these landmarks is limited by the errors introduced by changes in pelvic position between consecutive films, which can cause radiographic alterations. The advocates of particular methods have sometimes assessed their relative accuracy: Sutherland et al. (1982) using a combination of Köhler’s line and the teardrop, were unable to reduce errors below 5 mm. No single study, however, compares all the landmarks under standard conditions.

We aimed to assess the accuracy of the methods currently used in clinical practice and to compare them with our new method. This measures proximal migration against a line which passes between the outer lips of both acetabula and medial migration against a line tangential to the pelvic brim which passes through the horizontal midpoint of the obturator foramen (Fig. 3).

MATERIALS AND METHODS

Three articulated pelvic skeletons were chosen from the anatomy department, one with obvious male characteristics, one definitely female, and one of indeterminate proportions. The outlines of both acetabula were marked by the insertion of suitably sized head units from biarticular hemiarthroplasties. These were glued in position so that they remained static throughout the study. The pelvis was then suspended in a Perspex frame, and nine standard radiographs were taken of each pelvis:
1) Neutral film: a single film was in the neutral position, with the symphysis pubis projected to overlay the coccyx.
2) Coronal axis rotation (four films): the pelvis was rotated around its coronal axis, and films were taken at 5 and 10° on either side of the neutral position.
3) Vertical axis rotation (four films): the pelvis was rotated around its vertical axis, and films were taken at 5 and 10° on either side of the neutral position.

Radiographs were taken using a GEC Roentgen 703 machine with Agfa Curix RPI film and Curix Special screens. The tube-to-film distance was one metre. The posterior aspect of the pelvis rested on the cassette for all films and the exposure was 52 kV at 4 mA.

On each film, a line was drawn across the pelvis tangential to the superior aspect of the metal cups.

New landmark lines for measurement of proximal and medial migration.

Apparent cranial or caudal migration of the cups between neutral and rotated films was measured from this line to the following landmarks:
1) The sacroiliac line (SI).
2) A line approximately parallel to this, but passing through two points, each midway between the inferior margin of one sacroiliac joint and the pubic symphysis (SI/symp).
3) The inferior margin of the teardrop (TD).
4) A line joining the outer lips of both acetabula (acetabular margins – AM).

Apparent medial/lateral migration was measured...
similarly from the following landmarks to the nearest point on the appropriate metal cup:
1) The iliopectine line (IP).
2) Köhler’s line (K).
3) The medial margin of the teardrop (TM).
4) The ilio-ischial line (II).
5) A line tangential to the pelvic brim, and passing through the midpoint of the obturator foramen at its greatest horizontal span (obturator/brim – OB).

The results for each of the three pelvises in a given amount of rotation were pooled, giving 12 readings for each method of measurement for each range of rotation (two sides, two directions of rotation, three pelvises). The mean of the difference between the rotated and neutral films for each method of measurement then gave the mean error of each method for a given plane and amount of rotation.

In order to demonstrate consistency of results, the entire experiment was repeated using three different pelvises, and to assess inter-observer error, a selection of the films were viewed and measured by two independent observers.

RESULTS
The results are presented in Tables I and II, being expressed as the apparent change in distance between the neutral and rotated films, from the metal cup to each line or landmark, expressed in millimetres. The 12 readings for each method at each angle were compared using Student’s paired t-test.

For medial migration, the difference between the obturator/brim line and the other methods was highly significant at both 5 and 10°, except for measurements from the teardrop where the differences were not statistically significant. For proximal migration, the difference between the acetabular margin line and the S1/symphysis line at 5° was highly significant; at 10° the difference was significant (p < 0.05). The difference between the acetabular margin line and the other methods was highly significant at both 5 and 10°.

When the entire series of radiographs was repeated, using different pelvises, the mean errors for all of the methods tested differed from those in the original series by a maximum of 1.3 mm. Examining the new lines individually, the mean error for the acetabular margin line in the second series was within 0.3 mm of the original result at 5 and 10°, and that for the obturator/brim line was also within 0.3 mm of the corresponding result in the first series at both 5 and 10°.

In the inter-observer study, two independent observers examined the films from one pelvis, and their readings were compared with the original measurements. The differences between observers were calculated for each reading, and the mean of these differences was calculated for each method of measurement. The mean difference between the observers for the acetabular margin line was 0.4 mm (s.d. = 0.23 mm) and for the obturator/brim line 0.4 mm (s.d. = 0.2 mm). The mean difference between observers for the teardrop was substantial, at 2.4 mm (s.d. = 1.9 mm); this reflects the difficulty of defining this landmark.

DISCUSSION
The difficulty of defining the position of the acetabular margins within the pelvis is well recognised, but none of the easily identifiable bony landmarks around the acetabulum are close enough to the joint for their relative positions to be unaltered by variations in pelvic tilt. In a study of the routine pelvic radiographs of 47 patients, Sutherland et al. (1982) found a mean variation in position of 4.5° (range 0 to 10.5°) around the vertical axis, and a mean variation of 7.8° (range 0.9 to 19.9°) around the coronal axis. These authors were therefore unable to detect whether or not migration of an acetabular component had occurred until the apparent change in position had exceeded 5 mm. Great accuracy can be achieved by the use of stereophotogrammetric techniques, but these require the insertion of metallic markers at the time of operation, very precise standardisation of positioning for radiography and complex calculations (Lippert et al. 1982; Mogensen et al. 1982). This technique is impractical in the routine clinical situation.

The consistency of a landmark under conditions of rotation is directly related to its proximity to the relevant axis of rotation. For the most accurate measurement of proximal migration, the landmark should lie on a line connecting the centres of the hips. The lateral lip of the acetabulum is consistently identifiable and is within two centimetres of this line. When the pelvis rotates around its coronal axis, a slightly different portion of the lip may present to the x-ray beam, but the position of this relative to the centre of the hip changes very little. Although the growth of osteophytes may alter the appearance of the lip, recognisable features usually remain. Of the methods we tested for measurement of proximal migration, the acetabular line was more accurate than the others by a factor of three within both the 5 and 10° ranges.

The sacroiliac line is distant from the joint, so it is affected markedly by rotation. In order to approach closer to the hip centres, Davies (personal communication) constructed an approximately parallel line passing through points midway between the sacroiliac joint and the symphysis pubis. This is a useful reference line which performed much better than the sacroiliac line and showed a mean error of only 0.9 mm at 5° rotation. Sutherland et al. (1982) recommended the inferior margin of the teardrop as a mark for the detection of proximal migration, but our results show that the teardrop is a much less constant point during rotation around the coronal axis than it is around the vertical axis.

On the medial side of the acetabulum no such obvious feature as the acetabular margin presents itself.
as a suitable landmark. The teardrop was recommended by Charnley in a study on diagnostic criteria for protrusio acetabuli, but other authors have found that this mark readily changes shape and position on rotation (Katz 1969; Armbuster et al. 1978), and is often obscured by either the cement or the implant after hip replacement. Though it is sometimes difficult to define, we have found it to be a consistent landmark with a mean error of only 0.8 mm at the $5^\circ$ limit. The ilio-pubic line was used as an alternative by Charnley, although he acknowledged it to be an inferior reference line, and it has given inconsistent results in our study.

Armbuster et al. (1978), on the basis of a radiological study of dry-bone pelvises, favoured the ilio-ischial line. This is a sclerotic shadow cast by the obliquity of the quadrilateral plate in the medial wall of the acetabulum, which he found to be less affected by minor degrees of rotation than the teardrop though he gave no details of his results. Our study does not support these findings; the ilio-ischial line was significantly less consistent than the teardrop ($p < 0.01$).

Other authors have recommended the use of Köhler’s line which passes close to the medial wall of the acetabulum (Hubbard 1969; Sutherland 1982). Our results have shown this to be slightly more consistent than the ilio-ischial line. However, a reconstruction of Köhler’s line (Fig. 4) shows that it passes posterior to the most medial point of the acetabulum, whereas our line through the horizontal midpoint of the obturator foramen passes directly over it. Neither of these lines lies directly on the vertical axis of rotation, but the obturator/brim line approximates more closely to it. This theoretical account is supported by the greater accuracy achieved by the obturator/brim line in our study. There was no significant difference between the results of the obturator/brim line and the medial wall of the teardrop for measurement of medial migration, but the obturator/brim line is easier to define and cannot be obscured by the prosthesis. Both are significantly more accurate than the other lines examined.

Measurements from the acetabular margin line and the obturator/brim line are simple to perform, and both are accurate to within 2 mm at $10^\circ$ rotation limits. The results achieved using these methods have been demonstrated to be repeatable when the same radiographs are examined by independent observers, and when similar films are repeated in different pelvises. We are currently using this method for the accurate detection of acetabular erosion after hemiarthroplasty, but they should be equally applicable to the measurement of component migration after total hip replacement, or monitoring the progression of protrusio acetabuli.

Table I. Rotation around the coronal axis. Mean change in measurements (s.d.) at 5 and 10$^\circ$ on either side of neutral for each method of measurement in three pelvises

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean error at 5$^\circ$ (n=12)</th>
<th>Mean error at 10$^\circ$ (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sacroiliac line (SI)</td>
<td>5.3(2.2)</td>
<td>10.8(2.5)</td>
</tr>
<tr>
<td>Sacroiliac/symphysis line (SI/symp)</td>
<td>0.9(0.6)</td>
<td>1.4(1.1)</td>
</tr>
<tr>
<td>Inferior margin of teardrop (TD)</td>
<td>2.0(1.3)</td>
<td>2.5(1.3)</td>
</tr>
<tr>
<td>Acetabular margins (AM)</td>
<td>0.3(0.2)</td>
<td>0.5(0.4)</td>
</tr>
</tbody>
</table>

Significance of differences between results (Student’s paired t-test)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>5$^\circ$</th>
<th>10$^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI against AM</td>
<td>$p &lt; 0.001$</td>
<td>$p &lt; 0.001$</td>
</tr>
<tr>
<td>SI/symp against AM</td>
<td>$p &lt; 0.01$</td>
<td>$p &lt; 0.05$</td>
</tr>
<tr>
<td>TD against AM</td>
<td>$p &lt; 0.001$</td>
<td>$p &lt; 0.001$</td>
</tr>
</tbody>
</table>

Table II. Rotation around the vertical axis. Mean change in measurements (s.d.) at 5 and 10$^\circ$ on either side of neutral for each method of measurement in three pelvises

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean error at 5$^\circ$ (n=12)</th>
<th>Mean error at 10$^\circ$ (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iliopubic line (IP)</td>
<td>1.6(0.4)</td>
<td>2.8(0.6)</td>
</tr>
<tr>
<td>Köhler’s line (K)</td>
<td>1.8(0.8)</td>
<td>3.0(1.6)</td>
</tr>
<tr>
<td>Medial wall of teardrop (TM)</td>
<td>0.8(0.7)</td>
<td>1.0(0.6)</td>
</tr>
<tr>
<td>Ilio-ischial line (II)</td>
<td>2.1(1.0)</td>
<td>3.3(1.6)</td>
</tr>
<tr>
<td>Obturator/brim line (O/B)</td>
<td>0.7(0.6)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Significance of differences between results (Student’s paired t-test)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>5$^\circ$</th>
<th>10$^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>K against O/B</td>
<td>$p &lt; 0.001$</td>
<td>$p &lt; 0.001$</td>
</tr>
<tr>
<td>II against O/B</td>
<td>$p &lt; 0.01$</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td>IP against O/B</td>
<td>$p &lt; 0.001$</td>
<td>$p &lt; 0.001$</td>
</tr>
<tr>
<td>TD against O/B</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

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