The relationship between the angle of version and rate of wear of retrieved metal-on-metal resurfacings

A PROSPECTIVE, CT-BASED STUDY

We measured the orientation of the acetabular and femoral components in 45 patients (33 men, 12 women) with a mean age of 53.4 years (30 to 74) who had undergone revision of metal-on-metal hip resurfacings. Three-dimensional CT was used to measure the inclination and version of the acetabular component, femoral version and the horizontal femoral offset, and the linear wear of the removed acetabular components was measured using a roundness machine.

We found that acetabular version and combined version of the acetabular and femoral components were weakly positively correlated with the rate of wear. The acetabular inclination angle was strongly positively correlated with the rate of wear. Femoral version was weakly negatively correlated with the rate of wear. Application of a threshold of >5 μm/year for the rate of wear in order to separate the revisions into low or high wearing groups showed that more high wearing components were implanted outside Lewinnek’s safe zone, but that this was mainly due to the inclination of the acetabular component, which was the only parameter that significantly differed between the groups.

We were unable to show that excess version of the acetabular component alone or combined with femoral version was associated with an increase in the rate of wear based on our assessment of version using CT.

The inclination angle of the acetabular component of metal-on-metal (MoM) hip replacements has been statistically significantly associated with the rate of wear identified from explanted components. The mechanism involves edge loading but version of the acetabular component may also affect edge loading by impingement, subluxation/dislocation, and reduced cover of the head of the femoral component. De Haan et al attributed the failure of metal-on-metal hip resurfacings to insuffi cient or excessive version of the acetabular component in order to obtain the rim of the acetabular component.

Robust analysis of the effect of version of the acetabular component in vivo on any outcome variable needs to overcome the difficulties of obtaining valid three-dimensional measurements. CT measurements allow femoral version to be added to version of the acetabular component in order to obtain the combined version of both components.

The recent alert from the Medicines and Healthcare products Regulatory Agency of the United Kingdom concerned all MoM hips, encompassing resurfacing and total hip replacement (THR) using a large femoral head (>36 mm diameter) together with more conventional MoM bearings with heads of 28 mm in diameter. However, because conventional MoM bearings seem to have a long clinical heritage with minimal problems, we have focused on designs with head sizes >36 mm diameter.

Our aim was to determine the effect of isolated acetabular version and combined acetabular and femoral version on the rate of wear of failed MoM hips of the current generation. We wished...
to achieve this prospectively so that pre-revision CT could be used for the measurement of the version of components and could be related to the wear of the hip after revision.

**Patients and Methods**

The approval of the Institutional Review Board was obtained. A consecutive series of 45 patients (45 hips and 90 available components) underwent revision between February 2008 and February 2010. All the patients had CT scans performed before revision. We excluded eight patients who did not have adequate CT scans or MoM components of the current generation. In all, there were 33 men and 12 women with a mean age of 53.4 years (30 to 74) at primary hip replacement.

There were 25 Birmingham Hip Resurfacings (BHR) (Smith & Nephew, Warwick, United Kingdom); eight ASR (DePuy, Leeds, United Kingdom); four Cormet 2000 (Corin, Cirencester, United Kingdom); four Durom (Zimmer, Winterthur, Switzerland) and four Magnum (Biomet, Bridgend, United Kingdom) resurfacing devices.

We recorded gender, the age at implantation, the duration of implantation, the device used and the head size. From the pre-revision CT scans we measured the inclination and version of the acetabular component, the femoral version and the horizontal femoral offset.

**Three-dimensional (3D) CT measurement.** This was performed using 0.75 mm collimation (high resolution) and an artefact minimisation sequence (16-bit data processed on an extended scale), both of which allowed visualisation of the detail required to separate the face of the metal acetabular component from the metal femoral head. The radiation dose was only 1.7 mSv,\(^{12}\) compared with that of a traditional pelvic CT scan of 10 mSv. The anatomical inclination and version angles of the acetabular component were measured using a 3D-CT reconstruction software package (Robin 3D software).\(^{13,14}\) In order to quantify the proportion of patients inside and outside Lewinnek’s safe zone, we transformed the radiological values used to outline the perimeter into anatomical angles using the formula provided by Murray.\(^{15}\)

The retrieved acetabular components were measured for the position and depth of the wear scar using a Talyroid 365 roundness instrument (Taylor Hobson, Leicester, United Kingdom).\(^{16}\) This precision measuring machine uses a stylus probe to measure form, roundness and cylindricity to submicron accuracy (spindle accuracy of 0.02 μm, minimum gauge accuracy 12 nm). Each measurement was repeated three times and the mean value taken as the final reading. Circumferential and polar measurements of the explanted acetabular components were made. For the former, the component was mounted horizontally on the Talyroid rotating stage, centred and levelled to submicron accuracy using a function within the software. A total of 12 circular measurement profiles were made in increments of 1 mm along lines of latitude on the bearing surface of the component parallel to its rim (Fig. 1). The profiles were analysed using Ultra Software (Taylor Hobson Ltd, Leicester, United Kingdom). A maximum inscribed circle was fitted to each profile to represent the unworn surface of the component (Fig. 1). From the analysed profiles, the position and extent on any wear scar could be located in three dimensions (Fig. 2).

For the polar measurements of the acetabular component 12 profiles, at increments of 15° around the rim, were mea-
sured from its rim through the pole and back to the rim along the lines of longitude on the bearing surface. The polar measurement encompasses the region near the pole not covered by the circumferential measurement and allows wear and form to be distinguished from the circumferential measurement.

Femoral wear measurement. The heads were measured by mounting the head vertically on the Talyrond rotating stage. Partial roundness profiles were taken from the base of the head, through the pole, back to the base. In all 12 partial roundness profiles were taken by rotating the head at 15° increments. For analysis, a Minimum Circumscribed arc was fitted through each profile. This arc is the minimum diameter arc that completely enclosed the measured profile and provides an approximation of the manufactured shape of the head. However, head components are subject to form error of up to 20 μm, making it impossible to identify wear scars from a single profile. In order to separate the wear and form, all 12 profiles were superimposed using a Matlab program. This allows the worn and unworn regions of each profile to be clearly identified. The maximum linear wear depth can be calculated from the maximum deviation between worn and unworn profiles, and thus separates the form error from the wear calculation.

Measurement of femoral anteversion. The angle between the stem of the femoral component and the posterior condylar axis of the knee along the anatomical axis of the femur was recorded. The horizontal femoral offset was defined as the shortest distance between the centre of rotation of the femoral head and the anatomical axis.

Statistical analysis. The Pearson correlation coefficient was used to test the strength of possible associations between the wear rate and the following variables: inclination and version of the acetabular component, the horizontal femoral offset and the combined version of the two components.

The data were then categorised into low and high wearing groups after calculation of the mean linear wear rate from published MoM hip retrieval studies (Table I). High wear was therefore defined as a wear rate > 5 μm per year. We used the non-parametric Mann-Whitney U test to test for significant differences in the variables between the high and low wearing groups. A p-value ≤ 0.05 was considered to be significant.

Table I. Reports of the wear analysis of retrieved metal-on-metal hip articulations

<table>
<thead>
<tr>
<th>Author/s</th>
<th>Number of hips</th>
<th>Prosthesis*</th>
<th>Mean (range) time before explanted</th>
<th>Mean (range) in vivo linear wear rate (μm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langton et al5</td>
<td>15</td>
<td>ASR hip resurfacings and 1 ASR THR</td>
<td>18.0 mths (0.0 to 46.0)</td>
<td>Femoral components (n = 15) 1.3</td>
</tr>
<tr>
<td>Kwon et al18</td>
<td>8 pseudotumours 22 other causes</td>
<td>Hip resurfacings</td>
<td>Pseudotumour group 3.6 years (1.1 to 6.6)</td>
<td>Femoral components 8.1 for pseudotumours and 1.8 for other causes</td>
</tr>
<tr>
<td>Witzleb et al38</td>
<td>10</td>
<td>BHR</td>
<td>13.0 mths</td>
<td>Volumetric wear rates up to 270 mm³/year</td>
</tr>
<tr>
<td>Tuke et al19</td>
<td>5</td>
<td>2 McKee-Farrar; 2 Ring, 1 Müller</td>
<td>18.4 yrs</td>
<td>(Femoral and acetabular components) 2.2 (0.8 to 14.0)</td>
</tr>
<tr>
<td>Morlock et al27</td>
<td>32</td>
<td>Hip resurfacings</td>
<td>99.0 to 1200.0 days</td>
<td>Volumetric 1.1 to 26.0 mm³/year</td>
</tr>
<tr>
<td>Rieker et al20</td>
<td>337</td>
<td>Metasul</td>
<td>38 mths (1.0 to 12.0 yrs)</td>
<td>6.2 (no range reported)</td>
</tr>
<tr>
<td>Reinisch et al71</td>
<td>22</td>
<td>28 mm diameter plus Endoprothetik AG</td>
<td>32 mths (1.0 to 6.0 yrs)</td>
<td>7.6 (2.9 to 12.8)</td>
</tr>
<tr>
<td>McKellop et al52</td>
<td>11 acetabular components</td>
<td>McKee-Farrar</td>
<td>16.0 yrs</td>
<td>2.1 (0 to 195)</td>
</tr>
<tr>
<td>Schmidt et al23</td>
<td>13 acetabular components</td>
<td>McKee-Farrar</td>
<td>16.3 yrs</td>
<td>4.9 (0.1 to 300)</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>5.0</td>
</tr>
</tbody>
</table>

* THR, total hip replacement; BHR, Birmingham hip resurfacing

Table II. Details of the results. Correlation coefficients were calculated for each variable against the wear rate

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>25th centile</th>
<th>75th centile</th>
<th>Pearson correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetabular inclination (*)</td>
<td>50.1</td>
<td>43.3</td>
<td>58.6</td>
<td>0.55</td>
</tr>
<tr>
<td>Acetabular version (*)</td>
<td>24.5</td>
<td>10.0</td>
<td>36.0</td>
<td>0.17</td>
</tr>
<tr>
<td>Femoral version (*)</td>
<td>17.0</td>
<td>7.5</td>
<td>21.0</td>
<td>-0.13</td>
</tr>
<tr>
<td>Combined version (*)</td>
<td>41.5</td>
<td>25.3</td>
<td>48.5</td>
<td>0.18</td>
</tr>
<tr>
<td>Maximum acetabular wear depth (μm)</td>
<td>11.8</td>
<td>1.9</td>
<td>27.2</td>
<td>0.92</td>
</tr>
<tr>
<td>Duration in situ (mths)</td>
<td>32.5</td>
<td>22.0</td>
<td>45.0</td>
<td>0.04</td>
</tr>
<tr>
<td>Acetabular rate of wear (μm/yr)</td>
<td>5.6</td>
<td>3.2</td>
<td>27.2</td>
<td>1.00</td>
</tr>
<tr>
<td>Horizontal femoral offset (mm)</td>
<td>41.5</td>
<td>38.0</td>
<td>46.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Femoral rate of wear (μm/yr)</td>
<td>8.7</td>
<td>0.0</td>
<td>8.4</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Results

The measured parameters are summarised in Table II. The range of version of the acetabular component was greater than that of either its inclination or that of femoral version. The rate of wear of the acetabular component was very strongly positively correlated with its maximum acetabular wear depth (microns). Therefore all further analysis used the wear rate of the acetabular component for comparison, since this is the most frequently quoted parameter in this field.

The angle of inclination of the acetabular component was strongly positively correlated with the rate of wear (Fig. 3). Version of the acetabular component and combined version were weakly positively correlated with the rate of wear of the acetabular component (Figs 4 and 5). Femoral version was weakly negatively correlated with the rate of wear of the acetabular component.

The analysis comparing low and high wearing groups is shown in Table III. Inclination of the acetabular component was the only parameter studied which showed statistical significance (Mann-Whitney U test, p = 0.004). This is in agreement with the results of our correlation coefficient data. Plotting inclination, version and rate of wear by category (low wear ≤ 5 μm/year, high wear > 5 μm/year) showed that the proportion of low wearing hips inside Lewinnek’s safe zone\(^3\) was double that of high wearing hips: seven of 19 (36.8%) and five of 26 (19.2%), respectively (Fig. 6).

Horizontal femoral offset was not correlated with the rate of wear of the acetabular component. Furthermore, there was no correlation between the difference in horizontal femoral offset, that is the difference between the operated and the contralateral hip and the rate of wear of the acetabular component. The horizontal femoral offset was defined as the shortest distance between the centre of rota-
of the femoral head and the anatomical axis. Analysis of correlations between the rate of wear of the acetabular component and either inclination, acetabular version or combined version for the 25 BHR hips in isolation showed similar Pearson correlation coefficients of 0.58, 0.1 and 0.18, respectively, to those obtained for all the hips in our series (Table II).

The rate of wear of the femoral component was strongly correlated with the rate of acetabular wear (Table II) and produced the similar correlations against acetabular version and combined acetabular and femoral version of 0.21 and 0.16, respectively.

Discussion

We have analysed the effect of positioning of the components of MoM resurfacings on their performance in vivo, in particular, on the rate of wear. This is relevant because of the high proportion of unexplained failures of MoM hip resurfacings in contrast to standard replacements,\(^1\) and the association between the rate of wear and the formation of pseudotumour in MoM hips.\(^2\) Our study is the first to investigate this relationship, in any type of replacement using CT. Importantly, our CT measurements included acetabular and combined component version.\(^3\)

Our results showed that the wear rate of failed MoM resurfacings was strongly associated with the angle of inclination of the acetabular component, but only weakly associated with version, whether isolated acetabular or combined component version. A positive correlation between the acetabular inclination angle and the rate of wear was reported by Morlock et al\(^4\) using plain radiological measurement, but our use of 3D CT quantified this association more precisely. We showed a visible demarcation (Fig. 3) between low and high wear rates at 57° of acetabular inclination which is similar to the cut-off value of 55° proposed by De Haan et al\(^4\) when correlating blood metal ion levels with acetabular component inclination angles.

Most of the previous MoM hip retrieval studies\(^1,5,19-27\) concern either McKee-Farrar,\(^19,22-24,26\) other older-generation MoM hips,\(^25\) and articulations of small diameter (< 28 mm).\(^20,23\) A few have analysed the current MoM hips of large diameter,\(^1,5,27\) but only one series of eight hips included the pre-revision radiological assessment of acetabular version.\(^5\) It is difficult to determine a cut-off between the expected and excessive wear of MoM hips in vivo. It is possible that there is a variable response to levels of metal ions, suggesting that the definition of excessive wear may depend upon the individual patient. Nevertheless, this should not detract from our investigation into the relationship between the position of the acetabular component and the rate of wear.

Other data are available from two reports of retrieved ceramic-on-ceramic (CoC) hips,\(^6,7\) although we recognise that this type of bearing surface behaves differently from the MoM hip. One showed no association between the rate of wear and either acetabular inclination or version, and the other showed no association with acetabular inclination and a negative correlation with version. There was a statistically significant increase in the rate of wear for components with an acetabular version < 15°.\(^7\) The lack of an association between the angle of inclination and the rate of wear in CoC hips may be because the rate of wear is so low that it is close to the detection limit between form error and actual wear. Alternatively, CoC hips may be more tolerant to edge loading compared with MoM hips, as shown by hip simulator studies.\(^28,29\)

An important strength of our study was the use of 3D CT to measure both components. It is known that 3D CT is more precise and accurate than plain radiography and that this is more important for acetabular version than inclination.\(^30,31\) The difficulty in obtaining valid radiological measurements of version is a possible reason for the limited number of reports investigating version as a factor. The effect of acetabular version should ideally be considered in combination with femoral version to give the combined version.\(^9\) This requires measurement of the axis of femoral rotation and therefore information about the knee by CT as in our protocol.

There have been only two studies which have reported on the relationship between version and levels of blood metal ions.\(^5,12\) The first of these found a positive correlation for components with a bearing surface diameter of < 51 mm and a negative correlation for those > 51 mm but commented that the lowest levels of metal ions were found with version between 10° and 20°. The second found a positive correlation with version for components with a bearing surface diameter of < 51 mm and that the lowest levels of metal ions were found with version of between 10° and 20°.

Our study has several limitations. First, as with all retrieval studies, it was only possible to measure total wear and therefore did not allow separation of the bedding-in period, considered to occur within the first year of use, from steady-state wear.\(^33\) However, only four components failed within one year, all after nine months. Furthermore, there was a very strong positive correlation between total wear...
and the rate of wear. It must be acknowledged that there are limited data on the situation in vivo so that the quantification of the separation of bedding-in and steady-state wear can only be identified from hip simulator investigations.

Secondly, when measuring the position of the acetabular components in the pelvis we have assumed that the anterior pelvic plane is vertical. However, the pelvis tilts during sitting, walking and lying supine by a mean of 49° (-22° to 27°). Thirdly, not all the implants studied were produced by the same manufacturer, which influences the effective angle of version because of variation in the articular arc angle of the acetabular component. However, with the exception of the eight ASR resurfurcings, the remaining 37 hips had a mean articular arc angle of 161 ± 4°. The effect on version will be half the difference in the articular arc angle. However, this will be much less than that introduced by the uncertainty on plain radiological analysis of version compared with CT. Further reassurance of our results may be gained from our analysis of BHRs in isolation. The relationship between version and the rate of wear was very similar to that of the whole group. Lastly, it is possible that our study was underpowered. However, it is the largest study of its kind with the inclusion of 45 hips (90 components), and the first to correlate the rate of wear of failed MoM hip resurfacings with pre-revision CT measurements and also the first to study the relationship between acetabular version and the rate of wear in a large series of hips.

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References


