Migration and wear of long-term successful Charnley total hip replacements

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We analysed in-vivo migration and wear over a long period of all-polyethylene acetabular cups which had not been affected by mechanical loosening. The selection criteria of regular radiological follow-up, good clinical outcome (Charnley score of 5 or 6), continued walking without crutches and no radiological signs of loosening of the acetabular cups were fulfilled by 25 Charnley total hip arthroplasties.

Mean migration, measured by the Nunn method, was 0.6 mm in the medial and 0.2 mm in the cranial direction. The mean yearly rate of wear was 0.05 mm and 0.04 mm, with six and two cups having no detectable wear, as measured by the Livermore and Charnley-Cupic methods, respectively. The maximal detected wear was 3.7 mm. There were no changes in the rate of wear with time. Computerised Ein Bild Röntgen Analyse (single-image radiological analysis) measurements of 20 hips indicated plastic deformation of the cups.

We conclude that long-term successful cups do not migrate and have a very low rate of wear which was not affected by ageing of the polyethylene. There was no evidence that polyethylene wear alone caused mechanical loosening of the cup but high rates of wear seem to have an adverse prognostic value in terms of the long-term survival of the prosthesis.

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Patients and Methods

The patients were selected from about 9400 THRs performed at Wrightington Hospital between 1963 and 1974. All the implants were cemented Charnley low-friction arthroplasties with a high-density polyethylene cup and stainless-steel metal head, 22.25 mm in diameter. All the patients were operated on using the method described by Charnley.14 The cups had slight variations in the configuration of the marker wire.

The selected patients all had a minimum follow-up of 17 years and a good-to-excellent clinical result at the latest follow-up, with a score of 5 to 6 using the Charnley modification of the criteria of Merle d’Aubigné and Postel15 for pain, function and movement. None had had revision of the acetabular cup and none was using crutches. A complete series of at least nine postoperative radiographs...
and scored assessments was available for each patient. Demarcation of less than 1 mm was visible in zone one. A total of 25 hips in 21 patients fulfilled these criteria. The mean radiological follow-up was 22 years (17 to 25). There were 20 women and one man with a mean age at operation of 48 years (25 to 65) and a mean body-weight of 65 kg (46 to 86). The diagnosis was rheumatoid arthritis in ten hips, osteoarthritis in nine, congenital dislocation in four, fracture of the neck of the femur in one and psoriatic arthritis in one. Twelve hips were in patients who had involvement of other joints; eight were in those with two other affected joints, and in five patients only the hip undergoing operation was affected at that time. All but two hips were primary replacements. One patient had a non-union of the trochanteric osteotomy which caused occasional discomfort. Two patients had an undisplaced fracture of the shaft of the femur at operation; one had closed treatment and the other was managed by osteosynthesis.

On average, 12 radiographs (9 to 20) were studied for each patient. All measurements were started at the follow-up examination three months after operation and were corrected for radiological magnification using the known size of the head. Migration of the cup was measured on all radiographs by the method of Nunn et al.\textsuperscript{17} taking the teardrop line as the reference. Wear in vivo was assessed in three ways. The thickness of the polyethylene was measured by the method of Livermore, Istrup and Morrey.\textsuperscript{18} For all cups with detectable wear of at least 0.5 mm the direction of wear was measured on the last radiograph at 0° in the medial and 180° in the lateral direction. The measurements were made by the same person (TI). Wear was also determined by the Charnley-Cupic method\textsuperscript{19} by another author (LM) using an optical device for speeding up the procedure.

In 20 hips, migration and wear were analysed by the EBRA method (\textit{Ein Bild Röntgen Analyse}, single-image radiological analysis).\textsuperscript{20,21} The software was originally designed for equatorial marker wires, but was modified for use with Charnley cups in which the marker lies in the coronal plane. The presence of a tilt was analysed using specially-designed software. Five hips could not be measured because the marker wires were irregular. All EBRA measurements were made by the same person (TI) who was familiar with the method.

The rate of wear between each radiological examination was calculated for each patient and method. A regression analysis was made for rate of wear against time. The mean of the corresponding regression gradients of all patients was calculated. A positive mean gradient indicated an increasing rate of wear with time.

**Results**

Of the 368 radiographs, 359 were assessed by the Livermore method and all by the Charnley-Cupic method. Of the 25 hips, 20 with 307 radiographs were suitable for analysis by the EBRA method. Degenerative changes were seen, especially in the spine, and calcification of the tendons and blood vessels were often present, reflecting the length of follow-up. Such changes occasionally made it difficult to distinguish the pelvic markers. Changes in the projection resulted in exclusion of 140 radiographs from analysis by the EBRA software.

With the method of Nunn et al,\textsuperscript{17} the mean migration was 0.6 mm (–1.2 to +2.6; 95% confidence interval (CI) 0.19 to 0.98) in the horizontal and 0.2 mm (–1.7 to +1.4; 95% CI –0.11 to +0.54) in the vertical direction. The measurements were not linear. During follow-up, migration of 3.2 mm was seen on one radiograph (Fig. 1). With EBRA, the mean migration was 0.2 mm (–3.5 to +3.1; 95% CI –0.52 to +1.00) in the horizontal and –1.5 mm (–3.8 to +1.2; 95% CI –2.23 to –0.82) in the vertical direction. Negative values for migration in the cranial direction were obtained for 18 of 20 cups, suggesting caudal migration. No patient had a migration of as much as 1 mm in the first five years after operation. No wear at all was detected in six hips by the Livermore method and in one hip by the
Charnley-Cupic method. With EBRA, all 20 hips showed detectable wear, although in three it was below 0.5 mm (Table I).

The greatest wear was 3.7 mm after 24 years (0.15 mm per year), measured by the Livermore method. As shown in Figure 2, this patient had the greatest wear with all methods (EBRA 3.3 mm, Charnley-Cupic 1.6 mm).

The mean wear and rate of wear of all hips were greater when assessed by the Livermore than by the Charnley-Cupic method. We found the highest rates during a shorter period of follow-up (19 years) with EBRA (Table II).

Dividing the patients by diagnosis, we detected a slightly higher rate of wear in patients with inflammatory joint disease than in those with degenerative joint disease. When the patients were classified by the number of affected joints, those with several joints affected had a slightly higher rate of wear than those with only one or two.

The mean gradient for the regression of rates of wear and time was 0.003 (–0.03 to +0.04; 95% CI –0.004 to +0.01) with the Livermore method and 0.005 (–0.01 to +0.14; 95% CI –0.007 to +0.02) with the Charnley-Cupic method. With EBRA, the mean gradient was –0.001 (–0.01 to +0.03; 95% CI –0.007 to +0.005). Figure 3 shows regression analysis with time in one patient. We found no trend towards change in rate of wear with time. The mean direction of wear was 80° (sd 17°). The most medial direction of wear of 55° was seen in a patient with a shortening of 2 cm on the same side. The most lateral direction of wear of 110° was noted in a patient with an arthrodesis and definite shortening on the other side.

**Table I.** Mean wear (mm) in 12 patients with total wear of less than 0.5 mm as measured by at least one of the methods in use

<table>
<thead>
<tr>
<th>Case</th>
<th>Follow-up (yr)</th>
<th>Livermore</th>
<th>Charnley-Cupic</th>
<th>EBRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19</td>
<td>0.0</td>
<td>0.4 *</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>0.0</td>
<td>0.2</td>
<td>1.9</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>0.0</td>
<td>0.4</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>0.0</td>
<td>0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>0.0</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>6</td>
<td>17</td>
<td>0.0</td>
<td>0.0 *</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>0.5</td>
<td>0.4</td>
<td>1.9</td>
</tr>
<tr>
<td>8</td>
<td>18</td>
<td>0.6</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>0.6</td>
<td>0.4</td>
<td>*</td>
</tr>
<tr>
<td>10</td>
<td>22</td>
<td>0.7</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>11</td>
<td>21</td>
<td>1.2</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>0.5</td>
<td>0.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

* three patients with low wear, as measured by the Livermore and/or Charnley-Cupic methods, could not be analysed by EBRA

**Table II.** Rate of wear (mm/year) in the patients as assessed by the three different methods

<table>
<thead>
<tr>
<th>Assessment method</th>
<th>Rate of wear</th>
<th>Range</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livermore (n = 25)</td>
<td>0.052</td>
<td>0.00 to 0.15</td>
<td>0.031 to 0.073</td>
</tr>
<tr>
<td>Charnley-Cupic (n = 25)</td>
<td>0.036</td>
<td>0.00 to 0.08</td>
<td>0.026 to 0.046</td>
</tr>
<tr>
<td>EBRA (n = 20)</td>
<td>0.081</td>
<td>0.01 to 0.17</td>
<td>0.061 to 0.10</td>
</tr>
</tbody>
</table>

**Discussion**

At the time of the initial operation most of the patients were severely handicapped and would have had low scores on the Merle d'Aubigné and Postel assessment charts. It was necessary to review large numbers of case notes before finding 25 hips in patients who were still active and could walk without crutches. The mean age at the time of operation was low as evidenced by their long survival. There was only one man, probably because of the diagnosis and the longer life expectancy of women. The group of patients analysed may not be representative of those who may undergo THR today.

Fig. 2
The Charnley-Cupic method underestimates the wear in patients with the greatest wear, as determined by all three methods.
Migration is generally accepted as evidence of loosening of the prosthesis. Nunn et al. reported an accuracy of ±3 mm for measurement of migration with their method, which was confirmed by our study. The reference lines for measuring migration used by Nunn are the most accurate for simple measurement; errors may arise due to pelvic tilt or technical inaccuracy.

As assessed by EBRA none of the cups migrated more than 1 mm in the first five years after operation, which would have been a poor prognostic sign. Vertically, the mean migration was negative. Plastic deformation of the cups may have caused widening of the contrast wire in the coronal plane, when the elliptical projection of the contrast wire becomes larger. The calculated centre of the ellipse then migrates in the caudal direction.

Roentgen stereophotogrammetric analysis studies indicate that many cups may be loose immediately after primary implantation. We could not determine whether the implants were rigidly fixed from the beginning, but no major degrees of migration occurred in the early postoperative period or during the long-term follow-up in successful cases of cemented THR.

Wear as measured by EBRA was greater than that by other methods, perhaps because of plastic deformation affecting the shape of the contrast wire. The other methods, which measure the thickness of the plastic, are less affected by this phenomenon. Nevertheless, all measurements of linear wear are a combination of plastic deformation and time-wear which may be even less.

The explanation for the absence of wear is difficult. Only one hip showed no wear as determined by both the Livermore and Charnley-Cupic methods. No radiological wear should be interpreted as no wear detectable with the method used.

The mean wear and the rates of wear are the lowest yet published. Sychterz et al. studied wear of successful cups in vitro at post-mortem. In all-polyethylene cemented cups they reported similar rates of wear. They found a good correlation between radiological wear and direct measurements on the cups, but the study could be made only at the endpoint and did not provide information about patterns of wear with the implant in use. They concluded that polyethylene wear in well-functioning implants is not as great as reported previously. In our study, the mean age at operation was lower, which might indicate that our patients were more active. Lower rates of wear may be expected in patients with rheumatoid arthritis and in those with disease in several joints. All the patients included in our study, however, were not severely handicapped in their walking ability, as is shown in the charts. We found slightly higher rates of wear in patients with inflammatory joint disease and in those with several affected joints. We do not believe that the diagnosis or disability of the selected patients explains the extremely low rates of wear.

Since there is a correlation between aseptic loosening and wear, the exclusion of loose and suspect cups will lower the expected rate of wear. Cups which had been fixed initially, but with a higher rate of wear, may already have failed because of mechanical complications such as impingement of the head or wearing-out.

In our series of highly selected patients, we found no significant change in the rate of wear with time. In well-fixed cups the rate of wear seems to be constant throughout the patient’s life. Long-term successful THRs seem to have very low rates of wear. The degree of wear probably varies greatly in individual patients and implants.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

Fig. 3
Regression analysis of rates of wear and time in one patient, measured by the Livermore method. The gradient of the regression line is almost zero (0.0014), indicating no change with time. The wear-time diagram of this patient is shown in Figure 2.


