POLYETHYLENE WEAR IN CEMENTED METAL-BACKED ACETABULAR CUPS

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We examined radiographic polyethylene wear in 233 cemented total hip arthroplasties (201 patients) with either a metal-backed or a non-metal-backed acetabular cup. All patients had identical cemented one-piece titanium femoral stems with a femoral head diameter of 28 mm. The mean linear wear rate was 0.11 mm/yr in metal-backed sockets and 0.08 mm/yr in non-metal-backed sockets (p = 0.0002). The mean volumetric wear rate was 66.2 mm$^3$/yr in the metal-backed sockets and 48.2 mm$^3$/yr in the polyethylene sockets (p = 0.0002).

The addition of metal backing to a cemented acetabular cup therefore resulted in a 37% increase in mean polyethylene wear rates which may partially explain the higher failure rate of cemented metal-backed cups.

Linear regression analysis also implicated increased follow-up time (log), gross acetabular migration, metal backing and male gender in increasing polyethylene wear.

We advocate the use of an all-polyethylene cup in cemented total hip arthroplasty. The increased polyethylene wear must also cause concern about the wear rate of uncemented metal-backed acetabular sockets.

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Metal backing of acetabular cups is common in cemented total hip arthroplasties. The original purpose was to allow the changing of a worn polyethylene liner without disrupting the cement-bone interface (Harris 1971). Metal backing has been shown by finite element analysis to stiffen the polyethylene and produce a more even distribution of stress (Pederson, Crowninshield and Brand 1981; Carter 1983; Gonzalez, Glass and Mallory 1988). In theory, this reduces periacetabular stress, thus decreasing aseptic loosening rates and improving socket longevity (Van Syckle and Walker 1980; Carter, Vasu and Harris 1982; Carter 1983; Crowninshield et al 1983).

At first this was reported to be successful (Harris and White 1982; Mattingly et al 1985), but the results of later studies did not equal the biomechanical predictions (Ritter et al 1990; Yancey et al 1990). Harris and Penenberg (1987) observed frank or impending loosening in 41% of cemented metal-backed acetabular cups followed for at least ten years, and Ritter et al (1990), comparing cemented metal-backed with non-metal-backed cups, found a statistically significant increase in complete radiolucency (39% as against 23%), a greater gross migration rate (4% as against 2%), and a greater revision rate (6% as against 2%).

The diameter of the femoral head has recently been shown to affect acetabular wear rates (Livermore, Ilstrup and Morrey 1990), a 32 mm femoral head giving greater volumetric wear than a 22 mm or a 28 mm head. Others have reported increased acetabular revision rates with 32 mm femoral heads (Ritter et al 1983; Morrey and Ilstrup 1989). The smaller 22 mm femoral head, however, is known to produce greater linear wear, which may lead to neck-socket impingement and secondary acetabular loosening (Charnley and Halley 1975; Wroblewski 1985; Eftekhar and Nercessian 1988; Livermore et al 1990). Consequently, the 28 mm femoral head is considered to have the best wear characteristics (Bartel, Bicknell and Wright 1986; Livermore et al 1990). It has also been suggested that polyethylene wear debris is a factor in the aetiology of aseptic loosening in total hip arthroplasty (Wroblewski 1979, 1985, 1988; Uchida et al 1980; Pederson et al 1981; Nishio, Eguchi and Ogata 1982; Wilson, Rimnac and Wright 1987; Howie et al 1988;

Post-mortem examination or analysis of revised cups does not provide sufficient numbers for determination of polyethylene wear, and radiographic measurements have been considered imprecise (Clarke et al 1976). A method of accurately determining polyethylene wear, however, has been reported by Livermore et al (1990). We used their technique to study wear in two groups of cemented total hip arthroplasties. All had a 28 mm diameter femoral head, but one group had a pegless all-polyethylene cup and the other a pegged, one-piece metal-backed cup.

PATIENTS AND METHODS

Between 1980 and 1983 the senior author (MAR) performed a total of 315 hip arthroplasties in 276 patients; the clinical results have been previously reported (Ritter et al 1990). From this total we excluded 82 hips in 75 patients because of death, loss to follow-up, or revision or resection arthroplasty before three years. Details of the remaining 233 cemented total hip arthroplasties in 201 patients which form the basis for our study are shown in Table I.

All patients had cemented Miami Orthopaedic Surgical Consultants (MOSC) stems (Biomet Inc, Warsaw, Indiana). These are one-piece titanium stems with a non-implanted femoral head of 28 mm diameter and a head-neck offset greater than 25 mm. The selection of cup was not randomised, but initially was by availability. From 1980 to 1981, only non-pegged, all-polyethylene cups were implanted. A cup with a metal backing 1.5 mm thick and 3 mm polyethylene spacers became available in mid-1981, after which both socket types were used randomly until the remaining all-polyethylene sockets had been implanted. From 1982 onwards, all the implanted sockets were metal-backed. In the whole series, 134 cups were metal-backed and 99 polyethylene alone. Both types of cup were moulded from Himont medical-grade ultra-high-molecular-weight polyethylene (Biomet Inc, Warsaw, Indiana).

Operative technique. We used a straight lateral approach with trochanteric osteotomy. The current techniques of cementing utilised low-viscosity cement for both the acetabulum and the femur. For the acetabulum we used pulsatile lavage, large drill holes, Neosynephrine-soaked gel foam, thorough drying, and cement pressurisation; for femoral cementing we used a distal plugging device, pulsatile lavage and brushing, Neosynephrine-soaked sponges, drying, proximal-to-distal cement insertion using a vent tube, and cement pressurisation. Postoperatively, all patients had identical rehabilitation with encouragement of early partial weight-bearing, using crutches or a walker for the first two months.

Radiographic study. Standard anteroposterior pelvic radiographs were taken at intervals on non-portable equipment by the same technician using the same technique. The most recent postoperative radiograph and that made two months after arthroplasty were examined to determine polyethylene wear by the technique of Livermore et al (1990). The time interval was rounded to the nearest half-year and all measurements were made by one of the authors (HEC). For 28 hips in 22 patients measurements were made on films taken elsewhere, after carefully assessing pelvic position. Each radiograph was measured twice to the nearest 0.05 mm using a manual caliper. The direction of linear wear in the frontal plane was referenced from a vertical line drawn through the centre of the femoral head and perpendicular to a line tangential to the ischial tuberosities (Livermore et al 1990). Wear medial to this line was recorded as positive. A computer software program (Advanced System Consultants, Indianapolis, Indiana) was developed to convert the radiographic measurements into actual linear wear and rates of linear wear after correcting for magnification. This adjustment accounts for the expression of results to three places of decimals.

| Table I. Details of 233 cemented total hip replacements in 201 patients, in which two types of acetabular cup were used* |
|-----------------|----------------|----------------|
|                  | Metal-backed   | All-polyethylene |
| Hips             | 134            | 99             |
| Patients         |                |                |
| Female           | 69 (59%)       | 51 (60%)       |
| Male             | 47             | 34             |
| Mean age in years (range) | 69 (22 to 89) | 67 (36 to 88) |
| Mean weight in kg (range) | 59 (40 to 127) | 59 (43 to 112) |
| Primary arthroplasty | 121 (90%)    | 83 (84%)      |
| Diagnosis        |                |                |
| Osteoarthritis   | 92 (68.6%)     | 59 (59.6%)     |
| Rheumatoid arthritis | 10 (7.5%)  | 6 (6.1%)       |
| Osteonecrosis    | 10 (7.5%)      | 13 (13.2%)     |
| Revision arthroplasty | 13 (9.7%) | 16 (16.2%)     |
| Failed cup or hemiarthroplasty | 4 (3.0%) | 3 (3.0%)       |
| Other            | 4 (3.0%)       | 2 (2.0%)       |
| Average follow-up in years (range) | 6.0 (3 to 10) | 6.8 (3 to 10) |

*Difference statistically insignificant at p > 0.05

As acetalubar wear is cylindrical the volume of wear debris can be calculated from the radius of the femoral head and the amount of linear wear (Charnley, Kamangar and Longfield 1969; Livermore et al 1990), and can be expressed as volumetric wear rate per year. Since the completion of the measurements that we report, a second observer has independently re-measured all the radiographs in the all-polyethylene group. He found exactly the same mean wear rate. More support for the method comes from several direct retrieval specimens in which direct measurement correlated well with the earlier radiographic estimates.

We recorded gross acetalubar migration when the socket had moved by more than 5 mm or the lateral tilt had changed by more than 10°.
Statistical analysis. We used the binomial test for percentages and a t-test for numerical means with the SAS software program (SAS Institute, Cary, North Carolina). The Wilcoxon rank-sum test was performed on ordered categorical data. Linear regression analysis was used to analyse several independent variables that might affect the dependent variables of acetabular wear. To describe acetabular wear, an estimated linear wear equation was modelled.

RESULTS

Amount of wear. The results are shown in Table II. The linear wear averaged 0.641 mm (0 to 1.897 mm) in metal-backed cups and 0.534 mm (0 to 2.597 mm) in non-metal-backed cups (p = 0.04). The volumetric wear in metal-backed cups averaged 394.86 mm$^3$ (0 to 1168.38 mm$^3$) while that in non-metal-backed cups averaged 329.06 mm$^3$ (range 0 to 1599.01 mm$^3$) at p = 0.04.

Table II. Wear and rates of wear in metal-backed and non-metal-backed acetabular cups (mean ± SD and range)

<table>
<thead>
<tr>
<th>Cup</th>
<th>Wear (mm)</th>
<th>Rate of wear (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linear (mm)</td>
<td>Linear (mm)</td>
</tr>
<tr>
<td></td>
<td>Volumetric (mm$^3$)</td>
<td>Volumetric (mm$^3$)</td>
</tr>
<tr>
<td>Metal-backed (n = 134)</td>
<td>0.641 ± 0.347 (0 to 1.897)$^*$</td>
<td>394.6 ± 213.75 (0 to 1168.38)</td>
</tr>
<tr>
<td>All-polyethylene (n = 99)</td>
<td>0.534 ± 0.436 (0 to 2.597)$^*$</td>
<td>329.06 ± 268.47 (0 to 1599.01)</td>
</tr>
</tbody>
</table>

*difference statistically significant at p = 0.04

**difference statistically significant at p = 0.0002

Table III. Sizes and numbers of metal-backed and all-polyethylene acetabular cups implanted

<table>
<thead>
<tr>
<th>Metal-backed</th>
<th>Polyethylene thickness (mm)</th>
<th>All-polyethylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside diameter (mm)</td>
<td>Number</td>
<td>Thickness (mm)</td>
</tr>
<tr>
<td>48</td>
<td>4</td>
<td>5.5</td>
</tr>
<tr>
<td>51</td>
<td>1</td>
<td>7.0</td>
</tr>
<tr>
<td>54</td>
<td>34</td>
<td>8.5</td>
</tr>
<tr>
<td>57</td>
<td>52</td>
<td>10.0</td>
</tr>
<tr>
<td>60</td>
<td>43</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Wear rates. The results are shown in Table II. Linear wear rates for metal-backed acetabular components averaged 0.107 mm/yr (0 to 0.305 mm/yr) while those for non-metal-backed components averaged 0.078 mm/yr (0 to 0.371 mm/yr). This difference is statistically significant (p = 0.0002). Volumetric wear rates for metal-backed components averaged 66.13 mm$^3$/yr (0 to 188.10 mm$^3$/yr) and for non-metal-backed components it was 48.22 mm$^3$/yr (0 to 228.43 mm$^3$/yr). This difference is also statistically significant (p = 0.0002). The direction of linear wear averaged +12° in the metal-backed group and +23° in the non-metal-backed group.

Acetabular migration. Gross evidence of migration was seen in 19 (14%) metal-backed cups as compared with only three (3%) non-metal-backed cups (p = 0.0015).

Linear regression analysis. A hypothetical model was constructed using linear regression analysis to evaluate factors which influenced linear wear. This type of wear was chosen because it was best fitted to the mathematical model. Potential factors were analysed alone and in combination.

Four variables were found to influence polyethylene wear. First, metal backing added an estimated 0.15 mm (0.147 ± 0.049, p = 0.0029) of linear wear; secondly, gross acetabular loosening was associated with an increase of linear wear of 0.17 mm (0.172 ± 0.080, p = 0.033) when compared with radiographically stable sockets. The third factor was length of time after surgery; the increasing wear gave a logarithmic curve and was very highly significant (p = 0.0001). Finally, male gender was associated with an increase in linear wear of 0.21 mm (0.208 ± 0.057, p = 0.0003). We found no significant correlations of linear wear with age, diagnosis, cup size, revision cases, acetabular lateral tilt, and/or patient weight. The last showed a very insignificant effect (p = 0.478) but was kept in the model for adjustment purposes. A linear wear equation was derived using the regression model:

Linear wear = -0.265 -0.0005 (weight) + 0.172 (if loose) + 0.147 (if metal) + 0.409 × log (follow-up years) + 0.208 (if male).

Initial thickness of polyethylene. For a given outside diameter, the polyethylene in non-metal-backed cups was 1.5 mm thicker than that in the equivalent metal-backed cups. The size and number of all the acetabular cups implanted are shown in Table III.

DISCUSSION

The methods of measuring acetabular wear described by Charnley and Cupic (1973) and by Charnley and Halley (1975) have been shown to be imprecise by Clarke et al (1976), but Livermore et al (1990) were able to report a radiographic technique with an average accuracy of 0.075 mm. In our series, blinded radiographic evaluation was obviously impossible, and therefore, to eliminate interobserver error, each radiograph was measured twice by a single observer. Small errors would greatly influence the results, but we feel that the intra-observer error was small in comparison with the mean radiographic differences between the two socket types. Since it is impossible to obtain large numbers of post-mortem specimens, we
feel that this radiographic method is acceptable. It is unlikely that polyethylene creep influenced the results (Rimnac et al 1988).

Our results for non-metal-backed sockets (linear wear rate 0.08 mm/yr, volumetric wear rate 48.2 mm³/yr) are remarkably similar to those of 0.08 mm/yr and 48.4 mm³/yr, respectively reported by Livermore et al (1990), although they used a T-28 femoral stem with a stainless-steel-bearing surface. Consequently, the titanium femoral-bearing surface used in our series does not seem to be an important factor in the wear rates that we measured. There has been some concern about titanium as a bearing surface, but in the absence of third-body wear, it has been reported that polyethylene wear rates in vivo are comparable for stainless steel, cobalt chrome, and titanium (Agins et al 1988; Lombardi et al 1989; Black et al 1990; McKellop et al 1990).

Our retrospective series was well matched for age, sex, diagnosis, patient weight, cup size, length of follow-up, postoperative management and percentage of primary cases. All operations were performed by one surgeon (MAR) at the same institution, using the same technique. The only difference between the two groups was the type of acetabular component. The metal-backed acetabular components had 3 mm polyethylene spacer pegs on the periphery and a decreased polyethylene thickness. The thinnest polyethylene width, however, in a metal-backed component was 5.5 mm and this just meets the minimum recommendation of 5 to 6 mm (Bartel, Wright and Edwards 1983). The pegless, all-polyethylene components had a thicker initial polyethylene thickness, but previous theoretical studies have suggested that the lack of pegs can result in unequal cement thicknesses and undesirable eccentric placement of the socket (Oh 1983).

The 37% increase in mean linear and volumetric wear was highly significant (p = 0.0002); it may be explained by the increased polyethylene peak stresses produced by the addition of a metal backing (Dalstra and Huiskes 1991). The increase in mean volumetric wear may also be related to the increased acetabular loosening rates which we have previously reported for metal-backed components (Ritter et al 1990).

We found that metal backing, acetabular loosening, male gender, and a long follow-up time were associated with accelerated wear. Implantation time and component loosening are recognised factors (Clarke et al 1976; Dowling 1983; Wroblewski 1985, 1988; Rimnac et al 1988), but the influence of metal backing and of male gender has not previously been reported.

Metal backing may adversely change the wear characteristics of ultra-high-molecular-weight polyethylene and result in a larger amount of wear debris. Schmalzried et al (1992) have implicated accelerated macrophage activity due to particulate polyethylene debris in acetabular loosening. Our results are consistent with this biological theory of acetabular loosening.

In view of the 37% increase in mean polyethylene wear rate and the four-fold increase in socket migration with metal-backed acetabular cups we advocate the use of an all-polyethylene cup when this is to be cemented into position. The increased polyethylene wear must also cause concern as to the wear rate of polyethylene in uncemented metal-backed acetabular components.

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REFERENCES


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