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Dual mobility retentive acetabular liners and wear: Surface analysis of 40 retrieved polyethylene implants

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ABSTRACT

Purpose of the study: Dual mobility systems with retentive acetabular liners have been used in clinical practice for total hip arthroplasty since 1976. The dual mobility system preserves a wide range of motion while providing greater stability. This study measured wear on the concave and convex surfaces of 40 retrieved polyethylene liners, to evaluate the advantages of this system in relation to wear.

Material and methods: Forty polyethylene inserts that had been removed due to infection or mechanical failure after a mean 8 years were analyzed. The mean age of patients at arthroplasty was 46 years old. Macroscopic analysis was followed by surface analysis with direct measurement of changes in the curvature radii. The internal concave surface was measured in three dimensions using a 4-mm stylus (BNH 706). External convexity was measured by lateral projection. The estimated error was ± 5 µm for both measurement methods. Manufacturers’ tolerance for these implants was approximately 50 µm. Linear wear and wear volume was determined by comparing the measured dimensions with the theoretical dimensions of new liners.

Results: Macroscopically, all of the pieces studied had lost the initial machined grooves on the convex surface; 40% of the pieces showed visible wear of the retentive collar. Mean annual convex surface wear was 9 µm (SD 9 µm) and 73 µm (SD 69 µm) for the concave surface. Mean total wear, which was the sum of the wear on the convex and concave surfaces was 82 µm (SD 72 µm). Wear volume was 28.9 mm³/yr for the convex surface (SD 27.6) and 25.5 for the concave surface (SD 23.2) with a mean annual total wear volume of 54.3 mm³/yr (SD 39.6).

Discussion: Total wear in the 40 dual mobility liners that had functioned in vivo was similar to that reported in metal–polyethylene bearings with 22.2 mm femoral heads. The results of wear in both the convex and concave surfaces show that wear with the dual mobility system was not increased compared to conventional metal–polyethylene bearings, while providing better retention and greater stability.

Conclusion: The use of dual mobility acetabular liners is an attractive solution when a metal–polyethylene bearing is needed. The increased joint stability is not associated with increased wear.

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1. Introduction

The concept of dual mobility was developed in 1976 by Bousquet et al. [1]. The dual mobility system includes a polyethylene liner with a concave surface for internal mobility and a convex surface for external mobility. There is a collar on the internal polyethylene insert that ensures retention of the head component. The presence of two levels of mobility theoretically preserves satisfactory range of motion while ensuring stability and retention. The study by Aubriot et al. [2] showed that the results with this type of dual mobility acetabular component were promising after 5 years of follow-up. The estimated survival of implants at 12 years in the study by Farizon et al. [3] was 95.37% which is much better than the results reported by Anderson et al. [4] with constrained acetabular components. Leclercq et al. [5] also reported that this type of dual mobility acetabular component can be successfully used to treat recurrent dislocation of total hip arthroplasties (THA) and is somewhat similar to the principle of the tripolar cup described by Grigoris et al. [6]. At a moment when different dual mobility systems are being developed, we performed an objective evaluation of the characteristics of wear of polyethylene liners that had been used in vivo. Indeed, it seemed important to determine whether the improved stability was associated with increased wear.

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Table 1

<table>
<thead>
<tr>
<th>Reason for liner removal</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraprosthetic dislocation</td>
<td>13</td>
</tr>
<tr>
<td>Isolated</td>
<td>8</td>
</tr>
<tr>
<td>With acetabular loosening</td>
<td>5</td>
</tr>
<tr>
<td>Isolated acetabular loosening</td>
<td>16</td>
</tr>
<tr>
<td>Bipolar loosening</td>
<td>1</td>
</tr>
<tr>
<td>Isolated femoral loosening</td>
<td>5</td>
</tr>
<tr>
<td>Infection</td>
<td>2</td>
</tr>
<tr>
<td>Fracture of the femoral component</td>
<td>2</td>
</tr>
<tr>
<td>Instability with non-union of the greater trochanter</td>
<td>1</td>
</tr>
</tbody>
</table>

2. Materials and methods

2.1. Inclusion criteria

All the components analyzed were implanted between April 1981 and September 1992 and removed at the same center (Centre d’orthopédie et traumatologie, CHRU de Saint-Étienne). Only implants that had been in place for more than three years were included in the study. The threshold of three years made it possible to exclude potentially defective components. Moreover if a shorter period had been used, manufacturing tolerances and measurement errors could have masked wear. Implants that were heat-treated after removal (resterilized) were not included because of the changes in size that can be caused by this type of treatment. According to Schmalzried et al. [7] wear is essentially a function of activity. Components from patients who were over the age of 80 at THA were not included in the study. Indeed the activity in extremely elderly patients is often reduced, and components from these subjects could have abnormally low wear.

2.2. Patients

Patient data were obtained retrospectively from the patients’ medical files. There were 21 women and 19 men. The mean age at THA was 46 years old, (range 19–76). Two thirds of the patients considered to be active at THA and one third were considered to be sedentary. The level of activity was intense in 15% (sports or farming). Twelve/40 interventions were for revision THA. The etiology of primary THA was osteoarthritis of the hip in 9 cases, aseptic osteonecrosis in 9, femoral fractures in 3, congential hip dislocation in 3, inflammatory rheumatic disorder in 2, sequellar proximal femoral epiphysiolysis of the hip and separation of the implant from the bone in one case each. The indication for dual mobility prostheses was not a potentially higher risk of dislocation, because until 1998 these prostheses were used in our unit for almost all THA. Arthroplasties were removed after a mean 8 years (96 months) (range 36–186 months).

The reasons for surgical revision resulting in the retrieval and analysis of the polyethylene liners were found in the medical file or the surgical report and are summarized in Table 1. There were 13 cases of intraprosthetic dislocation of the polyethylene liner; intraprosthetic dislocation was isolated in 8 cases and associated with acetabular loosening in 5 cases. There was isolated acetabular loosening in 16 cases, femoral loosening in 5 cases, bipolar loosening in one case, peri-prosthetic infection in 2 cases, fracture of the femoral component in 2 cases and in one case instability with recurrent dislocation associated with non-union of the greater trochanter.

2.3. Implants

The characteristics of polyethylene wear were evaluated in 40 dual mobility polyethylene liners removed in our hospital unit.

Three components make up a dual mobility system (Fig. 1): a) a thin spherical concave metallic cup. In this study there were titanium alloy cups in 4 cases, and steel 316L cups in 36 cases. Cup fixation was ensured in all cases by 2 plugs, one ischiatic and the other pubic, and a 4.5 mm diameter screw inserted into the ilium through anchor holes located in the upper part of the cup. All of the metallic cups were lined with a layer of aluminium oxide which was applied with a plasma torch. b) A high molecular weight, polyethylene liner with a perfectly spherical exterior, for femoral head component insertion on the interior. The entrance of the liner was smaller than the diameter of the femoral head to ensure retention. External and internal dual mobilities were concentric. c) The femoral head component.

All of the polyethylene liners studied came from modular femoral components with two different stem designs: thirty-two of these stems were made of stainless steel with a neck diameter of 16 mm, the remaining eight were titanium alloys with a neck diameter of 13 mm. All of the polyethylene liners had an internal diameter which was designed to contain a 22.2 mm stainless steel head.

None of the studied polyethylene liners had undergone heat-treated resterilization after decontamination. Liner manufacturing tolerance was ± 0.05 mm in all cases. These liners and all of the other components of the prostheses were obtained from the same manufacturer (Serc®). All of the polyethylene liners were produced by the manufacturer from bars of high density polyethylene. All of these liners were made from UHMWPE polyethylene with a molecular weight of $4.5 \times 10^5$ g/mol and a density of 0.93 g/cc. Sterilization was ensured by gamma sterilization in air at 25 kGray.

At implantation the minimum thickness of polyethylene in the liner was 6.3 mm for the smallest diameter used (41 mm diameter cup). The maximum thickness of the polyethylene was 16.3 mm for a metal cup of 61 mm (Table 2).

2.4. Methods of measurement

Evaluation of the polyethylene liners included macroscopic assessment and measurement of changes in the concave and convex surfaces. Measurement of the changes in concave and convex surface dimensions was performed according to ISO 4291 norms: 1985 in relation to methods of evaluation of departures from roundness and variations in radius.
Table 2
Distribution of the liners in relation to polyethylene thickness at implantation.

<table>
<thead>
<tr>
<th>External cup diameter (mm)</th>
<th>Polyethylene thickness (mm) ± 0.05</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>6.3</td>
<td>3</td>
</tr>
<tr>
<td>43</td>
<td>7.3</td>
<td>3</td>
</tr>
<tr>
<td>45</td>
<td>8.3</td>
<td>7</td>
</tr>
<tr>
<td>47</td>
<td>9.3</td>
<td>2</td>
</tr>
<tr>
<td>49</td>
<td>10.3</td>
<td>4</td>
</tr>
<tr>
<td>51</td>
<td>11.3</td>
<td>8</td>
</tr>
<tr>
<td>53</td>
<td>12.3</td>
<td>5</td>
</tr>
<tr>
<td>55</td>
<td>13.3</td>
<td>4</td>
</tr>
<tr>
<td>57</td>
<td>14.3</td>
<td>3</td>
</tr>
<tr>
<td>59</td>
<td>15.3</td>
<td>0</td>
</tr>
<tr>
<td>61</td>
<td>16.3</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

2.5. Macroscopic analysis

Macroscopic analysis mainly involved looking for machined grooves in the convex surface of the liner. It also included macroscopic assessment of the retentive collar which was classified as worn or not worn.

2.6. Measurement of changes in the dimensions of the concave surface

The diameter and the roundness of the liners was determined with a BHN 706, a tridimensional measurement machine equipped with a measurement head PH9, a TP2 probe and a 4 mm stylus (Mitutoyo America Corporation). This device, which was attached to a national calibration chain, included a measurement uncertainty of ±5 μm. To study the concave surface, the liners were oriented as shown in Fig. 2. The position of 85 points distributed throughout the interior of the liner was determined with a measurement uncertainty of ±5 μm. In the planes parallel to the XY plane, 3 series of 16 points, were equally distributed on 360° and were measured, for Z = cos 90°, Z = cos 120° et Z = cos 150° respectively. On the planes that were at right angles to the XY plane, 4 series of 9 points, were also distributed equally on 180° and measured for respectively X = cos 0°, X = cos 45°, X = cos 90° and X = cos 135°. Finally the position of the pole of the liner was determined. Internal wear and shape defects were calculated in relation to the theoretical diameter provided by the manufacturer using the least squares method.

2.7. Measurement of changes in the dimensions of the convex surface

The roundness of the external diameter of the liners was determined with a machine that measured by lateral projection, equipped with a measurement recorder. The margin of error of this device was ±5 μm. The position of the 97 points, distributed on 4 equal arcs separated by 45° was determined with this device. External wear and shape defects were calculated from a theoretical diameter provided by the manufacturer using the least squares method.

2.8. Statistical method

The statistical analysis of the data was performed with SPSS© software. The Pearson’s correlation coefficient was obtained for quantitative variables. A non-parametric test was performed for qualitative variables using the Chi square test. P < 0.05 was considered to be significant.

3. Results

3.1. Macroscopic analysis

During the macroscopic analysis of convexity, machined grooves had disappeared in 100% of the 40 liners in the study. In 16/40 cases, there was a certain amount of wear of the retentive collar. In 24 cases, there was no sign of macroscopic wear. All of the liners with intraprosthetic dislocation had visible wear of the retentive collar. The probability of presenting with intraprosthetic dislocation was not equivalent in liners studied depending on their size. Only one of the liners with intraprosthetic dislocation had an external diameter of less than 49 mm (Fig. 3). In the 40 liners in the study, intraprosthetic dislocation was more frequently the reason for removal when the external diameter of the liner was ≥49 mm (Chi square test, P = 0.007).

3.2. Changes in the dimensions of the concave surface

The results of wear in the concave surface took into account a shape defect measured with a stylus probe. Concave surface wear...
was expressed by the following formula: \((\Phi_1 + DF) - \Phi_2\)/2, in which \(\Phi_1\) was the mean internal diameter measured, DF was the concave shape defect and \(\Phi_2\) was the theoretical diameter of the concave surface or 22.25 mm. Mean internal wear was 0.561 ranging from 0.024 to 2.726 mm, SD 0.663 mm. Mean annual internal wear was 0.073, ranging from 0.002 to 0.273 mm, SD 0.069 mm.

### 3.3. Changes in the dimensions of the convex surface

Convex surface wear was based on the following formula: \((\Phi_2 - \Phi_1)/2\), where \(\Phi_1\) was the theoretical diameter of the convex surface and \(\Phi_2\) was the mean external diameter measured. Mean external wear was 0.053, ranging from 0.000 to 0.143 mm, SD 0.035 mm. Mean annual external wear was 0.009 ranging from 0.000 to 0.045 mm, SD 0.009 mm. No difference was found in external wear between liners with a titanium cup (mean annual wear = 0.008 mm/year) and liners with a steel cup (mean annual wear = 0.009 mm/year).

### 3.4. Total wear

Mean total wear was 0.625, ranging from 0.036 to 2.803 mm, SD 0.671 mm. Mean total annual wear was 0.082 ranging from 0.002 to 0.282 mm/year, SD 0.072 mm/year. There was a strong linear correlation between wear of the concave surface, with a correlation coefficient of 0.996 between the two series. External wear represented a mean 16.7% of total wear. This varied considerably with a SD of 17.8%. The correlation between external wear and total wear was much weaker, both for annual wear or measured wear with a linear correlation coefficient of 0.13. Internal wear, external wear and total wear were not significantly correlated to either the duration of implantation, or liner diameters. Table 3 shows the results for each of the liners in the study.

### 3.5. Wear volume

Wear volume was determined by calculating concave, convex and total interface wear volumes. The volume V1 of concave wear was the difference between the volumes determined by the diameters (\(\Phi_1 + DF\)) and \(\Phi_2\), the theoretical diameter of the concave surface or 22.25 mm. The volume V2 of convex wear was the difference between the volumes determined by the diameters \(\Phi_2\), the theoretical diameter of the convex surface and \(\Phi_2\), the mean external measured diameter. Mean wear volume in the middle of manufacturing tolerances was 28.9 mm³/year for convex wear (SD 27.6), 25.5 mm³/year for concave wear (SD 23.2), for a total annual wear volume of 54.3 mm³/year (SD 39.6). Table 4 shows the results of wear volume for each liner in the middle as well as the high and low ranges of manufacturing tolerances. Fig. 4 shows external wear for each liner in relation to the observed internal wear.

### 4. Discussion

We report the wear observed in liners that were removed after at least 3 years of use in vivo. The reasons for revision were mainly mechanical failure so that the results reported here should be taken with caution because these components probably functioned suboptimally for at least some of the time they were implanted. Nevertheless, this problem was limited by only including components that had functioned for at least three years. Because these were dual mobility components, none of the radiographic techniques could be used to measure wear; neither classic techniques such as that suggested by Wroblewski [8] nor that proposed by Devane et al. [9] using semi-automatic digital contour measurement. Internal wear cannot be differentiated from external wear with these techniques. An analysis of retrieved components is the only way to differentiate internal from external wear.

#### 4.1. Mobility and external wear

Complete disappearance of the machined grooves from the entire convex surface confirmed that there was movement at this level, and that the external surface had been broken in. There was very little external wear despite the large polyethylene surface. In 22/40 cases it was below the manufacturers’ tolerance, or 50 μm. It was not more than 45 μm per year in any of the components analyzed. This limited wear of the convex polyethylene surface supports results reported by Katayama et al. [10] in a study of heads retrieved from THA with a rotational polyethylene head system and a metal cup. The physicochemical analysis of these components revealed very slight roughness on the contact surface, which for these authors was a result of breaking-in and explained the limited wear observed on these convex polyethylene surfaces. Although there was very slight convex linear wear it was similar to the level of concave wear expressed as wear volume, with significant variability among the liners as shown in Fig. 4.

According to Huk et al. [11] modular THA, even those that are not dual mobility systems, have convex polyethylene surface wear...
4.2. Total wear and retentive capacity

Kusaba et Kuroki [13] reported a mean annual wear of 0.17 mm measured by a radiographic technique in a series of 68 so-called bipolar prostheses with a retentive collar and a 22.2 mm head. Wear in the retentive collar was also found to be greater in cases of peri-prosthetic osteolysis. In a comparison of 19 bipolar prostheses retrieved from a series of 103 Charnley prostheses reported by Wroblewski, Kusaba et Kuroki [13], wear was doubled with retentive systems. We therefore recommend that the use of this type of retentive system be discontinued. In our series of dual mobility liners, despite the presence of a retentive collar, annual wear was similar to the radiographic measurements reported by Wroblewski [14]. Nevertheless, it was not possible to perform a statistical comparison of the two series because we do not have dispersion parameters for that series.

Mean total annual wear in our study reflects very different situations, with a high variability, because the standard deviation of the entire series was 0.072 with a range of between 0.002 and 0.282 mm/yr. A meta-analysis of 26 publications on wear in polyethylene cups by Schmalzried et al. [15] also found a very high variability in each study. If the studies that only included metal-polyethylene liners with 22.2 mm heads were taken into account mean linear wear in 1167 components was 0.099 mm/year with a range of between 0 and 0.6 mm/year. Our series of 40 retrieved components had mean wear values and ranges that were similar to those in the meta-analysis by Schmalzried et al. [15]. Mean wear volume, which was 54.3 mm³/year in our study, was similar to that in the studies by Wroblewski [8,14] of 80 and 36 mm³/year.

4.3. Retentive collar wear

We did not measure retentive collar wear in our study. When wear is significant, the head of the prosthesis is no longer retained, and there is a risk of intraprosthetic dislocation, as reported by Lecuire et al. [16]. In our series a large external diameter was
more frequent in cases of intraprothetic dislocation. One possible explanation is that when a force opposes the movement of the convex surface of the liner, its moment is proportional to the external diameter. The force necessary to overcome this resistance is exerted on the collar and its moment depends on the diameter of the concave surface. In our series, the diameter was 22.2 mm in all cases. To respect equal moments, the force exerted upon the collar was therefore proportional to the external diameter. At present larger head diameters are recommended as the external diameter increases. The consequences of this change have not been evaluated.

5. Conclusion

The results of our analysis of 40 polyethylene dual mobility acetabular liners show that total wear was similar to that observed in another series of metal-polyethylene liners with a 22.2 mm diameter head component. The mean external wear is only a sixth of total wear, with, nevertheless, a great variability of results. The improved stability of the retentive collar does not seem to be associated with an increase in total wear, which combines concave and convex wear. In the liners analyzed in this study, wear of the retentive collar was found in 40% of the cases. It would be interesting to analyze which factors are responsible for wear in the retentive collar. The added stability of the retentive collar is not associated with an increase in total wear, and the survival curve reported by Farizon et al. [3] was more than 95% at 12 years showing that this type of dual mobility system provided increased stability without significant wear.

Disclosure of interest

Authors’ disclosure of conflict of interest was not requested when the article was originally published.

References


