Surface roughness of retrieved femoral heads in CoCr-Polyethylene Hip Bearings – A retrieval assessment with 11-17 years follow-up

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Keywords: Hip arthroplasty, materials, metal-polyethylene bearings, roughness wear

Introduction

Metal-on-polyethylene (MPE) bearings have been the gold standard in total hip arthroplasty (THA) for over 40 years. However, even for the improved polyethylenes steadily gathering a reputation of very high wear resistance, it also clear that there are additional issues to consider (Fig. 1). It is well documented that impingement of metal-on-polyethylene (MPE) is a serious risk that can damage the polyethylene liner, produce additional wear debris and also lead to 3rd-body abrasion and roughening of the femoral head.1-3 Adding to these risks is the contemporary use of larger femoral heads with the consequence of adjusting to thinner polyethylene liners once believed to be a contraindication in cup design.4 The superior surface finish of CoCr implants mated with polyethylene bearings is believed to be one factor in the longevity of metal-on-polyethylene bearings (MPE). However, it may be that under long-term conditions in vivo, these 3rd body-wear particles eventually degrade the MPE surfaces.2,5-7

The two-body and three-body wear mechanisms associated with MPE is an unavoidable risk given the nature of the hip mechanics. Studies of cup impingement have documented an incidence ranging 45-68%. However in MOM studies, impingement evidence has climbed to 96%.8 We therefore sought evidence of roughening damage to the femoral heads as a result of 3rd-body wear. A study of MPE retrievals with average 12-years follow-up (N = 35 cases)9 described CoCr roughness averaging 62nm (Ra= 41-80nm). A subsequent retrieval study (N=43: 6-years) with half the follow-up time described much lower roughness of 10nm (Ra), with roughness for non-worn surfaces reported as low as 3nm.10

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The 1st goal of this study was determine if femoral heads became rougher or smoother in MPE bearings with time (10-20 years). The 2nd goal was to determine if CoCr roughness simulated in laboratory tests was an adequate representation of that occurring in-vivo.

Methods

The MOM cases were performed by various surgeons and revised in the Orthopedic Dept. of Loma Linda University. The analytical studies were conducted in the DARF Retrieval Center. Six CoCr femoral heads were chosen with 11-17 years duration. Except for one 26mm head, all were 28mm and mated with non-cemented, metal-backed acetabular shells with conventional polyethylene liners. All studies conducted at DARF Center were of a non-destructive nature for loaned MOM. Implants were scrutinized for any impingement damage and liners mounted on heads to check geometry of any damage sites. Implant 3D-geometry was studied by CMM, wear patterns were imaged by SEM and energy dispersive spectroscopy (EDS). Surface roughness was analyzed by white-light interferometry (WLI).

Unique to the DARF Center, the first step in the analysis was to determine which areas the patient habitually walked on in the head and cup. Here the main-wear zones (Fig. 1: MWZ) were uniquely defined as “normal”. Accordingly, the remaining areas were defined as non-wear zones (NWZ) and these were also studied for clues to “abnormal” wear damage. These areas were mapped visually and optically on each femoral head and cup.

Surface roughness was assessed by interferometry (Newview 600, Zygo Inc) for both MWZ (12 data points) and NWZ areas (6 data points). Care was taken to exclude areas of protein contamination from such roughness surveys. In addition, any abnormal wear damage of a local nature was excluded from such roughness surveys and profiled separately in greater detail. SEM imaging was used to confirm wear topography (MA 15, Zeiss Inc) and any metal contamination (EDS, Bruker Inc). The extent of the surface areas was then determined using standard spherical algorithms and their locations marked for additional microscopic analyses (Fig. 1).

Results

After 11 to 17 years duration (Table 1: average 13 years), the MWZ on femoral heads covered 292-774mm² in area (Table 2: average = 558mm²), representing a 2.7-fold variation. Relating these MWZ areas to the hemispherical surface area of the head, these patients had walked on 24-63% of the available surface area (45% on average). SEM imaging revealed the typical carbide pattern (size < 10μm), small pits and fine micron-size,
surface scratches. There was no evidence of the large micro-grooves (> 40μm width, > 0.5μm depth) commonly identified on MOM retrievals.

The surface roughness of the MWZ areas appeared exceedingly smooth at 8-13nm (Ra = 11 average roughness) and only slightly larger than the range 4-6nm for the NWZ (average Ra = 5nm). Individual profiles of such worn surfaces showed peaks and valleys within ±10nm range and occasional scratches penetrating 30nm into the CoCr surface (Fig. 5). Representing the ‘worst case’ scenario in this study, some areas revealed scratches with peaks and valleys within the ±30nm range, some as wide as 20um (Fig. 6).

**Discussion**

Micro-imaging revealed that femoral surfaces in these MPE bearings appeared excellent even with 11-17 years of use in vivo. The appearance of the micron-size pits and fine surface scratches on these CoCr bearings were typical of 3rd-body abrasion created by release of small surface carbides. Totally absent in this MPE study were the micro-grooves created in MOM bearings by large CoCr particles acting as third-body abrasives. The latter phenomenon are believed to be a consequence of impingement between femoral necks and exposed CoCr liners. Thus our study illustrated that CoCr femoral head surfaces used with polyethylene liners may become only slightly rougher with long-term implantation. These data were therefore supportive of a previous retrieval study with a mean follow-up of 7 years. It was noted that such roughness grades

**Table 1 MPE explants with patient demographics**

<table>
<thead>
<tr>
<th>Explant #</th>
<th>Manufacturer</th>
<th>Reason for Revision</th>
<th>F/U (yrs)</th>
<th>MWZ area</th>
<th>MWZ %</th>
<th>MWZ Ra (nm)</th>
<th>NWZ Ra (nm)</th>
<th>MWZ/ NWZ</th>
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</thead>
<tbody>
<tr>
<td>1 (44F)</td>
<td>Zimmer</td>
<td>osteolysis</td>
<td>17</td>
<td>699</td>
<td>56</td>
<td>11</td>
<td>6</td>
<td>1.8</td>
</tr>
<tr>
<td>2 (58F)</td>
<td>IOI</td>
<td>osteolysis</td>
<td>15</td>
<td>391</td>
<td>32</td>
<td>11</td>
<td>6</td>
<td>1.8</td>
</tr>
<tr>
<td>3 (67F)</td>
<td>BC</td>
<td>cup migration</td>
<td>12</td>
<td>634</td>
<td>51</td>
<td>8</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>4 (83M)</td>
<td>Zimmer</td>
<td>osteolysis</td>
<td>12</td>
<td>774</td>
<td>63</td>
<td>10</td>
<td>5</td>
<td>2.0</td>
</tr>
<tr>
<td>5 (91F)</td>
<td>DePuy</td>
<td>osteolysis</td>
<td>11</td>
<td>557</td>
<td>45</td>
<td>13</td>
<td>6</td>
<td>2.2</td>
</tr>
<tr>
<td>6 (59M)</td>
<td>DePuy</td>
<td>osteolysis</td>
<td>11</td>
<td>292</td>
<td>24</td>
<td>10</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>Averages  (n=6)</td>
<td></td>
<td></td>
<td>13</td>
<td>558</td>
<td>45</td>
<td>10.5</td>
<td>5.2</td>
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</table>

**Fig. 5. SEM imaging typical CoCr head.**

**Fig. 6. SEM imaging “worst case” CoCr head.**

**Fig. 7. Comparison of published surface roughness studies (ranking system redrawn from study by Sorimachi et al1).**
remained well below the ASTM guideline\(^\text{13}\) for even a new THA bearing (Fig. 7: Ra = 50nm). Therefore, our conclusion was that this level of CoCr roughness could not be a contributor to long-term wear and osteolysis in these patients with metal-on-polyethylene bearings.

The mapping of habitual wear areas on the CoCr heads revealed that MPE patients walked on an average of 45% of the femoral head hemisphere. In MOM bearings, the area of habitual wear was noted to be slightly larger at 55% of the hemisphere.\(^8\) These new MPE data indicated that the patients walked similarly on MPE and MOM bearings, despite the fact that the cups represent remarkably different hardness and contact mechanics.\(^8\) The design preference for the American surgeon is to use a polyethylene liner inside a metal acetabular-shell (‘press-fit’ cup). Thus the protective polyethylene cup rim may be of considerable benefit if impingement and subluxation presents.\(^14\)

### Significance and Conclusions

1. Our study showed the surface finish of 28mm CoCr femoral heads (Ra < 15nm) used in combination with polyethylene liners can remain excellent into the 2nd decade of use.

2. With modular metal shells there is the added risk of cup-impingement and possible damage to the polyethylene liner. However we found no evidence of the large microgrooves typically produced in MOM bearings by circulating metal particulates, i.e. 3rd-body abrasion.

3. The wear area assessments showed that these patients walked on their MPE bearings in a very similar way to patients with MOM bearings.

<table>
<thead>
<tr>
<th>Explant #</th>
<th>F/U (yrs)</th>
<th>MWZ area (mm(^2))</th>
<th>MWZ %Hemi</th>
<th>MWZ Ra (nm)</th>
<th>NWZ Ra (nm)</th>
<th>MWZ/NWZ Ratio</th>
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<tbody>
<tr>
<td>1 (44F)</td>
<td>17</td>
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<td>56</td>
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<td>2.0</td>
</tr>
</tbody>
</table>

*Table 2: Summary of MWZ area calculations and head roughness (Ra) data (note 1,000nm = 1micron)*

### Acknowledgements

This project was supported by the DARF Center, Colton CA and the Dept. of Orthopedics, Loma Linda University Medical Center, Loma Linda CA. Grateful thanks are due to T. Halim for technical support.

### References