Reduced UHMWPE Wear Using Diamond-like Carbon Coated Ceramic Femoral Heads in a Hip Wear Simulator

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INTRODUCTION

• Diamond-like carbon (DLC) coatings may enhance bearing surfaces for joint replacement
  o Magnesia-stabilized zirconia (Mg-PSZ) has been shown to maintain a hard and smooth surface in vivo
  o DLC-coated Mg-PSZ femoral heads were shown to have superior coating strength relative to DLC-coated CoCr heads, and significantly greater hardness and wearability relative to non-coated Mg-PSZ heads
• The purpose of this study was to determine the tribological benefits offered by DLC coatings on Mg-PSZ substrates articulated against cross-linked UHMWPE (XLPE) in a hip wear simulator
• Hypotheses:
  o The DLC-Mg-PSZ coating will remain intact, with no increase in roughness
  o DLC-Mg-PSZ femoral heads will lead to reduced XLPE wear compared to CoCr and Mg-PSZ femoral heads

MATERIALS AND METHODS

• Two CoCr, 3 Mg-PSZ, and 3 DLC-coated Mg-PSZ femoral heads, all 28mm diameter, were used in this study
• Eleven XLPE acetabular liners (eight wear specimens and three soak controls) were machined from GUR 1050, which had been cross-linked (10 Mrad) and then re-melted
• All liners were pre-soaked in distilled water until weight gain ceased
• Specimens were tested in a MATCO 8-station hip wear simulator in 25% bovine serum, using a Paul curve at 1.2 Hz with peak loads of 2.3-2.4 kN
• After each stage, XLPE wear was measured gravimetrically and femoral head roughness (Sa) was measured by optical profilometry (10x magnification, 632 µm x 474 µm scan size)
• The average roughness (Sa) of the femoral heads was correlated to the number of cycles, to determine whether roughness increased or decreased during the test
• XLPE wear was averaged by femoral head type and compared by t-tests, with p < 0.05 for significance

RESULTS

Table 1. Average gravimetric wear of XLPE liners per stage.

<table>
<thead>
<tr>
<th>Cycles (M)</th>
<th>Soak-corrected loss/gain (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CoCr</td>
</tr>
<tr>
<td>0.375</td>
<td>0.5</td>
</tr>
<tr>
<td>0.750</td>
<td>1.9</td>
</tr>
<tr>
<td>1.125</td>
<td>0.1</td>
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<tr>
<td>1.500</td>
<td>-1.3</td>
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<tr>
<td>1.875</td>
<td>-0.8</td>
</tr>
<tr>
<td>2.250</td>
<td>-0.5</td>
</tr>
<tr>
<td>2.625</td>
<td>-0.8</td>
</tr>
<tr>
<td>3.000</td>
<td>-0.5</td>
</tr>
<tr>
<td>3.500</td>
<td>-0.8</td>
</tr>
<tr>
<td>4.000</td>
<td>-1.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>-3.9</td>
</tr>
</tbody>
</table>

• XLPE wear of liners articulating against CoCr heads was significantly greater than liners articulating against DLC-Mg-PSZ heads (p < 0.05)
• All liners initially gained weight relative to the soak controls; liners articulating against CoCr heads began to lose weight after 1.5M cycles
• Liners articulating against Mg-PSZ and DLC-Mg-PSZ heads exhibited a net weight gain through 4M cycles

Figure 1. Typical surface topography of A. CoCr, B. Mg-PSZ, and C. DLC-Mg-PSZ femoral heads before testing and after 4M cycles.

DISCUSSION

• CoCr-XLPE wear couples exhibited consistent XLPE weight loss after the initial weight gain, similar to previous studies
• The CoCr femoral heads were easily scratched, likely due to third-body wear from carbides excavated from the surface during normal wear, but the roughening of CoCr heads reported by others was not observed in the current study
• DLC-coated Mg-PSZ heads did not roughen or exhibit pitting, with significantly less XLPE wear than CoCr after 4M cycles

CONCLUSIONS

• Before testing began, the topography of the CoCr heads was dominated by embedded carbides; during testing, CoCr heads became scratched and qualitatively rougher in appearance, with evidence of carbide pullout
• Mg-PSZ and DLC-Mg-PSZ heads did not exhibit scratches during testing
• DLC-Mg-PSZ heads did not exhibit pitting or other coating damage

Figure 2. Average femoral head roughness (Sa) as a function of the number of wear cycles.

• Progressive roughening was not observed
• Scratches in CoCr heads were typically small (less than 100 nm deep) relative to the carbide inclusions (300-500 nm deep), and thus the scratches did not cause a significant increase in roughness after 4M cycles
• Mg-PSZ and DLC-Mg-PSZ heads likewise did not exhibit increased roughness after 4M cycles

Figure 3. Graph showing the wear reduction of XLPE against DLC-Mg-PSZ heads compared to CoCr heads.

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