Chromium Nitride Coating for the Reduction of Cobalt Release and Metallic Wear in Metal-on-Polyethylene Bearings

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Introduction
• Hypersensitivity reactions have been well documented following metal-on-metal (MoM) hip replacements [1,2], often attributed to elevated levels of cobalt [2].
• Elevated blood serum cobalt levels and reports of pseudotumours from metal-on-polyethylene bearings suggest this may not be unique to MoM [3,4].
• Pseudotumours have recently been attributed to taper corrosion resulting from high torques applied, but scratching on the metal bearing surface has been well documented in metal-on-polyethylene retrievals [3,5].
• Coating of metal surfaces has been shown to reduce wear and minimise cobalt (Co) release in MoM bearings in vitro [6].

Aim
This study investigates the potential for a chromium nitride coating (CrN) to reduce the wear of the head and minimise Co release in metal-on-polyethylene bearings under standard and adverse hip simulator conditions.

Methods
• 0.1 wt% vitamin-E blended polyethylene liners (GUR1020, highly crosslinked at 120 kGy and mechanically annealed; Corin Ltd, UK), larger than commercially available.
• 7 x 52 mm diameter cast double heat treated CoCrMo heads; 3 uncoated heads (MoP) and 4 coated with chromium nitride (CrN) using electron beam physical vapour deposition (Tecvac Ltd, UK).
• Testing performed in an orbital hip simulator under conditions described in Table 1.
• Wear measured gravimetrically for the heads and fluid samples taken through testing analysed for cobalt release using graphite furnace atomic absorption spectrometry.

Table 1: Summary of test conditions

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Details</th>
<th>Duration, million cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>Following ISO 14242-3 (2009)</td>
<td>0-5</td>
</tr>
<tr>
<td>Alumina 3rd body</td>
<td>Added to test serum at 0.15 mg/mL, Bimodal distribution</td>
<td>5-6</td>
</tr>
<tr>
<td>Roughened</td>
<td>Standard conditions following removal of 3rd body particles</td>
<td>6-7</td>
</tr>
<tr>
<td>Jogging</td>
<td>Single peak load of 4.5 kN. 14,440 cycles each at 1, 1.5</td>
<td>7-7.0432</td>
</tr>
</tbody>
</table>

Results

Standard conditions (0-5 mc)

Head Wear

Figure 1: Head wear over the first million cycles of standard testing

Head wear was only measurable in the first million cycles of testing while Co ion release was measurable throughout testing. CrN coating reduced head wear and cobalt release.

3rd body conditions (5-6 mc)

Figure 3: Metal head after 3rd body testing

Figure 4: CrN head after 3rd body testing

Figure 5: Wear volume and cobalt release over 3 mc during 3rd body testing

Metal heads (fig 3) showed damage and large amounts of wear and Co ion release while CrN coated heads (fig 4) produced less wear and damage due to improved scratch resistance of the coating.

Roughened conditions (6-7.0432 mc)

Head Wear

Figure 6: Head wear during roughened testing

Figure 7: Co release during roughened walking and jogging

Head wear returned to rates observed in standard testing. Co ion release was higher in MoP bearings following particle removal than in standard testing. Jogging did not significantly increase Co release and head wear was not measurable.

Table 2: Summary of results

<table>
<thead>
<tr>
<th>Test conditions</th>
<th>Head wear rate, mm3/mc</th>
<th>Co release rate, ppb/mc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>0.04 ± 0.04</td>
<td>244 ± 63</td>
</tr>
<tr>
<td>CrN</td>
<td>0.26 ± 0.02</td>
<td>59 ± 17</td>
</tr>
<tr>
<td>Standard</td>
<td>0.11 ± 0.60</td>
<td>71900 ± 32300</td>
</tr>
<tr>
<td>3rd body</td>
<td>0.13 ± 0.01</td>
<td>850 ± 300</td>
</tr>
<tr>
<td>Roughened</td>
<td>0.24 ± 0.03</td>
<td>1210 ± 850</td>
</tr>
<tr>
<td>Jogging</td>
<td>-</td>
<td>83 ± 23</td>
</tr>
</tbody>
</table>

Discussion and Conclusions
• This study highlights the potential for head wear and cobalt release in metal-on-polyethylene bearings under adverse conditions.
• The CrN coated head wore less than the uncoated heads and the increased scratch resistance prevented permanent damage to the head.
• The CrN coating acted as a barrier to cobalt release even under extreme test conditions with alumina particles which are not clinically relevant.
• Cobalt was released in the MoP bearings at an increased rate after 3rd body damage.
• Adverse testing demonstrates the robustness of the coating which may reduce the risk of soft tissue reactions.

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References