WEAR OF CROSSLINKED UHMWPE IN A HIP JOINT SIMULATOR

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ABSTRACT
Crosslinking has been extensively introduced to reduce the wear of UHMWPE. In this study the wear rates and wear surfaces of UHMWPE with different levels of crosslinking were compared in a hip joint simulator. The UHMWPE was either non-irradiated, gamma irradiated in air (2.5MRad), or highly crosslinked (7.5 and 10MRad). The intentionally crosslinked materials showed a significantly lower volume change compared to the non-crosslinked UHMWPE. The results of the surface topography of the acetabular cups showed that the highly crosslinked materials became smoother than the other materials as the test progressed. This would benefit the crosslinked materials in aiding lubrication. Finite wear rates have been recorded for the first time in simulator studies with highly crosslinked polyethylene. The wear rates and wear surfaces compare with those found in clinical studies.

Keywords: Wear, UHMWPE, Crosslinking, Hip Prosthesis.

INTRODUCTION
Crosslinking has been extensively introduced to reduce the wear of UHMWPE. Zero wear of highly crosslinked UHMWPE has been reported [1,2] in hip simulators. These results have not been replicated in clinical studies [3,4,5]. Clinical investigations measure linear penetration and geometrical volume changes [4,5] which include wear and creep. In contrast previous simulator studies have determined wear gravimetrically [1,2] and measurements were affected by moisture uptake. Reports of zero wear in simulators were supported by observations of machining marks on the surface [2]. In contrast explants show loss of machining marks [4]. It is not clear if there is a real difference between simulator data and clinical observations, or if the difference is due to the measurement of creep and wear in clinical studies. The aim of this study was to compare the penetration rates, creep and wear rates produced by UHMWPE with different levels of crosslinking in hip simulations and to compare these with clinical data.

MATERIALS AND METHODS
Studies were carried out using 28mm diameter cobalt chrome femoral heads. These were articulated against UHMWPE in the Leeds ProSim hip joint simulator. This applied two independently controlled motions, flexion/extension of ±30/-15° and internal/external rotation of ±10°. These two motions were applied 90° out of phase. A twin peak, time dependent loading curve which gave a peak load of 3KN at heel strike and toe off and a swing phase load of 50N was also applied. The acetabular cups were manufactured from UHMWPE GUR 1050. The GUR 1050 was highly crosslinked with 10MRad or 7.5MRad of gamma irradiation in nitrogen followed by re-melting at a temperature above 150°C. Slightly crosslinked GUR 1050 was also tested (gamma irradiated with 2.5MRad in air). Non-crosslinked GUR 1050 UHMWPE was used as a control. Five cups of the materials were tested with one station from each set of five being used for creep measurements. Volume measurements were taken every million cycles using a coordinate measuring machine (CMM) and tests were run to 5 million cycles. The tests were carried out in low serum concentrations of 25% (v/v) bovine serum diluted with 0.1% (w/v) sodium azide in water. At each million cycles a 3D measurement was taken of the contact region of the acetabular cups using a Form Talysurf profilometer.

RESULTS
The geometrical penetration change with time for the four materials is shown in Figure 1. The penetration changes include both creep and wear. All four polyethylenes showed greater penetration in the first million cycles than the subsequent four million and this was associated with initial creep deformation in the first million cycles. The individual creep deformation cups confirmed this with volume changes in the first million cycles followed by stability. Creep volumes of between 10 and 25mm³ were measured with the lowest value being for the 10MRad polyethylene.
All materials showed a change in surface roughness, and loss of machining marks (Table 1). The highly crosslinked materials became smoother than the other materials as the test progressed.

<table>
<thead>
<tr>
<th>Materials (MRad)</th>
<th>Average surface roughness Ra (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start</td>
</tr>
<tr>
<td>0</td>
<td>1.21</td>
</tr>
<tr>
<td>2.5</td>
<td>1.57</td>
</tr>
<tr>
<td>7.5</td>
<td>1.31</td>
</tr>
<tr>
<td>10</td>
<td>1.32</td>
</tr>
</tbody>
</table>

Table 1. Average surface roughness of acetabular cups at start and end of test (mean ± 95% confidence limits)

The ratio of the volume change in the cross linked materials to that of the 0MRad material reduced throughout the test (Table 2). These results are equivalent to comparative volume change determined by geometrical measurements clinically.

<table>
<thead>
<tr>
<th>No of cycles (million)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of 10MRad to 0MRad</td>
<td>0.5</td>
<td>0.3</td>
<td>0.24</td>
<td>0.2</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 2. Ratio of volume change of highly crosslinked UHMWPE to non-crosslinked UHMWPE at each million cycles.

Consideration of the volume change per million cycles over the whole test which included creep and wear, and the volume change over 1-5 million cycles which excluded the initial creep and was predominantly wear is shown in Figure 2. The intentionally crosslinked materials showed a significantly lower volume change than the other two materials, with the 10MRad polyethylene having a slightly lower volume change than the 7.5MRad polyethylene. The creep deformation was a large proportion of the volume change in the highly crosslinked material. For the wear rate between 1-5 million cycles the wear of the highly crosslinked material was 4.6 mm³/million cycles and this was 12% of the wear rate of the 0MRad material.

DISCUSSION AND CONCLUSION
This study showed that highly crosslinked UHMWPE had a lower wear rate than non-crosslinked UHMWPE. Finite wear rates were recorded that were comparable with clinical data. Previous simulator studies that have reported zero wear [1,2] have used 90-100% serum as the lubricant. This study used 25% serum which is the current ISO standard. This may have contributed to finite wear rates and loss of machining marks on the highly crosslinked polyethylene cups. The smoother surfaces of the highly crosslinked cups as the study progressed could also have contributed to the lower wear, as this would aid better lubrication of the components. Finite wear rates have been recorded for the first time with highly crosslinked polyethylene. The short term volume changes and surface topography changes compared well with clinical observations of highly crosslinked components and finite long term wear rates have been predicted.

ACKNOWLEDGMENTS
This study was supported by EPRSC through a portfolio partnership award. The UHMWPE materials were provided by DePuy Inc.

REFERENCES