Relevance to Musculoskeletal Condition

Osteolysis in total hip joint replacements has been largely attributed to wear particles released from ultra-high-molecular weight polyethylene (UHMWPE). Improvements in UHMWPE, aimed at a significant reduction in osteolysis, would enhance the performance of total joint replacements.

Introduction

The orthopaedic industry has expended significant research effort in recent years in reducing wear of UHMWPE articulating surface components. One such approach has been in the development of a heavily crosslinked polyethylene. Crosslinking for long has been known to improve the wear resistance of industrial polyethylene. Clinical experience for over 20 years and an increasing magnitude of laboratory studies recently have demonstrated that crosslinking extends the lifespan of total joint replacements (1-5).

The objective of this study was to extract wear debris from bovine serum and to characterize wear particles released from heavily crosslinked UHMWPE in a physiologic hip simulator test and compared to particles released from conventional gamma sterilized UHMWPE cups. Since a certain degree of oxidation in the top layer of articulating surface is assumed to occur on shelf and in vivo, it was considered logical to artificially age the acetabular cups prior to hip simulator testing.

Materials and Methods

Crosslinking in compression molded GUR 1050 UHMWPE, ASTM type II material, was introduced by high energy e-beam processing. Degree of crosslinking in the material was measured by gel extraction. Gel fraction was determined by measurement of percent insoluble gel after immersion of UHMWPE in decalin at 189°C for 24 hours followed by toluene wash and drying. Wear tests were conducted on 62 mm OD acetalubular cups at 1.24 mm/s, typical size range for wear tested hip simulator cups (8) and in agreement, though at the lower end of the size range, with the results reported for particles retrieved from revision surgery (9-11).

This appears to be the first study documenting the morphology of wear particles released from a heavily crosslinked UHMWPE and therefore has no precedence for comparison. However, the typical features of size and shape reported for conventional gamma sterilized UHMWPE wear particles in literature show agreement with these results, indicating that heavily crosslinked UHMWPE released very few particles which were predominantly granular in shape with a negligible content of fibrils and a small proportion of flakes.

The particles released during wear testing of cups were extracted from bovine serum lubricant following Campbell’s method (7). In this technique, a 10cc of sample from fluid was lyophilized overnight and the dry powder was digested in 4N NaOH. The digestant was added to a 5% sucrose solution and ultracentrifuged for 4 hours at 40,000 rpm. The topmost layer containing the particles was then added to an isopropanol gradient and the centrifugation was repeated. The UHMWPE particles were removed from the interface of the isopropanol gradient (0.90 and 0.96g/cc) and placed into clean tubes. A 200 µm ultrafilter placed in a physiologic hip simulator test and compared to particles released from conventional gamma sterilized UHMWPE cups. Since a certain degree of oxidation in the top layer of articulating surface is assumed to occur on shelf and in vivo, it was considered logical to artificially age the acetabular cups prior to hip simulator testing.

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Results and Discussion

Gel fraction for heavily crosslinked UHMWPE was better than 99%, indicating that UHMWPE had achieved a state of complete three-dimensional network structure. Wear particles of conventional UHMWPE were abundant in quantity and comprised of three distinct morphologies: granules or spheroids, fibrils and flakes. These particles had typical features of those reported for UHMWPE cups worn in a hip simulator (6). The majority of these particles were submicron sized granules (98%), with some elongated fibrils (9%) and only a small proportion of flakes (5%). The average length of fibrils was 0.73 µm which is at the lower end of range for fibrillar particles generally observed in hip simulator wear tests. On the other hand, samples of heavily crosslinked UHMWPE contained very few wear particles, generally 1-3 particles in the field of view. These particles were predominantly granular in shape with less than 1% fibrils and 3% flakes. A large percentage of round- or spheroidal particles is consistent with a lower degree of deformation induced anisotropy introduced in crosslinked polyethylene during wear test, as well as with the intrinsic nature of UHMWPE resins. The area measurements, diameter (for round particles) or length (for fibrils) and shape factor for both types of UHMWPE samples are shown in Table 1, along with standard deviations. In both cases, the granules were in the size range of 0.1 to 0.2 microns in diameter, typical size range for wear tested hip simulator cups (8) and in agreement, though at the lower end of the size range, with the results reported for particles retrieved from revision surgery (9-11).

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Table 1. Wear Particles Analysis

<table>
<thead>
<tr>
<th>Materials</th>
<th>Particle Type</th>
<th>%</th>
<th>Diameter/ Length (µm)</th>
<th>Shape Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>granules fibrils flakes</td>
<td>86/1/5</td>
<td>0.1 ± 0.02/ 0.73 ± 0.24/ 0.23 ± 0.05</td>
<td>0.70 ± 0.05/ -/ -</td>
</tr>
<tr>
<td>Sterilized UHMWPE</td>
<td>granules fibrils flakes</td>
<td>9/1</td>
<td>0.08 ± 0.02/ 1.24 ± 0.25/ 0.36 ± 0.20</td>
<td>0.66 ± 0.05/ -/ 0.79 ± 0.01</td>
</tr>
<tr>
<td>Heavily Crosslinked UHMWPE</td>
<td>granule fibril flake</td>
<td>96/1/3</td>
<td>0.08 ± 0.02/ 1.24 ± 0.25/ 0.36 ± 0.20</td>
<td>0.66 ± 0.05/ -/ 0.79 ± 0.01</td>
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References