WEAR EVALUATION OF CROSSLINKED UHMWPE FOR KNEE PROSTHESES USING A MULTI-STATION ROLLING-SLIDING TRIBOTESTER

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ABSTRACT
Tribology-related failure of total knee replacement prostheses can lead to risky and expensive revision surgery. Recent changes in polyethylene processing may reduce the incidence of, or even eliminate contact fatigue failure related to bearing oxidation, but devices are still subject to failure modes relating to wear or non-oxidation related fatigue. Contemporary materials claim wear reduction and improved oxidation resistance through various crosslinking and annealing steps, but clinical wear performance of these materials in the knee is difficult to determine. A device incorporating clinically relevant motions and stress states has been used in this work to compare the wear properties of crosslinked polyethylene materials subjected to different irradiation and sterilization conditions. It can potentially be used to analyze the wear behavior of polyethylene materials from different manufacturers, allowing for better prediction of relative performance in vivo.

INTRODUCTION
Total joint replacements traditionally employ ultra high molecular weight polyethylene (UHMWPE) as a bearing material due to its desirable material properties and biological inactivity. Failure of these polyethylene bearings can lead to expensive and risky revision surgery, necessitating a better understanding of UHMWPE’s tribological properties. Advances in sterilization and processing of UHMWPE have resulted in the introduction of polymers with varying degrees of crosslinking. It is known that crosslinked materials have generally better wear resistance than conventional polyethylene, though the ultimate tensile strength and elongation at failure are often reduced (1).

Wear simulation for orthopedic UHMWPE is traditionally carried out using a pin-on-disk tester. Though repeatable and easy to model, this test method may lack clinical relevance in the knee due to the pure sliding motion. Final prosthetic device wear simulation is accomplished with knee simulators, which include both sliding and rolling motion. However, quantification of wear volume from knee simulators can only be estimated through gravimetric measurements. Further, comparisons of materials from different manufacturers can not be made without introducing confounding factors such as device design, and usually this information is proprietary.

To create a more reliable, clinically relevant wear test for UHMWPE used in knee applications, a previously described six-station rolling-sliding tribotester was used to study the behavior of crosslinked materials in diluted serum-based lubricant baths (2). The tribotester, originally designed for testing the contact-fatigue behavior of different orthopedic polymers, is equally useful for testing their wear behavior due to the clinically relevant stress and motion environment.

METHODS
Test specimens were manufactured in puck form from crosslinked and conventional UHMWPE bar stock provided by two orthopedic device manufacturers. Radiation doses prior to annealing ranged from 0 to 100 kGy. Test specimens were subsequently sterilized according to the manufacturers’
specifications. Loading and motion conditions for the cylinder on cylinder contact were selected based on design studies of typical total knee prostheses, resulting in a maximum specified contact stress of 20 MPa at 30% sliding motion. Oscillatory testing of polyethylene cylinders (6.35 cm diameter, 2.54 cm width) was performed at 1.5 Hz against polished CoCrMo counterface pucks (6.35 cm diameter). Lubricant for the tests was 25% serum in deionized water with EDTA and sodium azide added. Lubricant was replaced every 500,000 cycles and tests were run for 2 million cycles.

Linear wear was determined by rotating each test specimen through 360 degrees beneath a profilometer stylus. Each wear scar was measured three times. Pre-test measurements were subtracted, creating a profile of the wear scar accurate to within 2 microns. All measurements were taken immediately following testing to prevent viscoelastic relaxation from affecting the results. Pucks were re-measured seven days following testing to determine the amount of viscoelastic relaxation.

RESULTS

A typical profile of a wear scar is shown in Figure 2. Note that the length of the wear track is approximately 2.5 cm and the depth of the wear scar is approximately 17 microns. Wear is greatest at the two ends of the articulation. Data for the remaining tests is presented in Table 1. In all cases, the worn area of the pucks acquired the same burnished appearance of the articular surfaces of retrieved total knee devices. Further, among annealed materials higher irradiation doses, and hence higher crosslinking, resulted in lower wear rates.

![Figure 2 – A typical profile of a rolling-sliding wear scar](image)

<table>
<thead>
<tr>
<th>Polyethylene Treatment (radiation dose, post irradiation treatment, sterilization)</th>
<th>Wear Rate (mm/Mcycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kGy, Gas plasma</td>
<td>0.022</td>
</tr>
<tr>
<td>50 kGy gamma, above melt anneal, Gas plasma</td>
<td>0.026</td>
</tr>
<tr>
<td>65 kGy ebeam, above melt anneal, gas plasma</td>
<td>0.024</td>
</tr>
<tr>
<td>100 kGy gamma, above melt anneal, Gas Plasma</td>
<td>0.022</td>
</tr>
</tbody>
</table>

Table 1 – Test results

After seven days without loading, measurements of the pucks showed that viscoelastic relaxation was negligible for all samples.

DISCUSSION

Due to the simplified geometry of this system, one can measure the linear wear of a specimen to a high degree of precision. The measurement is not affected by fluid uptake as with gravimetric measurements, nor is it affected by variations in specimen geometry. This precision in measurement, together with the ability to calculate contact conditions through analytical methods, allows for efficient, repeatable wear testing in a clinically relevant setting.

Overall, the test results from the multi station rolling sliding tribotester show wear rates in the range reported in the literature for crosslinked materials(3). The materials with a higher degree of crosslinking show lower wear, though the reduction in wear is not as dramatic as that shown in a pin-on-disk tester (4).

It has been shown that combining minimal cross shear with a slightly abraded surface increases the wear rate of crosslinked materials relative to non-crosslinked materials (5). This is a possible explanation for the relatively favorable performance of the non-irradiated samples.

Greater wear at the ends of the rolling sliding contact indicate a change in motion or lubrication conditions. Because the device must change directions, there exists a point of zero motion. A drop in fluid film thickness is expected at this instant, resulting in reduced lubrication, more solid/solid contact, and higher wear.

This test confirms that a period of zero relative motion should be incorporated into orthopedic material tribotesting to appropriately model the conditions, including lubrication conditions, which naturally occur as part of the human gait cycle.

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REFERENCES


