INTRODUCTION

Surface engineering of metallic femoral knee implants is a potential approach for decreasing polyethylene wear in total knee replacements by increasing resistance to third body abrasion and subsequent two body abrasive wear and by reducing adhesive wear in the absence of an abrasive challenge [1]. In this study we report on the development of a clinically relevant test of engineered surface durability and its use to evaluate a chemical vapor deposition coating of aluminum oxide on cast CoCrMo. Contact profilometry measurements were performed on explanted CoCrMo femurs and the results used to develop an aggressive scratch testing protocol. Engineered surfaces scratched according to that protocol were evaluated in a long-term wear test.

MATERIALS AND METHODS

Explanted femur characterization: We reviewed a retrieval collection of 110 explanted TKR femoral components and identified 35 with obvious articular surface scratching. These 35 femurs had been implanted for an average of 5.7 years with a minimum and maximum of 3 months and 13 years. On each of these femurs, the surface profile of five articular areas that were judged by the unaided eye to be the most heavily scratched were measured with a Taylor Hobson contact profilometer. Rp, the maximum peak height in a profile, and Rt, the maximum total height, were recorded from 4 mm long scans in the M-L direction.

Uncoated CoCrMo scratching: Groups of five 7.5 mm long parallel scratches spaced 1 mm between centers at constant loads from 2 to 15 N were made on polished discs of as-cast CoCrMo using a 200 µm radius diamond indenter on a CSM Revetest® scratch tester. Rp and Rt were measured at three locations on each group by contact profilometry. Rp was thought to be the most relevant parameter for characterizing abrasive scratches and a relationship between it and the diamond indenter scratch load was developed and used to calculate the loads required to create scratches with Rp values matching those from the explanted femur measurements.

Scratch protocol: Networks of six repeating groups of five parallel diamond indenter scratches were made on the POD discs. The scratches were spaced 0.25 mm between centers. Each group of five parallel scratches was made with scratch loads selected to produce Rp values in as-cast CoCrMo that range from roughly twice the average to twice the maximum Rp measured on the explanted femurs. Oblique scratches 0.75 mm apart were then made over and at a 15° angle to these parallel scratch networks. Representative micrographs of these scratch networks are shown in Figures 1b and 1c.

Pin on disk wear test samples: Disks (n=3) of ASTM F75 cast CoCrMo were coated with an approximately 10 micron thick layer of alpha Al₂O₃ on TiN and TiCN interlayers by chemical vapor deposition (CVD) (IonBond AG, Switzerland). As-deposited coatings were polished to Ra < 0.2 micron and scratched according to the aforementioned protocol to create four scratch networks per disk as shown in Figure 1a. Shouldered pins with a 2.97 mm diameter contact end were machined from GVF (gamma barrier packaged) polyethylene.

Pin on disk wear test methods: An AMTI OrthoPod was used to slide pins over the scratch networks at a 1.66 Hz frequency in a square wear pattern 10 mm per side. A 173 N constant load was applied to produce a 25 MPa initial contact stress, which is representative of those predicted for low conformity TKR designs in deep flexion [2]. A 90% bovine calf serum solution with EDTA and sodium azide was used as the lubricant. It was maintained at 37°C and replaced every 330,000 cycles. The test was run for 20 M cycles with wear volume determined gravimetrically at 1 M cycle intervals. Images of each scratched location on all discs were systematically recorded at 50x magnification with an inverted metallurgical microscope before, after, and at periodic intervals during wear testing to monitor the coating condition.

RESULTS AND DISCUSSION

Table 1 lists the average, median, and maximum values for Rp and Rt among the 35 scratched explanted femurs. These Rp values are similar to those reported by Muratoglu et al. [3], who also selected scratched explants for analysis from a larger group.

Table 1. Summary of Rp and Rt measurements on explanted femurs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average (Std Dev)</th>
<th>Median</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rp</td>
<td>0.52 (0.36)</td>
<td>0.42</td>
<td>1.66</td>
</tr>
<tr>
<td>Rt</td>
<td>1.13 (0.8)</td>
<td>0.91</td>
<td>5.86</td>
</tr>
</tbody>
</table>

An identical location with a typical scratched appearance on one coated disk is shown in Figure 3 from before wear testing and after 2 and 20 M wear cycles. No spalling or chipping of the coating was observed on any disk, suggesting excellent coating adhesion and cohesion. Additionally, there was no evidence of progressive damage to the scratched coatings over the duration of the 20 M cycle test. Wear rates ranged from 1.41 ± 0.02 to 2.06 ± 1.08 mg / M cycle but did not significantly change over the course of the test with the lowest wear rate measured during the 15-16 M cycle interval.

CONCLUSION

A durability test for engineered surfaces involving high contact stress sliding wear over aggressive scratches was developed from measurements on explanted femurs. The CVD Al₂O₃ coating on cast CoCrMo performed well with no evidence of progressive coating damage through 20 M wear cycles.

REFERENCES

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