Wear Performance of Large Diameter Differential Hardness Metal-on-Metal and Ceramic-on-Metal Hip Bearings

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Statement of Purpose

Wear debris has long been a major concern in the performance and longevity of artificial hip joints. Second-generation metal-on-metal (MOM) bearings produce less wear than first generation components due to improved manufacturing techniques and better understanding of the role of carbon and diametric clearance. The new MOM bearings also generate substantially less wear debris than traditional metal-polyethylene bearing couples, but serum metal ion levels are still a major concern. We postulated that differential-hardness MOM and ceramic-on-metal (COM) bearings would reduce wear debris compared to like-hardness MOM bearings [1]. The present study compares wear of large diameter differential-hardness bearing couples including COM bearings to the existing like-hardness MOM bearing couples.

Materials and Methods

In this study, three groups of 54 mm bearing couples were tested. First test group consisted of like hardness (LH) MOM bearings. The femoral heads and acetabular cups were manufactured from ASTM F-75 cast Co-Cr alloy subjected to a hot isostatic pressurization process followed by solution annealing prior to final machining. The second group consisted of differential hardness (DH) MOM bearings. The femoral heads of this group were machined from an alloy of the same composition but with a different microstructure with higher hardness. The shells of the second groups were identical to the shells from the first group. The third group consisted of COM bearing couples. The heads were manufactured from aluminum oxide ceramic while the shells were identical to those in the first and the second groups. Simulator tests were performed on Shore Western Orbital Bearing Hip Wear Machine. A triple peak gait profile from 200-2000N was applied to the bearings at a frequency of 1 Hz to 5 million cycles. The lubricant was 90% alpha calf serum with 0.2% sodium azide and 20 mm EDTA. All bearings were tested in anatomically inverted position consistent with the methods used by Mckellop et al [2]. The test was interrupted at regular intervals for gravimetric assessment of the bearing couples. The gravimetric wear data were converted into the volumetric wear data using density value of Co-Cr 8.28mg/mm3 and alumina ceramic density of 3.97mg/mm3.

At 250k and 2.5M cycles the lubricant was collected and particle analysis was conducted. Particles were isolated by enzymatic digestion followed by density gradient centrifugation onto silicon wafers. High resolution images were obtained by SEM (Zeiss Supra). Particle size and shape were determined by image analysis and composition was determined by energy dispersive X-ray spectroscopy.

Results and Discussion

Table 1 shows the cumulative wear at 5M cycles & wear rates for the three different type bearing couples. The LH MOM bearings showed the greatest amount of overall volumetric wear and were similar to previously reported MOM studies [3-5]. All three bearing systems exhibited low steady-state rates of wear. Differential-hardness bearing systems exhibited 90% to 97% lower run-in wear rate, 45% to 84% lower steady-state wear rate, and 68% to 86% lower volumetric wear than the like-hardness bearing systems. COM bearings exhibited the lowest wear. A Student's t-test comparing run-in and steady-state wear rates between differential hardness and like hardness bearing systems showed statistical significance in both run-in wear rate ($p < 0.001$) and steady-state wear rate of LH MOM vs. COM ($p<0.001$), LH MOM vs. DH MOM ($p=0.002$).

Table 1: Mean Volumetric Wear and wear rate

Type	Volumetric Wear (mm^3)	Volumetric wear rate (mm^3/Mc)	
		Run-In	Steady-state
MOM (LH)	1.47 (0.1)	2.8 (1.5)	0.11 (0.07)
MOM (DH)	0.47 (0.1)	0.28 (0.1)	0.06 (0.01)
COM (DH)	0.20 (0.1)	0.084 (0.04)	0.018 (0.015)

Representative images of isolated wear particles for the three types of bearings after 250k cycles are shown in Figure 1. Analysis of particle size and shape distributions showed only minor differences between the three groups.

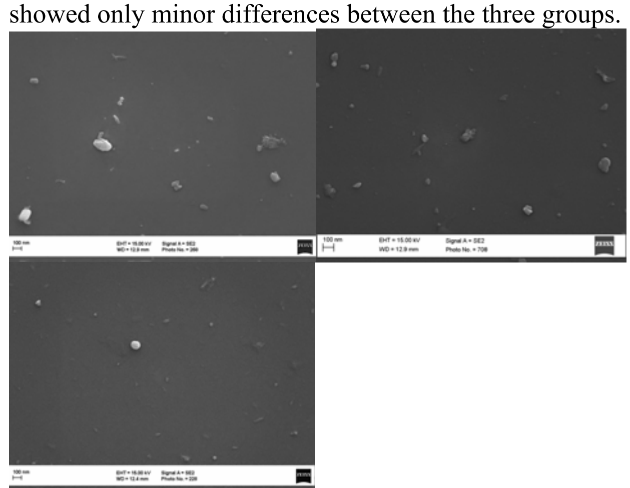

Figure 1. Particle analysis images at 250k cycles: (LH MOM (top left) DH MOM (top right), COM (bottom left)

Conclusions

Based on the results of this study, differential-hardness bearing systems exhibit much less wear than like-hardness bearing systems and have similar particle size distributions. This finding suggests that the in vivo metal ion release associated with current like-hardness MOM systems may be reduced with differential-hardness hip bearing systems.

References

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