Wear of Metal-on-Metal, Si_3N_4-on-Metal, Ceramic-on-Metal and Ceramic-on-Ceramic in a Hip Simulation Study

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Statement of Purpose: Efforts to reduce wear in metal-on-metal total hip prosthesis have included using the differential hardness of ceramic-on-metal bearings [1], or using the high hardness bearing materials with compatible mechanical properties such as Silicon Nitride (Si_3N_4) [2]. The goals for this study were to compare wear performance of standard Metal-on-Metal wear couples versus Si_3N_4-on-Metal, Ceramic-on-Metal, and Ceramic-on-Ceramic wear couples.

Methods: Four groups of materials were evaluated in this study (Table 1). The metal heads and liners (DePuy Products, Warsaw, IN) were high carbon wrought CoCrMo (ASTM F1537). Silicon Nitride femoral heads (Amedica Corporation, Salt Lake City, UT) and the Biolox Delta™ ceramic heads and liners (DePuy Products, Warsaw, IN) were made to the print of the metal heads. The nominal head size and the inside diameter of the liner was 36 mm.

Table 1. The Material Combination for Each Group

Group ID	Head	Liner
A (MOM)	Metal	Metal
B (SOM)	Silicon Nitride	Metal
C (COM)	Ceramic	Metal
D (COC)	Ceramic	Ceramic

The radii of heads and inserts were measured on a Zeiss Prismo (Carl Zeiss IMT Corporation, Maple Groove, MN) coordinate measuring machine (CMM). Diametrical clearance for each couple was calculated and head-insert match was performed to ensure similar clearance for each group.

The test was performed on a twelve-station hip simulator (AMTI, Watertown, MA). The testing position was anatomic (heads below the inserts). The inserts were assembled in metal shells (DePuy Products, Warsaw, IN) potted in bone cement at 45° of inclination from the abduction axis. All heads were mounted on taper fixtures. Paul-type physiological loading (3000N Max, and 300N Min) was synchronized with kinematic inputs (with the range of flexion/extension ±23°, internal/external rotation ±10°, no abduction/adduction) [3]. The interface was lubricated with bovine serum (HyClone Laboratories, Logan UT.), which contained 0.2% sodium azide added as a preservative and 20mM EDTA. The protein concentration was 17 mg/ml (about 25% of original serum). Serum was changed at every weighing interval.

The components were tested for two million cycles. Each head and insert was weighed every 0.5-million cycles, with an additional weighing interval at 0.25M cycles to observe the break-in wear. Wear volume was calculated by dividing weight loss by its density: 8.28 mg/mm^3 for metal components, 3.24 mg/mm^3 for Si_3Ni_4 components, and 4.37 mg/mm^3 for ceramic components.

Statistical significance was determined by t-test comparing the two groups using a p-value of 0.05.

Results: For MOM group, it had the highest total wear (2.22 mm^3) of all groups (Figure 1). The wear rate of MOM (1.11 mm^3/Mcyc) was consistent with reported values [1]. The wear of SOM group (0.34 mm^3) was 85% lower than MOM group. No observable break-in for COM or COC. Both groups had negligible wear at the end of the 2-million testing cycles.

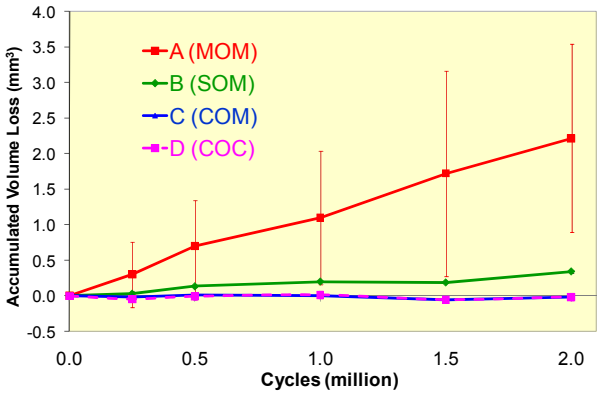

Figure 1. Sample Only

For MOM group, the wear of heads was slightly lower than the wear of liners (44%:56%, row A, Table 2). For SOM group, the Si_3N_4 heads, however, generated higher wear than the metal liners (90%:10%, row B, Table 2). For COM and COC groups, the wear for heads and liners were too low to be compared.

Table 2. Total Wear (mm^3) after 2-million cycles

Group ID	Head	Liner	Combined
A (MOM)	0.98 ±0.54	1.24 ±0.78	2.22 ±1.32
B (SOM)	0.31 ±0.03	0.03 ±0.00	0.34 ±0.02
C (COM)	-0.05 ±0.04	0.03 ±0.00	-0.01 ±0.04
D (COC)	0.00 ±0.03	-0.01 ±0.03	-0.01 ±0.05

Although SOM, COM, and COC test groups show a lower total cumulative wear than MOM, none of the groups show a statistically significant difference versus the MOM control group (p=0.133, p=0.099, and p=0.100, respectively).

Conclusions: The results showed that SOM group had 85% wear reduction, and COM and COC groups had greater than 98% wear reduction, comparing to MOM group. Greater than 90% of the wear in the SOM group were found on the Si_3N_4 heads, while the wear was more evenly distributed on both the head and liners in other groups. COM and COC groups provided the best wear performance based on the results.

References: [1] Firkins, et al. J Biomech, 2001; 34(10): p1291. [2] Bal, et al. J Arthroplasty, 2009; 24(1): p110-6. [3] Liao, et al. SFB, 2009: p 363.