Profiling 3rd-body Abrasion In A 10-cycle MOM Simulator Study - Alumina And Hydroxyapatite Ceramic Particles Compared To PMMA And CoCr As Control Debris

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Disclosures:  T. Halim: 5; DJO. I.C. Clarke: 3B; Depuy, Smith & Nephew, Stryker. 5; DJO. M. Burgett: 5; DJO. T.K. Donaldson: 2; Biomet. 5; DJO. J. Lazennec: None. C. Savisaar: None. J.G. Bowsher: None.

Introduction: Following total hip arthroplasty (THA), the debris cloud circulating in the joint space may include bone cement (PMMA), metals (CoCr, Ti, Ti6Al4V) and ceramics (hydroxyapatite, alumina). Many pin-on-disk and hip-simulator machines have studied the consequences of abrasive wear, but mainly in metal-on-polyethylene (MPE) bearings. Thus only three studies appear to have studied abrasive wear in metal-on-metal (MOM) bearings. Metal debris markedly elevated wear in one simulator study (28mm MOM: 0.5mg Ti, x4 intervals).[7] In the 2nd study, insertion of hydroxyapatite powder (36mm MOM: 280mg HA x10 intervals) demonstrated much lower wear-rates.[6] Surface-profiling methods in the 3rd simulator study (38mm MOM: 10-cycle test) revealed that metal particles could create large scratches (20-108μm wide) whereas PMMA flakes had minimal effect (scratches < 23μm wide).[3] The current study analyzed scratch profiles produced by alumina and HAP ceramics. PMMA and CoCr particles was used as control debris, these noted for low and high abrasion risks, respectively.[3]

Methods: We characterized alumina (C-1, C-2) and hydroxyapatite powders (HA-1, HA-2) provided by three orthopedic vendors by SEM imaging (MA15, Zeiss) and equivalent circle diameter (ECD) for sizing. HA particles were also scraped from retrieved HA-coated femoral stems (HA-3). The PMMA and CoCr controls were similar to particles previously reported.[2] Six 38mm MOM bearings (DJO Surgical, Austin, TX) were mounted in the hip simulator in ‘inverted’ cup mode.[2, 6, 7] Particle allotments (5mg) were placed in each cup and then 1ml of lubricant added (protein concentration 17mg/ml). [3] The simulator was run (0.3-3kN, 1 Hz) for a total of 10-seconds. Implants were ultrasonically cleaned, air-dried, and wear scars mapped. Roughness of femoral heads was characterized by white-light interferometry (WLI: NewView 600, Zygo) using 12 fields of view in each worn area.[3] Scratch profiles were also recorded (N=12 per head). SEM imaging detailed scratch topography while EDS-imaging (Bruker) was used to identify contaminants.

Results: Median diameters (ECD) of HA types ranged 31-36µm with peak size 65µm. The PMMA control particles were much larger with median size 139µm and peak 248µm. Alumina C1 and C2 beads had median sizes 46µm and 88µm, respectively with corresponding peak sizes 82 and 168µm. The CoCr control debris approximated size of alumina C1 particles, having median 114µm and peak 182µm. All material types scratched the MOM surfaces but with dramatic differences in scratch widths and depths. Scratches produced by HA debris were typically less than 10µm wide, here showing 5 parallel scratches with 10µm pitch and approximately < 0.3µm deep (Fig. 1). These were comparable to scratches produced by PMMA particles. Alumina C1 and C2 debris produced scratches that ranged 16-92µm wide in C-1 challenge and 39-134µm wide in C-2 challenge (Fig. 2). Their corresponding peak-to-valley depths (PV) averaged 1.6
and 2µm, respectively. The C1 damage appeared comparable to that created by CoCr debris (20-97µm wide, 2.1µm average depth). Aspect ratios (scratch width/PV) varied from 0.026 to 0.038. Notable difference was the smearing of alumina debris onto CoCr surfaces (Fig. 3).

Discussion: Abrasive wear varies with many parameters, including material yield-strength, hardness relative to counterfaces, size-distribution (range, median, outliers) and number of particles present. For this study we focused on the profiles of scratches produced by ceramic particles in CoCr surfaces. Our particle size selection was addressed by MOM retrieval studies that revealed 40-100 µm wide scratches in the CoCr bearings.[1] Thus abrading particles had to at least be of similar magnitude.[3] The PMMA and HA particles were remarkably different in size yet both created fine scratches. Here material properties were more dominant than particle size. This was consistent with the low MOM wear-rates recorded with both HA[6] and PMMA particles.[4] The CoCr and C1 particles were remarkably different in properties but produced similar large scratches while the larger C2 debris produced wider scratches than either CoCr or C1. Thus size did matter here and this combination represented a major risk for adverse CoCr wear.[4] In addition, this study showed for the first time that alumina beads could be transferred and flattened against CoCr surfaces, somewhat similar to the behavior of Ti6Al4V particles.[3] An issue not addressed in such a 10-second abrasion test is the question, what would be the life cycle of these CoCr particles? The alumina particle has extreme hardness and presumed to be completely inert. The ability of a CoCr particle to decompose (or rapidly ionize) and thereby escape from the joint space may create different wear results in longer-term simulator studies and in vivo.[3, 5]

Significance: Abrasive wear represents complex interactions both in vivo and in vitro. This simulator study used profile methods to show for the 1st time that hydroxyapatite ceramic particles produced fine scratches similar to acrylic bone-cement, whereas alumina ceramic particles produced large scratches akin to those produced by metal debris. The profiling evidence of differing abrasion performance due to combinations of material properties and size effects is important in the design of future experiments and assessing clinical risks.
Fig. 1A)

WLI Oblique Image

background CoCr scratches

10-cycle scratches

Ra = 44nm
Rz = 230nm
Ppk = 98nm
Val = -224nm
PV = 329nm

Fig. 1B)

Profile (nm)

Distance (µm)

HA-2 200k cycles

52 µm
0.3 µm