Factors Affecting the Performance of Metal Components in Artificial Hips

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Introduction: Most artificial hip replacements rely on articulation between metal, generally CoCrMo alloy, and UHMWPE (ultra high molecular weight polyethylene) components. Particles of UHMWPE created by wear are believed to lead to failure of the artificial joint by bone osteolysis. Using highly-cross-linked, wear resistant UHMWPE, or eliminating the UHMWPE in favor of alternative wear couples, e.g., metal-on-metal (MoM) or ceramic-on-metal, are methods to prevent this cause of osteolysis. Recent failures of MoM total hip systems have renewed an effort to understand the complex mechanics of material interactions in the total hip systems. Failure may be caused not only by wear of the metal-metal articulating surfaces, but there are other material interfaces, especially in today's modular total hips, that can play a role in artificial hip failure. Here, we present our initial investigations on three questions: 1) Can surface carbides dislodge to become potential abrasive particles? 2) What is the effect of residual stress created by machining CoCrMo alloys on deformation of artificial joint components during wear? and 3) What can we learn about the metal-metal interaction at the interface between the ball and stem from retrieved artificial joint specimens?

Methods: To investigate the potential pull-out of surface carbides, samples of cast and wrought CoCrMo implant alloy surfaces were polished with different grades of abrasive paper to simulate severe wear. The wear surfaces were examined using a digital optical microscope and a non-contact optical profilometer.

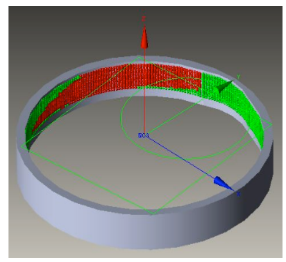
The redistribution of residual stresses may deform the device as material is worn away [1]. The deformation may change the device's geometry to increase wear damage. We created ring specimens with an inner diameter of 45mm, wall thickness of 2.5mm and a height of 10mm of wrought CoCrMo implant alloy to mimic the cup geometry used in actual implants. The inner surface was machined using recommended tooling using aggressive feed, speed, and depth of cut to induce residual stresses in the finished surface. To represent wear, and the removal of residual stress, a small portion of the ring's inner surface was removed using electrical discharge machining (EDM). The modified ring geometry was measured by a high resolution coordinate measuring machine (CMM), using a constant contact probe recording approximately 10,000 measurements, to determine whether there was a change in geometry.

Finally, we report very preliminary findings from a retrieved total hip specimen – not to draw conclusions about in vivo behavior from a single specimen, but rather to show potential areas for future investigations based on our observations. A femoral component of a total artificial hip (from the retrieval program at the Anderson Orthopaedic Research Institute) was observed using a digital optical microscope and a non-contact optical profilometer.

Results: We observed more carbides on the cast material surface, as expected. For the wrought material, a few isolated pits were evident on the wear surface; perhaps as the result of carbide pull-out. Scratches, which were different from the polishing marks, appeared to initiate at the site of the carbide pull-out, and progressed in only one direction. The 3-D profiles from the profilometer showed that the depth of the pits were approximately 15 μm. There was no evidence of sheared carbides; either pits were observed after pull-out, or the carbides were intact.

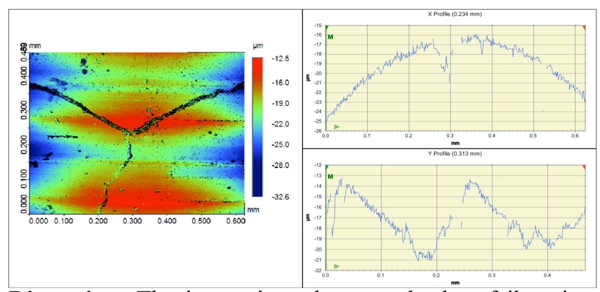
For residual stresses, the modified ring was not uniformly within tolerance (Fig. 1). The areas of red in Fig. 1 show regions that were out of tolerance, while those shown in green were within tolerance.

Examination of the retrieved CoCrMo trunnion showed non-uniform wear around its circumference. More wear was evident on the inferior side, where the machining marks were visibly affected. What initially appeared to be fractures on the surface (Fig. 2) are believed to be grain boundaries, etched by corrosive processes at the interface. The depth of the etching was about 6 μm.



LEFT - Figure 1: Out-of-tolerance measurements of modified cylindrical ring.

BELOW – Figure 2: Surface roughness image showing machining marks and grain boundaries.



Discussion: The interactions that may lead to failure in a modular artificial joint are complex and not well understood. Carbides that are dislodged from the surface may act to accelerate wear. Residual stresses, released by wear of the material, may lead to small deformations that can also increase wear. Additional studies, with higher resolution CMMs, are necessary to characterize the effects of residual stress. Both prospective experiments and retrospective (retrieval) analyses will aid in developing an understanding of the processes that lead to artificial joint failure. Both digital microscopy and profilometry revealed characteristics in a retrieved prosthesis that raise further questions about the metal-metal interaction at the modular interface. For example, how are wear and corrosion at that interface related and do the wear and corrosion at that interface play a role in the failure of the artificial joint?

Conclusions: Our initial studies examined only a few of the many complex phenomena that occur in the metal-metal interactions in artificial hips. The preliminary results from these studies suggest that the specific mechanisms – carbide dislodgement, residual stresses, and taper wear – may occur in artificial joints. The effects these mechanisms have on the long-term survival of the implant require additional study.

References: Vesnovsky O., et al. *Trans. 35th Ann. Meeting, SFB* (2011) p.805.