Characterization of Wear and Corrosion Products from Around a Retrieved CoCrMo Taper Junction

Alina M. Crainic[1], Mauro Callisti[1], Martin R. Palmer[2], Richard B. Cook[1]
[1]National Centre for Advanced Tribology at Southampton (nCATS), University of Southampton, Southampton, UK, [2]National Oceanography Centre, University of Southampton, Southampton, UK

Disclosures: Alina M. Crainic (N), Mauro Callisti (N), Martin R. Palmer (N), Richard B. Cook (3B, 5 - Zimmer Biomet)

INTRODUCTION: Adverse local tissue reactions (ALTRs) to solid and soluble debris originating from metal-on-metal (MoM) hip replacements currently represent the main reason for MoM revision surgery. The introduction of modularity at the femoral components in non-MoM joints has resulted in ALTRs and pseudotumour formation due to wear and corrosion at the taper interface, independently of the bearings [1-2]. Products originating at this site were suggested to elicit more severe body reactions, at lower volumetric wear rates, compared to debris released from the bearings[3]. Body responses are dictated by the interactions of the particles with the biological environment, and are highly dependent on the size, morphology, chemical composition and aggregation state of the particles. Investigating the properties of the particles released from this particular junction, means a better understanding of the wear and corrosion processes responsible for their generation and will help in our understanding of the body's reaction to them. To our knowledge, no study has previously reported on the characterization of wear particles and corrosion products originating from explanted taper junctions. Here we propose a method to isolate and characterize corrosion products accumulated around trunnions, developed on a corrosion flake from a retrieved CoCrMo stem taper and we present the findings of the size, morphology, chemical composition and aggregation state of particles released from a taper interface.

METHODS: A sample of material released from the taper interface was obtained from a retrieved modular total hip replacement consisting of a CPT stem coupled with an ADEPT femoral head (both CoCrMo alloy). The trunnion presented macroscopic signs of corrosion and an accumulation of black product at the base of the trunnion, which was carefully collected and processed. Visual inspection of the product indicated a mixture of black and red-brownish materials, which corresponded to a metallic and an organic phase respectively. The removal of organic contaminants was performed with an alkaline treatment which aimed at providing clean metal particles, appropriate for high resolution imaging. The fragments were incubated in 12M KOH at 37°C, under continuous stirring at 180 RPM for 17 h. This resulted in a separation of the fractions: a black heavy phase, migrating to the bottom of the tube and a red-brown, light phase found at the top of the digestion media. The metallic nature and morphology of the heavy phase was checked with scanning electron microscopy (SEM) and energy dispersive X-Ray analysis (EDX), which confirmed the presence of large particles containing Cr, Mo and Co. The metallic fraction was isolated from the organic phase by centrifugation and further subjected to a new digestion step in fresh 12M KOH. After 48 h, the metal debris was separated by a two-step centrifugation, which aimed to size fractionate the particles. Both fractions were investigated on carbon coated copper grids, by scanning transmission electron microscopy (STEM), with a Cs-corrected JEOL ARM200F (cold-FEG) TEM/STEM, operated at 200 kV and equipped with an EDX detector.

RESULTS: STEM characterization of the fraction isolated at lower accelerating force (6000 x g), revealed large particulates with non-uniform thickness and electron density (**Fig 1.a**). EDX spectra demonstrated the presence of Cr, Co, Mo and O (**Fig 1.d**), while elemental mapping showed intense and well-localized signal for Cr and O (**Fig 1.b-c**). By increasing magnification, smaller agglomerates made up of 3-10 nm particles became available for analysis in both fractions (low and high speed centrifugation) (**Fig 2.a-d**). EDX mapping showed well-localized Cr and O signals (**Fig 2.e-f**) and the measurement of the lattice spacing (0.244 nm) confirmed the Cr_2O_3 structure[4].

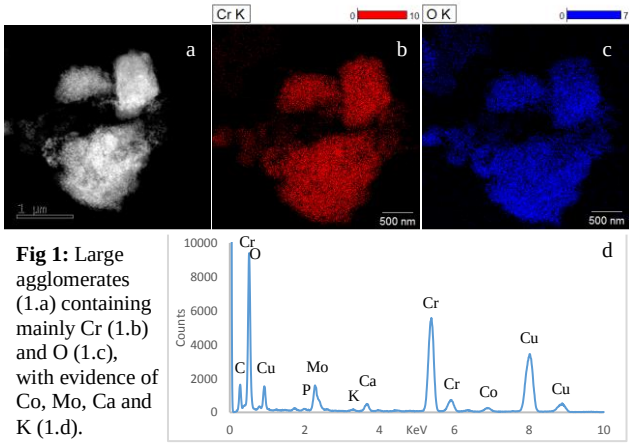

Fig 1: Large agglomerates (1.a) containing mainly Cr (1.b) and O (1.c), with evidence of Co, Mo, Ca and K (1.d).

DISCUSSION: The present study reports on the isolation and characterization of corrosion products released *in vivo* from a CoCrMo taper interface. STEM and EDX analysis revealed large particulates, consisting of Cr, O and traces of Co and Mo, with a structure that indicates a cluster of small particles. Although not so clear in the EDX mapping, the presence of Co and Mo is confirmed in the associated spectra. Mo was identified in most of the particles larger than 50 nm while the proportion of Co was considerably reduced compared to the bulk alloy, in which Co is the major element (~65%). With the use of high resolution STEM and EDX we identified small Cr_2O_3 particles of 3-10 nm size, found both individually and in clusters (**Fig 2.a**). At lower magnification, the clusters can appear as single, large particles with irregular shape, overestimating the size of the actual debris. The atomic resolution allowed for the measurement of lattice spacing which further confirmed the Cr_2O_3 structure. The evidence of Co and Mo as well as the presence of Cr_2O_3 suggests that the corrosion products might originate from the mechanical mixing of CoCrMo and Cr_2O_3 particles in the crevice fluid. The less ordered structure of some of the small particles identified in this study (**Fig 2.d**), can be a proof of the stress-induced phase transformations, while the low proportion of Co in the particles and the high systemic Co reported with failing trunnions[1-2], can be justified by its high solubility, potentially accelerated by the electrochemical conditions in the crevice (low pH and O_2 level). On the contrary, Mo remains in the particles and this suggests a possible inhibition of dissolution by the local environment. Small particles raise concerns due to their mobility and increased reactivity dictated by their high surface area, which might be another cause for the structural transformation, in an attempt to reach a more stable energy configuration. Further research is necessary to assess the effects of the alkaline digestion on the chemical composition of the particles and more corrosion flakes need be investigated in order to confirm the hypotheses proposed here.

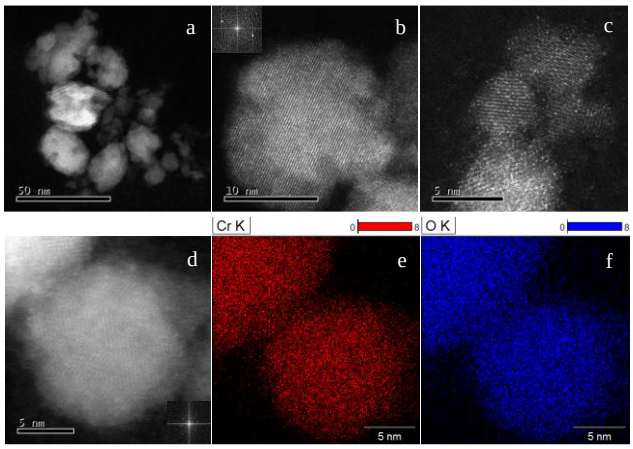

Fig 2: Agglomeration (2.a) of nanoparticles (2.b-d) ranging in size from ~3 nm (2.c) up to 15-20 nm (2.b), containing mainly Cr (2.e) and O (2.f).

SIGNIFICANCE: The study is the first to show the size, morphology and composition of particles released *in vivo* from a taper interface.

ACKNOWLEDGMENTS: EPSRC grant code EP/K040375/1 for the 'South of England Analytical Electron Microscope'

REFERENCES: [**1**]Cook, R.B., J Arthroplasty, 2013, 28(8):1430; [**2**]Cooper, H.R., J Bone Joint Surg Am, 2013, 95(10):865; [**3**]Langton, D.J., Bone Joint J, 2013, 95(5):S28; [**4**]Pang, X., J Mater Res, 2007, 22(12):3531.