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Hemiarthroplasty and Cobalt Chromium Ion Release into Cartilage

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INTRODUCTION: Cobalt-Chromium (CoCr) alloy is a common material for hemiarthroplasty. In this scenario only one side of the diseased joint is replaced, thus that the opposing cartilage articulates against the prosthetic device. Hemiarthroplasty is a promising treatment option for mild joint degeneration, offering the benefits of bone preservation and reduced operative time. However, in vitro work has shown that cell death at the articulating surface is accelerated when articulating against CoCr as compared to non-metallic replacement materials, despite similar levels of matrix wear. Metal ions, which are released during articulation, are likely to blame; however the effect of local metal ion infiltration on chondrocytes is largely unknown. We therefore utilized a tribological bioreactor to articulate bovine cartilage explants against a CoCr counterface, and then evaluated the tissue matrix for the presence of metal ions through x-ray fluorescence microscopy. We hypothesized that the deposition of Co and Cr can be detected at higher concentrations at the surface than in the deep zone of cartilage.

METHODS: Full thickness (~3 mm) oval articular cartilage explants were extracted from the femoral trochlear groove of six to eight month old bovine stifile joints using a custom punch. Testing was conducted in a tribological bioreactor, housed in an incubator with 95% humidity, 5% CO2 and 37 degC. Three explants were confined in porous polyethylene scaffolds, and loaded with a 32 mm diameter CoCr ball. Applying a contact pressure of 2 MPa, the explants were articulated against a CoCr ball (ball rotation: ±30° at 0.5 Hz, explant rotation: ±15° at 0.1 Hz) for three hours or 5,400 cycles. Immediately after testing, samples were removed from their scaffolds and cut along the long axis through the center of the wear path. Individual halves were then flash frozen in liquid nitrogen, and stored overnight at -80 degC. Explants were then prepared with Optimum Cutting Temperature (O.C.T.) gel for cryostat sectioning. Samples were stored overnight at -20 degC in O.C.T. matrix, and 10µm sections were taken with a Leica CM3050S cryostat the following day. Immediately after sectioning, sections were affixed to custom sample holders designed for x-ray fluorescent microscopy, and were kept at -20 degC for 3 days until microscopy was performed at the synchrotron. Samples were raster scanned at 2-ID-E APS (Argonne National Laboratory) with 600 nm zone plate focused x-ray beam (10.35 keV). Overview fast scans were performed with 10 micron pixel size and high resolution slow scans were performed with 1 and 0.3 micron pixel size. Fluorescent spectrum was collected for each pixel with 50 milliseconds dwell time and analyzed using MAPS software with AXO thin film standard calibration. Images for P, S, Cl, K, Ca, Cr, Fe, Co, Cu, and Zn were obtained.

RESULTS: X-ray fluorescence mapping provided images of elemental distribution through articulated and deep layers of cartilage, where all elements were successfully imaged and concentrations could be determined. In the superficial zone of cartilage where samples were articulated, Co and Cr were uniformly distributed. Elevated levels of both Co and Cr were found when comparing the articulated surfaces to the non-contacted deep zones. In addition to the total increase in ion concentration, some sample locations contained metal hotspots of 1-5 microns with a 4-5-times higher concentration of CoCr as compared to the surrounding areas.

DISCUSSION: We hypothesized that potentially harmful deposition of Co and Cr can be detected and evaluated using XFM. It worked for the determination of Co, Cr in concert with other element depositions in tissues with high sensitivity and without labeling, staining or any other tissue alterations, typically required by microscopy techniques. The deep zone of cartilage was not in direct contact with the CoCr head during articulation. The presence of ions in this area is thus due to the deep zone exposure to ions released into the media while the surface deposits represent ion concentrations due to direct contact. Previous data from our laboratory and others has shown high chrondrocyte death at the surface to articulation against CoCr, thus a future question could evaluate the role of cobalt and chromium ions in mechanisms of chrondrocyte death. Furthermore, the direct metal-on-cartilage interaction that occurs in hemiarthroplasty can lead to the formation of metal-protein complexes, which induce hypersensitivity responses from various cell types via the production of pro-inflammatory cytokines and chemokines.

Author: WIMMER, Markus (Rush University Medical Center)

Co-authors: Dr VESELACK, Teresa (Rush University Medical Center); Dr ANTIPOVA, Olga (Argonne National Laboratory)

Presenter: WIMMER, Markus (Rush University Medical Center)

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