

X-ray Spectromicroscopy Provides Spatial Insights Regarding Metal Wear Particles Deposited In Periprosthetic Soft Tissues Surrounding Total Hip Arthroplasty: A Proof-of-concept Study

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INTRODUCTION: Metallic wear particles deposited in soft tissues surrounding total hip arthroplasty (THA) have possible long-term consequences, including tissue damage and necrosis, requiring revision surgery. The current clinically accepted noninvasive biomarker for early detection of metallosis is assessing levels of ionized metals (cobalt and chromium) in body fluids (e.g., serum, whole blood); however, these metrics do not convey spatial information regarding the source of metals present in body fluids, nor information about individualized, host-mediated localized destruction of periprosthetic bone and soft tissues. X-ray fluorescence (XRF) mapping has the potential to help overcome limitations of current technologies by allowing for detection of metal particles deposited in periprosthetic tissues that are smaller than would be visible optically and prior to the biological progression to tissue necrosis. The focus of the current proof-of-concept case study is the introduction of XRF mapping techniques with 1- μ m spatial resolution as a potential gold standard for detection of metal particles deposited in periprosthetic soft tissues surrounding THA and correlation with the established marker of MRI and histologic assays from intraoperative tissue samples procured at the time of THA revision surgery.

METHODS: Data for this study were collected from two subject cases within a broader study of MRI, blood markers, mechanical implant wear, and biospecimens from subjects undergoing revision surgery for symptomatic THA (NCT02255331). The prospective study was approved by the local Institutional Review Board and informed written consent was obtained from all subjects, including over 180 participants. Details on subject recruitment, collected biological specimens, conventional image analytics, and broad statistical correlation analysis between the synovial response, wear and corrosion scoring, implant type, and various histologic classifications can be found within a previously reported analysis of this study cohort from which the cases reported are derived.

Samples of periprosthetic tissue were either placed on polymeric microscopy slide for support during the measurements. These slides have been mounted into the beamline for XRF mapping. XRF mapping with 1 μ m spatial resolution has been applied using beamline 5-ID, the Sub-micron Resolution X-ray spectroscopy beamline (SRX) of the National Synchrotron Light Source-II. Using a visible light microscope integrated into the beamline, a region of interest within the sample has been chosen and the associated scan parameters have been defined. For this study, XRF maps have been collected using a 1- μ m step size. Within the created XRF maps, hotspots of Co, Cr, and Fe have been identified. RGB overlay images have been created with PyXRF, clearly displaying the spatial distribution of the metals. The PyXRF software package utilized for analysis of XRF data is open-source and can be found at the github.io platform for hosting open-source software: <http://nsls-ii.github.io/PyXRF/>.

RESULTS SECTION: X-ray fluorescence mapping co-localized cobalt and chromium deposited in tissues surrounding metal-on-metal THA. Figure 1 displays the XRF mapping results for the case sample and a control sample of periprosthetic soft tissue—the former indicates cobalt and chromium within the periprosthetic tissue sample are highly co-localized, as indicated by the spatial confluence of green and blue fluorescence signals, respectively. Iron is present throughout the sample, as indicated by the red fluorescence signal background that is more homogeneously distributed than cobalt and chromium.

DISCUSSION: This report is the first to apply XRF mapping techniques to obtain spatial information regarding the deposition of metal wear particles in periprosthetic soft tissues surrounding a THA implant. XRF mapping was leveraged to co-localize cobalt and chromium in periprosthetic tissues collected at the time of the revision THA procedure in a subject who originally had a metal-on-metal primary THA implant bearing surface, high magnetic off-resonance score for metallosis, and histologically defined classic aseptic lymphocyte-dominant vasculitis-associated lesion. Notably, this report only represents proof-of-concept application of XRF mapping techniques to detect metal wear particles within periprosthetic soft tissues and thus is not without limitations. Foremost, specimen selection was inherently biased by selection of subject cases that, based on magnetic off-resonance scoring and histological grading, were either predicted to contain or not contain metallic wear particles that could be identified through application of X-ray spectromicroscopy techniques. Furthermore, to address issues of measuring scale and target application of XRF mapping with a 1- μ m sized X-ray beam to the same periprosthetic regions of interest subjected to off-resonance scoring and histological evaluation, blinding of co-investigators to specimen was not implemented.

SIGNIFICANCE/CLINICAL RELEVANCE: This report is the first to apply XRF mapping techniques to obtain spatial information regarding the deposition of metal wear particles in periprosthetic soft tissues surrounding a THA implant. Future studies are needed to correlate X-ray spectroscopy results with magnetic resonance scoring to support noninvasive prediction of wear particle deposition and candidacy for revision surgery.

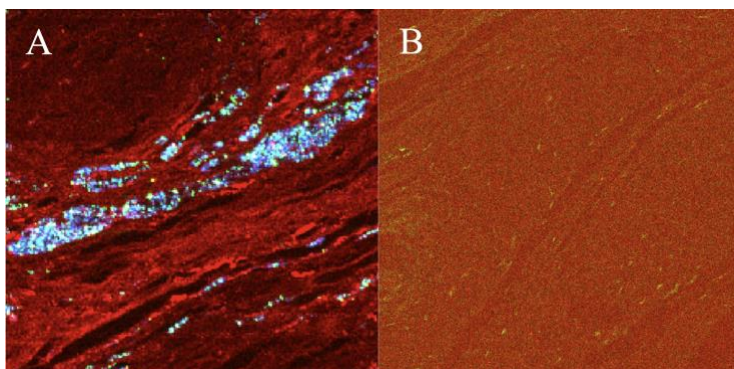


Figure 1. X-ray fluorescence mapping images of periprosthetic soft tissues surrounding total hip arthroplasty in case (A) and control (B) samples, which features iron in red, cobalt in blue, and chromium in green. The case sample demonstrated colocalization of ionized cobalt and chromium whereas the control sample was most consistent with homogeneously distributed iron without notable wear particle deposition.