Identifying In-Vivo Prosthetic Wear Debris Using Spectroscopic Techniques

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Statement of Purpose: Following total joint arthroplasty, the ability to identify the composition of wear particulates from within the joint could have far reaching implications in monitoring patient sensitivity, aseptic bone resorption and prosthetic wear rate.

In this study, we report on the use of the industrial spectroscopic techniques of X-ray photoelectron spectroscopy (XPS), micro-Raman spectroscopy, and scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) to identify the fine wear particulates and other impurities deposited within the knee joint following total knee arthroplasty (TKA).

Methods: Synovial fluid was extracted from four knee joints scheduled for revision TKA. Following high-speed centrifugation, the small dished-shaped debris flake left at the bottom of the centrifuge tube was analyzed using the previously mentioned non-destructive spectroscopic methods. For XPS the samples were argon ion sputtered (a below-surface milling technique) up to 7-hours to remove surface contamination.

The table below describes the prosthetic composition of each synovial sample, along with any visible wear as noted intraoperatively.

Sample	Femur	Tibia	Wear
1	CoCrMo	Ti6Al4V	Femur/Tibial[1]
2	CoCrMo	Ti6Al4V	Femur/Tibial[1]
3	Ti6Al4V	Ti6Al4V	Femur/Patella[2]
4	Ti6Al4V	Ti6Al4V	Femur/Patella[2]

[1]polyethylene only; [2]polyethylene and metal

Results: XPS - A representative area scan is shown in figure 1. Titanium (Ti) and oxygen (O) were identified in samples 1, 3 and 4. Sample-2, the only sample without Ti evidence, was implanted with a Ti-alloy tibial tray that was absent of any visible wear. However, sample-1, also absent of visible tibial tray wear, did show large amounts of Ti and O present, identifying backside wear of the tibial component.

SEM/EDS - The SEM scans showed numerous micron and sub-micron sized metal-like particulates present in all four samples. A representative EDS area scan is shown in figure 2. Cobalt (Co) and chromium (Cr) wear debris were detected for both samples implanted with Co-alloy femurs. Interestingly for all four samples, Ti, aluminum (Al) and Vanadium (V) wear debris was detected in roughly the same Ti:Al:V weight percent ratio (e.g. Al-5.5%, V-3.1%) as the originally manufactured alloy material (Al-6%, V-4%).

Micro-Raman - While there was no detectable evidence of ultra-high molecular weight polyethylene (UHMWPE) present in any of the four samples, Raman scans did corroborate with the XPS findings, showing the presence of oxidized Ti.

Discussion: In an effort to decipher compositional wearing of TKA prostheses in-vivo, we have introduced the industrial spectroscopic techniques of XPS, micro-Raman and SEM/EDS to the biological community.

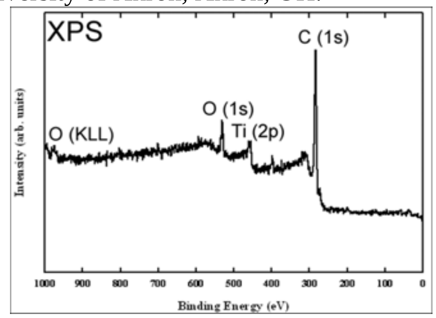

Figure 1

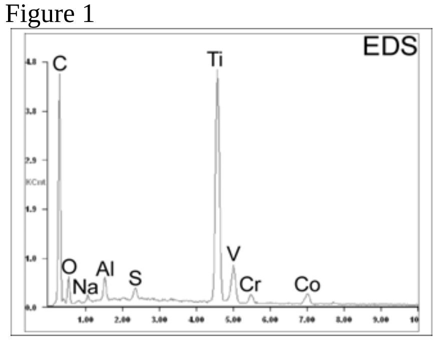

Figure 2

Using these spectroscopic techniques we were successful in identifying a variety of metallic wear debris present within the synovial fluid of postoperative TKA samples. As seen in our previous work [1], the metallic wear particulates identified appear to emanate from both the bearing (articulating) surfaces as well as from the backside (non-articulating) surfaces.

While it may be questioned whether the debris was produced by corrosive dissolution or actual implant wear, we point out that our EDS Ti:Al:V ratios, within experimental uncertainty, are comparable to those of the original alloy material, indicating material wear. To further support the EDS findings, the more sensitive XPS results show samples with more Ti have greater O, indicating a passive titanium oxide complex.

Concerning however is the absence of UHMWPE from within the samples. We hypothesize this featureless evidence is due to sample preparation, washing away the majority of lighter polyethylene particles and leaving only some sintered remnants within the carbonaceous material. However with the recent acquisition of other new spectro-scopic instruments we plan to investigate this featureless UHMWPE phenomenon further.

Conclusions: This study demonstrates a novel approach for introducing multiple spectroscopic techniques to identify the fine metal wear particulates deposited within the joint of postoperative TKA.

References: 1. Tokash, JC, Stojilovic, N, Ramsier, RD, Kovacik, MW, and Mostardi, RA: Surface Analysis of Prosthetic Wear Debris. Surface and Interface Analysis, 37(4): 379-384, 2005.

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