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Understanding the Effects of Wear Particles: Lessons Learned from Postmortem Retrievals

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Total hip and knee replacements have been successful in treating the disability caused by severe osteoarthritis. However, over time joint prostheses do wear and even loosen, producing particulate wear debris. Analysis of postmortem retrieved prostheses, their surrounding tissues, and select remote organs have been most beneficial to understanding the mechanisms of wear and potentially adverse tissue reactions associated with particulate debris. The purpose of this lecture is to highlight the contributions of postmortem retrieval studies to the current understanding of the generation and dissemination of particulate wear debris and the potential effects on local tissues and remote organs. The results of three retrieval studies will be presented.

Joint prostheses, thoracic and abdominal organ samples, and bone marrow cores were obtained postmortem from patients who had previously undergone hip or knee replacement surgery (arthroplasty). The time that patients had hosted the implants ranged from 1 to 24 years. Undecalcified plastic embedded sections of the implants with surrounding bone as well as paraffin embedded hematoxylin & eosin stained sections of the organs and marrow samples were prepared and studied using light and scanning electron microscopy (SEM). Wear particles in the tissues were identified using polarized light, energy dispersive x-ray (EDX) analysis and laser Raman microprobe spectroscopy [1]. The bearing surfaces of the implants were examined with light microscopy at magnifications of 10-50X. Damage to the backside (non-articulating) side of conventional polyethylene liners of the acetabular components was defined as alteration of the original machined surface.

Cellular response to orthopedic wear debris is the accumulation of macrophages potentially forming large masses (particle-induced granulomas) that displace the supporting bone and can lead to loosening of an implant or even structural failure of the bone. In the earliest generation acetabular components, particle-induced granulomas invaded the bone fixing the prosthesis to the skeleton and formed lesions in the surrounding pelvic bone [2]. The composition of the particles in these granulomas revealed several sources. The majority of the particles proved to be polyethylene generated at the bearing surface and at the backside of the acetabular cup. EDX analysis identified metallic particles such as titanium alloy, CoCr alloy, stainless steel generated by fretting and/or corrosion of other metallic components of the joint replacement. Design changes in third generation cementless acetabular components significantly reduced backside wear of the polyethylene bearing surface and the incidence of particle-induced granulomas in periacetabular bone ($p \leq 0.014$).

Metal and polyethylene particles were identified in the liver, spleen and abdominal lymph nodes of patients with total hip and knee implants. The concentration of wear particles, for the majority of the patients, was relatively low and without apparent pathological importance. Metallic wear particles were more prevalent in patients who had a history of a failed hip arthroplasty (88%) than in patients who had successful hip (18%) and/or knee replacements (20%). The principle source of wear particles involved unintended wear between nonbearing surfaces caused by implant loosening or fretting corrosion of modular connections, rather than wear between the two primary bearing surfaces as intended [3].

Intracellular metal alloy particles generated by wear of the prosthetic devices were also detected in the red bone marrow [4]. The particles were detected in the cytoplasm of single or clustered macrophages often lining the sinusoidal channels of the marrow (Figure 1). Though a few particles were resolvable, many macrophages had gray-colored cytoplasm suggesting abundant particles at or below the resolution of the light microscope. SEM analysis showed the majority of the metal alloy particles were submicron in size, and ranged from 0.1 to 3 micrometers (Figure 2).

The results of these postmortem studies stress the importance of reducing particle generation at both bearing and non-bearing surfaces of joint replacement prostheses. Wear particles are disseminated to remote organs and throughout the marrow and can be retained for the life time of the joint replacement patient. Improved prosthetic designs and material wear properties can lengthen implant durability and aid in minimizing the amount of wear particles produced.

References:

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[4] RM Urban *et al*, Trans ORS 35 (2010), p. 2138.
[5] The authors acknowledge funding from NIH Grant AR39310, Zimmer, Rush Arthritis and Orthopedics Institute.

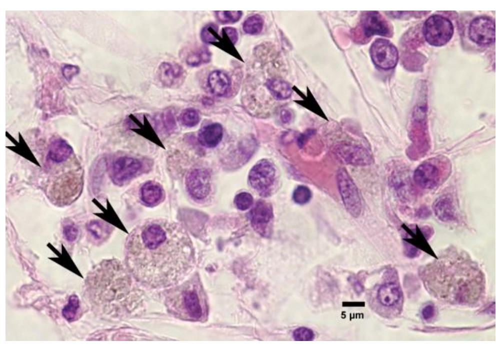

Figure 1. Cluster of wear particle laden macrophages (arrows) in bone marrow of humerus of patient with bilateral revised knee replacements for 18 years. H&E, 600X.

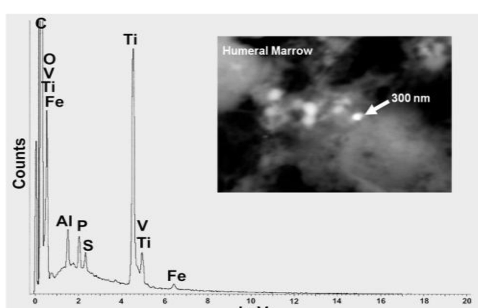

Figure 2. EDX spectrum of a 300 nm particle (inset) within a humeral bone marrow macrophage. Based on the elemental composition of the spectra, this particle originated from the titanium alloy total knee component hosted for 18 years by the patient.

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