Radioisotope tracing of polymer wear progression and wear particle pathways relevant to joint prostheses

Heiko Timmers[a], Jacob A. Warner[a], Yanyan Liu[a], Laura G. Gladkis[a], Paul N. Smith[b], Jennie M. Scarvell[b]

[a]*School of Physical, Environmental and Mathematical Sciences, University of New South Wales in Canberra, ACT 2600, Australia*
[b]*Trauma and Orthopaedic Research Unit, The Canberra Hospital, PO BOX 11, Woden, ACT 2606, Australia*

Knee and hip replacement prostheses using the hard polymer ultra-high molecular weight (UHMW) polyethylene as bearing material have become a routine and successful intervention for patients with injured or arthritic joints. Polymer wear, caused by the articulating cobalt chrome counterparts of the prosthesis, results in a distribution of polymer wear debris particles that vary in shape and have average diameters ranging from millimeters to nanometers. The transport of the polymer debris out of the prosthesis to sensitive regions, such as the prosthesis-bone interfaces, triggers bio-responses that also affect healthy bone and thus the stability of the prosthesis. Reducing polymer wear, shifting the size and shape distributions of wear particles, as well as understanding and limiting the wear particle pathways out of prostheses, may all be expected to potentially reduce the bioactivity and thus extend the life-time of replacement prostheses.

Radioisotope tracers offer increased sensitivity in wear measurements on prostheses compared to conventional techniques. Furthermore, following the detachment of wear particles, the radioisotope tracer may remain with the particle and particle pathways may be followed. Radioisotope tracers were ion-implanted into UHMW polyethylene for tribological measurements on model systems and realistic simulations of knee prosthesis motion. The radioisotope ^{111}In was directly implanted at an energy of 160 keV labelling a 100 nm depth-range just underneath the polyethylene surface. Such shallow labelling has been shown to enable studies of the commencement of polymer wear identifying particle transfer between the articulating surfaces and giving detailed data towards modelling the process. The characteristic wear depth associated with the harmful spectrum of bioactive debris particles in prostheses is, however, of the order of microns. Thus radioisotopes near ^{100}Pd were synthesized using the 14UD Pelletron and recoil-implanted into UHMW polyetheylene plugs to a depth of several microns. The plugs were carefully fitted into commercial knee prostheses and worn in *in-vitro* simulations under load over the equivalent of the first year of patient activity. Results, supported by independent micro-scratching measurements, show a fast, non-linear wear-in phase that has not been quantified before. A much steadier, long-term wear process follows. The effectively constant wear rate measured agrees well with other published data and some bio-responses of debris have been studied in cell-cultures.

Following wear experiments the radioisotope tracers have been identified via characteristic gamma-rays in the prosthesis lubricant and on cobalt-chrome prosthesis parts, implying the observation of polymer debris transport within and out of the prosthesis. Filtering polymer debris transported to the lubricant into size fractions and detecting associated radioactivity, however, has been inconclusive. No significant signal was detected for size fractions with diameters larger than 10 nm. This suggests that either the vast majority of polymer debris particles are smaller than 10 nm or, instead, that the tracer does not remain with particles, thus not permitting the tracing of such debris.

Problems with the novel design of metal-on-metal prostheses have highlighted that metallic wear particles may play a role in the complex bio-responses. In future work the radioisotope tracing approach may thus be applied even more successfully to the much less studied wear of the cobalt-chrome components of conventional joint prostheses.