^{7}Be implantation as an alternative technique for wear measurement of UHMWPE – A Proof of Principle Study

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Statement of Purpose: The current generation of highly cross-linked ultrahigh molecular weight polyethylenes (PE) for hip and knee joint replacement have achieved such low in vitro wear rates that efforts have been underway to develop more sensitive methods to measure polyethylene wear. The most widely used technique, the gravimetric method, suffers from the notable disadvantage that mass gain by fluid absorption can considerably exceed mass loss by wear, making the wear measurement inaccurate, sometimes even leading to negative "wear" values. The purpose of this study was to investigate the use of a radioactive tracer, beryllium-7 (^{7}Be), to circumvent the problem of fluid absorption and thereby achieve a much more sensitive and accurate wear measurements.

Methods: Since the implantation of ^{7}Be atoms into PE may cause material degradation through oxidation, pilot studies using a 'cold' ^{7}Li beam were executed. Two PE pins were treated with either 10^{11} or 10^{13} ions/sec, both at the high end of the intended beam current for ^{7}Be. To evaluate oxidation, FTIR spectral line maps were obtained along the axis of the pins. After microtoming, an oxidation index was generated by normalizing the carbonyl peak (1740 cm^{-1}) with the vinylene group (1360 cm^{-1}). Data were compared against untreated and artificially aged [1] control pins.

The radioactive ^{7}Be source for the experiment was obtained from the ATOMKI cyclotron institute in Debrecen, Hungary where it had been produced via the ^{7}Li(p,n)^{7}Be reaction. After chemical extraction from the ^{7}Li matrix the ^{7}Be was transferred to a sputter cathode for injection in a tandem accelerator at the Oak Ridge National Laboratory, TN. The activity available resulted in ^{7}Be beam currents of 10^{5}-10^{6} ions/sec at the sample location. A new implantation setup consisting of a wheel with 20 foils of increasing thickness and additional energy "smearing" foils was installed at the beam line. This setup assured a homogenous distribution of implanted nuclei from 0 to 8.5 microns. Three cross-linked (e-beam, WIAM) and four conventional PE pins, all compressionmolded from GUR 1050, were thus activated with 10^{9} to 10^{10} nuclei.

The pins were mounted on a six-station pin-on-flat apparatus (OrthoPOD^{TM}; AMTI, Inc.) together with non-activated control pins. The flat-faced UHMWPE pins slid against polished wrought cobalt-chromium disks up to 7.1 million cycles. During the wear test, each pin was immersed in 15 g of lubricant (bovine newborn calf serum) at 37°C and subjected to a constant nominal contact pressure of 3 MPa along a 5 x 5 mm path. Weight loss measurements were performed at predetermined intervals. A 20% Germanium gamma detector was employed to determine activity loss of the PE pins. Wear of each pin was calculated by considering the natural decay of ^{7}Be.

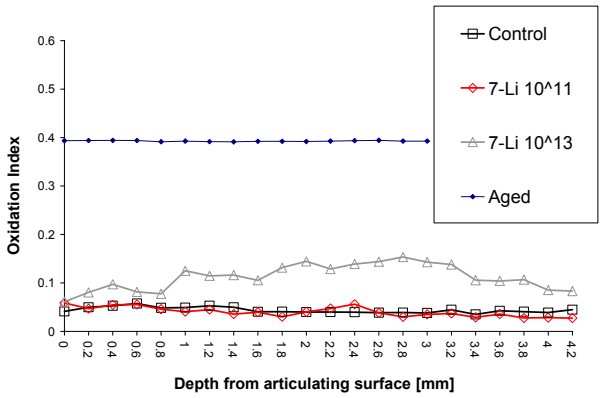

Fig 1. Oxidation index after ion beam treatment

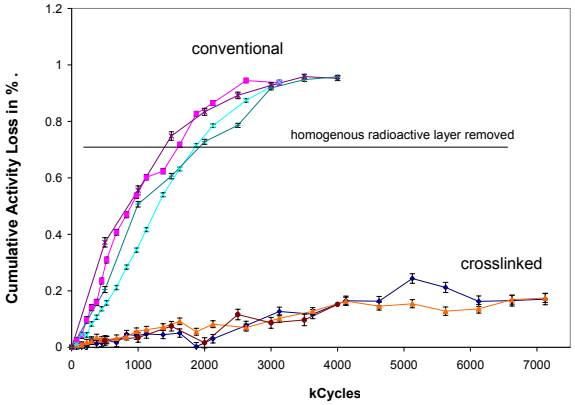

Fig 2. Activity loss of crosslinked vs. conventional PE.

Results: The average of the two indices per condition is shown in Fig.1. The oxidation index observed in the control was within the expected range for non-treated, non-aged PE samples. The 10^{11} ions/sec condition did not show any change in oxidation index neither on the surface nor in subsurface levels. The 10^{13} ions/sec condition showed slightly increased oxidation in the subsurface levels while no significant increase in oxidation on the surface was observed. Fig.2 shows the cumulative activity loss of conventional pins versus crosslinked pins as a function of wear cycles. The measured activity losses translate into wear rates of 3.41±0.93 vs. 0.26±0.008 microns assuming identical material densities.

Conclusions: This proof of principle study demonstrated the general feasibility of ^{7}Be implantation for PE wear analysis. The wear rates of crosslinked and conventional PE differed by approximately 10, thus being in the expected range. Future applications of this tracer technology may include the analysis of location specific wear, as for example the material loss of the post of a tibial insert. The technique may also be used for continuous wear measurements while applying various loading profiles, thus allowing a quicker and more sophisticated assessment of input variables on PE wear.

Reference: [1] ASTM STD F2003-2