ON THE CHANGES OF AN ADHESIVE/ABRASIVE WEAR MECHANISM OF POLYETHYLENE TIBIAL KNEE INSERTS UPON CROSSLINKING: AN IN VITRO SIMULATED GAIT STUDY

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Introduction: Crosslinking of ultra-high molecular weight polyethylene (UHMWPE) improves the wear resistance in both acetabular liners [1] and tibial knee inserts [2]. While the effects of crosslinking on the wear of acetabular liners have been extensively studied, there are a limited number of reports with tibial knee inserts. The improvement in the adhesive/abrasive wear resistance with crosslinked tibial knee inserts has been demonstrated, yet the underlying mechanisms are not well understood.

The objective of the current study was to investigate the surfaces of the scarred regions of conventional and highly crosslinked UHMWPE tibial knee inserts following simulated gait on a knee simulator, to examine and compare the morphological changes induced by articulation and also to unveil some of the mechanisms that could be responsible for the observed differences in wear behavior.

Materials and Methods: Three conventional UHMWPE tibial knee inserts of Sulzer Natural Knee II design (left, size-3) were machined from GUR 1050 ram extruded bar stock and sterilized with gamma irradiation (25-40 kGy) in oxygenless packaging. These were tested along with three highly crosslinked UHMWPE components of the same design. The highly crosslinked UHMWPE (WIAM-95) was prepared by irradiation at 125°C using a 10-MeV Rhodotron T100 electron-beam accelerator (Studer, Switzerland). The total dose level was 95 kGy. Subsequent to irradiation the samples were melt-annealed at 150°C for two hours to substantially reduce the concentration of the residual free radicals. The highly crosslinked inserts were artificially aged in air at 80°C for 35 days. All inserts were tested on an AMTI knee simulator for five million simulated gait cycles. The WIAM-95 inserts were then continued to ten million simulated gait cycles. The knee simulator study used 100% bovine calf serum stabilized with sodium azide and EDTA as a lubricant. We quantified the wear of the test inserts gravimetrically at every million-cycle interval throughout the test. At the end of the simulated gait test one conventional insert and one highly crosslinked insert were selected at random for analysis by scanning electron microscopy (FEI/Philips XL30 FEG SEM). Both the medial and lateral condyles of the articulating surfaces were gold coated prior to the SEM analysis. Each deformation scar was examined as a function of distance from the anterior to the posterior edge of the deformation scar. Representative micrographs were recorded at regular intervals (1-mm) at magnifications up to 35,000X.

Results and Discussion: The conventional UHMWPE tibial inserts exhibited an average weight loss of 29±9 mg following five million cycles of simulated gait. In contrast, the WIAM-95 inserts did not show measurable weight loss. These inserts gained 9±2 mg during the first three million cycles, after which there was no measurable weight change.

The analysis of one of each conventional and WIAM-95 tibial inserts showed surface rippling (see Figure 1-3). In certain regions, the WIAM-95 insert showed more surface rippling than the conventional insert. In the case of the conventional insert, all inspected locations showed a transition zone between regions with and without ripples as shown in Figure 1. At the transition zones in the conventional insert, the ripples appeared to be forming ribbon-like flakes and detaching from the surface (Figure 2). This detachment of the flakes could be one of mechanisms of adhesive/abrasive wear with conventional UHMWPE tibial inserts. On the aged WIAM-95 insert the transition zones and flaking of the ripples were not present, presumably indicating a reduction in adhesive/abrasive wear. The higher abundance of rippling on the surface of the aged WIAM-95 compared to the conventional tibial insert also suggests that the ripples are formed but not dissipated by the detachment process, consequently leading to lower adhesive/abrasive wear with the highly crosslinked polymer.

In addition, the ripples in both inserts showed the formation of very superficial micro-tears. In the conventional insert, the detachment of the flakes appeared to be secondary to the formation of the micro-tears. In contrast, for the aged WIAM-95 insert micro-tears simply appeared to accumulate but not lead to any appreciable wear.

We postulate that the surface rippling is a consequence of the large-strain surface orientation induced by the articulation of the femoral component on the polyethylene tibial insert during simulated gait. This orientation has been shown to extend only few hundred micrometers below the articulating surface of polyethylene components [3]. As a result, the subsurface would constrain the large-strain surface deformation and cause surface buckling, forming the ripples.

The morphological changes on the surface of polyethylene evolve with deformation and reach a steady state. In the present study, we limited the morphological analysis to the steady state appearance of the articulating surfaces. Future studies will focus on better understanding the evolution of the ripples and micro-tears during the early stages of simulated gait cycles.


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