INTRODUCTION

Delamination is a common failure mechanism in ultra-high molecular weight polyethylene (UHMWPE) tibial inserts [Wright and Rimmnac, 1988]. Changes in polyethylene mechanical properties, such as subsurface embrittlement due to oxidation, may promote crack propagation. The assessment of through-thickness properties may, therefore, provide insight into delamination mechanisms. Using the small punch test [Kurtz et al., 1997], researchers have studied changes in subsurface mechanical properties in aged and unaged tibial components [Edidin et al., 1999; Ely et al., 2000]. In this present study, we used nanoindentation to measure stiffness and hardness profiles in cross sections of unused polyethylene tibial components. Nanoindentation has previously been used to characterize surface properties of UHMWPE [Schmidt et al., 2000].

MATERIALS AND METHODS

Preliminary work focused on specimen preparation and the establishment of optimal nanoindentation parameters. UHMWPE tibial inserts of unknown origin were used for this purpose. Samples were cut from the tibial plateau and the cross sections microtomed to eliminate surface roughness. Nanoindentation was first performed on specimens as microtomed. Other specimens were polished using a technique developed at Oak Ridge National Laboratory (ORNL) for this project (Table 1).

Nanoindentation was performed at the ORNL High Temperatures Material Laboratory using a Nanoindenter II (MTS/Nano Instruments, Oak Ridge, TN). In the preliminary tests, the nanoindenter was operated using the continuous stiffness method [Oliver and Pharr, 1992] with a Berkovich indenter at a rate of 20 nm/s to a maximum depth of 400 nm. The load was held for 15 seconds while contact stiffness was measured, then the specimen was unloaded to 80% for measurement of thermal drift. Five indents were made at each location, from which average properties were determined. This was done every 200 µm across the entire cross-section.

The results of the preliminary work demonstrated that the ORNL polishing protocol adequately prepared the UHMWPE specimens for nanoindentation. Furthermore, nanoindentation using the Berkovich indenter in continuous stiffness mode provided repeatable indentation stiffness measures for UHMWPE.

Mechanical properties of samples cut from two unused UHMWPE tibial inserts were then measured using nanoindentation. The first was a machined isostatically molded
1900H component. The second was a direct compression molded 1900H component. Both had been sterilized with gamma irradiation (25-40 kGy, in argon) in December 1995 and February 1996, respectively. They had been subsequently packaged in an argon environment and remained sealed until they were removed for sectioning. Cross sections were micromotmed and polished, and nanoindentation was performed using the Berkovich indenter in continuous stiffness mode, as described previously.

RESULTS

Profiles of stiffness, modulus, and hardness were obtained from the nanoindentation experiments. Figure 1 shows an example plot of stiffness versus depth through three cross sections of the machined isostatically molded 1900H component. The figure shows increases in stiffness from the surface to depths of 0.5 - 1 mm, followed by a decline in stiffness to approximately 3 mm below the surface. Here, samples 1 and 2 both show a trend of increasing stiffness with increased depth, while the third specimen stiffness remained low. Hardness and modulus profiles revealed similar trends.

DISCUSSION

The subsurface elevations in stiffness and hardness reported here are consistent with observations of subsurface peaks in oxidation levels at 1-2 mm beneath the surface [Sutula et al., 1995]. Further characterization of oxidation levels should be performed to validate this conjecture.

The results of the present study suggest that nanoindentation may provide an alternative to the small punch test [Kurtz et al., 1997] to examine the through-thickness characteristics of polyethylene components. The technique may be used in future studies to examine variations in mechanical properties associated with shelf-aging, accelerated aging and delamination wear.

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