NANOINDENTIONAL OF RETRIEVED POLYETHYLENE TIBAL COMPONENTS*

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Introduction

Delamination is a common failure mechanism in ultra-high molecular weight polyethylene (UHMWPE) tibial inserts [1]. Changes in polyethylene mechanical properties may promote crack propagation, such as subsurface embrittlement due to oxidation. The assessment of through-thickness properties may therefore provide insight into delamination mechanisms. In the present study, we aimed to quantify the stiffness and hardness profiles in cross sections of retrieved and unused polyethylene tibial components using nanoindentation. The technique has been used successfully to characterize surface properties of UHMWPE [2]. A rigorous polishing approach was employed to reduce preparation artifacts and to achieve the necessary smoothness for repeatable nano-indentation. Various nanoindentation techniques were used to examine the elastic response and plastic deformation of these cross sections.

Materials and Methods

Two retrieved UHMWPE polyethylene tibial inserts displaying regions of delamination were selected from the UAB Division of Orthopaedic Surgery's retrieval collection. Information was unavailable regarding resin type, manufacturing and sterilization techniques, as well as time in vivo. Using a microtome, rectangular cross sections were removed from each sample: beneath the articulating region near a delamination and from non-articulating regions. Cross sections were also obtained from unused medical grade UHMWPE. 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, described in Table 1.

Table 1. Polishing protocol for polyethylene specimens

Abrasive	SiC paper	Diamond	Diamond
Grain size	800, 1200, 2400, 4000	3 micron	1 micron
Rotation	⇒	⇒	⇒
Lubricant	water	DP-LUB	DP-LUB
Speed (rpm)	150	150	150
Force (N)	20	30	25
Time (min)	1 for each grain size	10	5

Nanoindentation was performed at the ORNL High Temperatures Material Laboratory using a Nanoindenter II (MTS/Nano Instruments, Oak Ridge, TN). The nanoindenter was operated using the continuous stiffness method [3] with a Berkovich indenter at a rate of

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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. The tests were repeated operating in basic mode, where the specimens were similarly loaded with a cube corner indenter, without hold segments or correction for thermal drift. Five indents were made at each depth, horizontally spaced every 15 μm, from which average properties were determined. This was done every 200μm across the entire cross-section. Stiffness, *S*, was obtained from the reduced elastic modulus, E_r, and the indentation area, *A*, as

$$S = 2E_r \sqrt{A/\pi} \qquad (1)$$

Results

Profiles of stiffness, reduced modulus and hardness were obtained from the nanoindentation experiments. The same trends were observed regardless of indenter type and indentation method. Polishing allowed measurements at very shallow penetration depths and reduced data scatter. Figure 1 shows an example plot of stiffness versus depth through the cross section for articulating and non-articulating regions of one specimen, along with values from the unused medical grade UHMWPE. The figure shows increases in stiffness from the surface to depths of about 1 mm, followed by a flattening out of the stiffness by 2 to 2.5 mm, for both the articulating and non-articulating regions. The stiffness of the unused polyethylene was relatively constant through its entire thickness. Hardness and modulus profiles revealed similar trends.

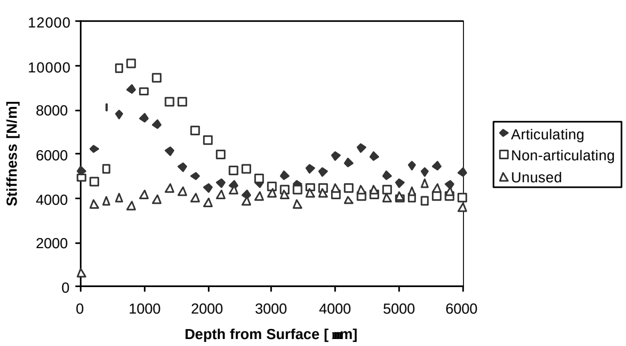

Figure 1. Nano-stiffness as a function of depth beneath the surface.

Discussion

The primary purpose of this work was to develop a specimen preparation technique that would allow measurement of mechanical properties using a nanoindenter, and to investigate different indentation methods. From this study it appears that nanoindentation using the Berkovich indenter in continuous stiffness mode, in conjunction with stated polishing technique, provided repeatable measures of stiffness and hardness of the polyethylene implants.

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The subsurface elevations in stiffness and hardness reported here are consistent with previous reports of mechanical degradation after years of shelf-aging, using the small punch test [4]. Although the present work is preliminary, the similar profiles beneath articulating and nonarticulating regions suggest that the changes in the mechanical properties are primarily a result of aging and oxidation, and that strain hardening beneath articulating surfaces may play a less significant role in promoting delamination in tibial inserts. Further study is warranted.

References

[1] Wright and Rimnac, *JBJS*, 70(9) 202-207, 1988. [2] Schmidt et al., *Proc. Soc. Biomats*., 1255, 2000. [3] Nano Instruments, *Mechanical Testing by Indentation*, 1997. [4] Edidin et al., *Trans. ORS*, 74, 1999.

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