Nanoindentation Results From Direct Molded Vs. Machined UHMWPE Tibial Bearings

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Introduction

Nanoindentation has been used to compare the micromechanical properties of direct molded vs. machined bearing surfaces on UHMWPE tibial components. Differences in micromechanical properties (hardness and elastic storage modulus) were observed between these two types of bearing surfaces, and are believed to result from (1) differences in surface roughness, and (2) differences in morphology of the UHMWPE.

Clinical studies of in-vivo UHMWPE wear rates in acetabular cups have reported differences between direct molded and machined bearings.[1,2] Other studies of retrieved components have reported differences as well.[3] Variations in surface characteristics (rather than bulk properties) may cause these differences in wear behavior.

This study's objective was to compare micro-mechanical interactions at the bearing surfaces of direct molded components with those of machined components. A nanoindenter was used to perform instrumented microindentations on these surfaces. Data was analyzed to study both the load vs. displacement behavior during the indentation cycle, and also to measure the elastic storage modulus and hardness as a function of depth.

Materials & Methods

Tibial components were selected because their surface geometry was suitable for nanoindentation. Biomet supplied 2 types of Maxim tibial bearings. One type was fabricated by direct molding the bearing from resin, and the other type was fabricated by machining bulk stock. Both types were fabricated from Hifax 1900H resin. Measurements of surface roughness had previously been performed on these bearing types.

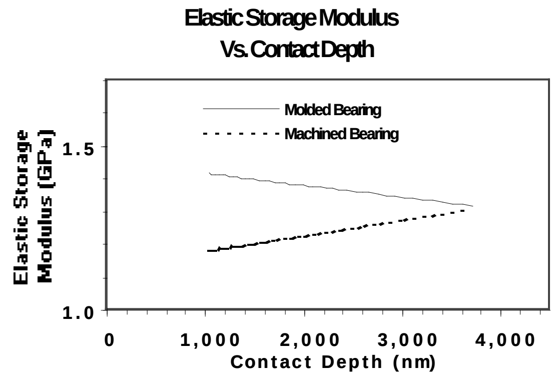
One specimen for nanoindentation was cut from the contact region on the top surface of each bearing type. Each specimen was approximately 13 mm x 13 mm x 6 mm. The original bearing surface was kept intact so that it could be studied by nanoindentation.

The Nano Indenter XP (Nano Instruments, Inc.) was used for instrumented indentation testing using a Berkovich indenter. A surface approach rate of 10 nm/sec was used to find the point of contact. Indentation measurements were made in Continuous Stiffness Measurement (CSM) mode with a constant (1/P dP/dt) load ramp of 0.05 s^{-1} and an excitation rate of 45 Hz with a sinusoidal displacement of 2 nm. Load was applied up to a maximum of 20 mN, and then held at that level for 100 sec before unloading.

Data collected in CSM mode included load (P), displacement (h), and stiffness (S) vs. time. The contact area (A) and the contact depth (h_c) were calculated from the indenter geometry based on measured displacements. Hardness (H) and elastic storage modulus (E) were then calculated using the following equations:

$$H = P / A$$

$$E_r = (\pi)^{1/2}(S) / (2.068)(A)^{1/2}$$



$$[1/E_r] = [(1-\nu^2)/E] + [(1-\nu_i^2)/E_i]$$

where E_r is the reduced modulus, ν is the Poisson's ratio of the specimen (0.46 for UHMWPE[4]), and ν_i and E_i are properties of the indenter.

Results and Discussion

Data were obtained from 13 indents on the direct molded bearing, and from 7 indents on the machined bearing. Other indents did not produce usable data. The average contact depths at maximum load were 4,530 ± 60 nm for the direct molded bearing and 4,820 ± 270 nm for the machined bearing. Load vs. displacement curves were repeatable for the molded surface, but were variable for the machined surface (due to surface roughness).

The elastic storage modulus was found to vary with contact depth for both bearing types, as plotted above. This graph shows lines averaged over all indents for each specimen. The modulus increased near the surface in the direct molded bearing, but decreased near the surface in the machined bearing. Hardness data also showed that the surface of the molded bearing was harder than that of the machined bearing, although properties were similar below the surface.

Molded bearings were found to have stiffer, harder surfaces than machined bearings. Mechanical properties vary slightly with depth in both types of bearings.

References

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