Tribological Evaluation of Nanostructured Diamond Coatings Against Ultra-High Molecular Weight Polyethylene

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Statement of Purpose: A common temporomandibular joint (TMJ) prosthesis design consists of a CoCr alloy condyle that articulates against a fossa component of ultra-high molecular weight polyethylene (PE). Device failures have been linked to PE wear debris.[1] Vohra and co-workers have patented methods to deposit nano-structured diamond (NSD) coatings onto Ti6Al4V by Microwave Plasma-Assisted Chemical Vapor Deposition (MPCVD) where nitrogen feed gas is added to the plasma chemistry.[2] More recently, helium has been added to the plasma in the CVD process to produce smoother coatings.[3] The goal of the present study was to quantify wear of polyethylene against NSD-coated Ti6Al4V and CoCr in pin-on-disk tests.

Methods: Flat circular disks of Ti6Al4V and CoCr were ground with SiC sandpaper and then polished to a mirror-like finish with a colloidal silica/hydrogen peroxide solution. NSD coatings were deposited onto the Ti6Al4V substrates using a Wavemat Corporation® 6 kW MPCVD machine. Six NSD samples were produced by the "nitrogen" process,[2] and four NSD samples were produced by the "helium" process.[3] An AMTI OrthoPOD was used to perform pin-on-disk wear testing (square wear path, ~100N load, at 1.5 Hz) of medical-grade PE pins (4.76 mm contact diameter) on the NSD-coated disks and on three CoCr disks. Three separate wear tests were performed in bovine serum at 37°C, with 20 mM EDTA and 1% sodium azide added.[4] One unloaded pin was included as a soak control in each test to account for fluid absorption. Specimens were weighed (± 0.00001 gm) before and after testing using a Mettler Toledo AG245 microbalance. Wear factors, k (mm^3/Nm), were calculated to compare wear properties. Average surface roughness values for each NSD-coated disk were determined using an optical profilometer based on five separate scan areas (0.3 mm^2). Wear factors and surface roughness values from the NSD-coated and CoCr samples were compared using non-parametric statistics. Linear regression was used to determine if there was a significant correlation between wear factors and surface roughness.

Results / Discussion: A large variation was observed in wear factors for the nitrogen NSD samples (Fig. 1), with the average value over twice that of CoCr. The average wear factor for the helium NSD samples was close to that of CoCr (Fig. 1). However, no significant difference was found between the three groups ($p = 0.19$; Kruskal-Wallis). Three NSD samples were associated with less PE wear than the CoCr samples. The lowest wear factor for UHMWPE on CoCr was 4.13×10^{-7} mm^3/Nm. Wear factors of 2.29×10^{-7} mm^3/Nm and 3.12×10^{-7} mm^3/Nm were determined for two of the "helium" NSD samples. Additionally, one nitrogen NSD sample had a wear factor of 2.77×10^{-7} mm^3/Nm.

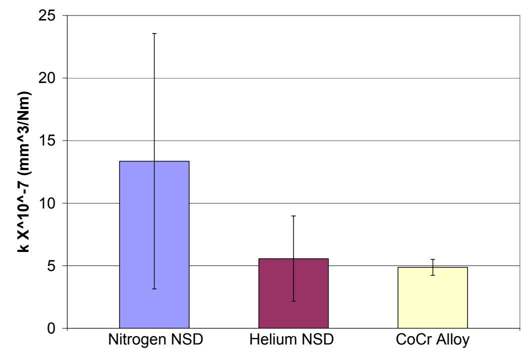

Figure 1. Wear factor of the NSD samples and CoCr alloy

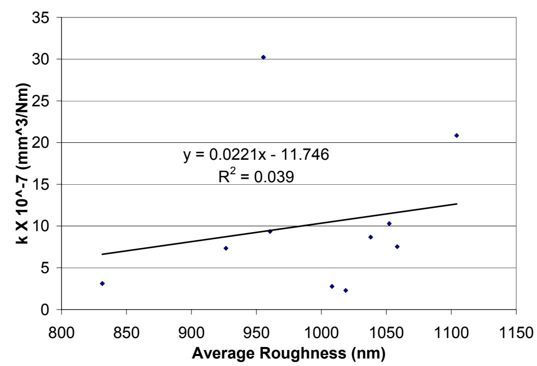

Figure 2. Wear factor vs. roughness for NSD coated specimens

The average roughness values for the nitrogen coatings (1050 ± 165.2 nm) and for the helium coatings (967 ± 99.1 nm) were not statistically different ($p = 0.67$; Man Whitney U). No correlation was observed between wear factor and surface roughness (Fig. 2; $p = 0.58$).

Conclusions: Polyethylene wear rates against NSD-coated Ti6Al4V disks were comparable to wear rates against CoCr in sliding pin-on-disk wear tests. Wear was not a function of surface roughness for the NSD-coated disks. These results support further exploration of NSD coatings as potential materials for future TMJ prosthesis designs.

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References: 1. Willert et al., Tissue React Plastic Metal Wear Prod of Joint Endopros, 1976; 2. Catledge et al., J. Applied Physics, 1999; 3. Konovalov et al., J. Nanosciences and Nanotechnology, 2005 4. ASTM Standard F 732, 2003.