Relationship between friction of artificial joint materials and thermal unfolding of interfacial albumin

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Introduction: Under the articulation of artificial joints, ultra-high molecular weight polyethylene (UHMWPE) acts as a bearing surface under the lubrication of synovial fluid containing various proteins. Albumin is the most abundant composition and acts as the interfacial molecule in the boundary lubrication regime. The dissipated energy including thermal energy from the tribological process may lead to the conformational change of albumin molecules. In this study, a series of experiments were designed and carried out to investigate the association of thermal unfolding albumin and the frictional characteristics of highly-crosslinked UHMWPE (x-UHMWPE). An accelerated oxidation experiment was used to prepare UHMWPE with an oxidized surface. Analysis of the albumin protein by circular dichroism (CD) spectroscopy was performed to detect the conformational changes during a thermal process. In addition, a molecular simulation was performed to understand the structural change of albumin at various temperatures and the exposed hydrophobic contact areas.

Materials and Methods: Highly-crosslinked GUR1050 UHMWPE (x-UHMWPE) materials were obtained from United Orthopaedic Corporation, Taiwan. UHMWPE cylinder pins were machined to 6.35 mm in diameter and 25.4 mm in length with diamond turning on both end surfaces without polishing. The mean roughness (Ra) of UHMWPE pins' end surface is 0.82 μm. 316 stainless steel plates were prepared as the articulating materials and the surfaces were polished (Ra = 0.11 μm). The surface roughness of the stainless steel plates was slightly higher than that expected for artificial joints (Ra ~ 0.01 μm). To obtain the oxidized x-UHMWPE for comparison, x-UHMWPE is aged at elevated temperature to accelerate oxidation of the material. The ASTM F2003-02 used as a guideline for the experiments. x-UHMWPE pins were placed in a thermal chamber under 80 degree C and 1 atm for 23 days. The materials were then stored in a vacuum drier before the friction tests were performed. Before and after the accelerated oxidation process, Fourier transform infrared-attenuated total reflectance (FTIR-ATR, Spectrum GX2000 PERKIN ELMER) was applied to determine the oxidation level of UHMWPE. An oxidation index (OI) is defined as the ratio of the area of the absorption peaks between 1650 and 1850 cm⁻¹ (C=O) to the area of the absorption peak(s) between 1330 and 1396 cm⁻¹ (C-H). The measured oxidation index for the materials taken from the shelf (x-UHMWPE) and the one undergoing the accelerated oxidation process (oxidized x-UHMWPE) are 0.92 and 1.58 respectively.

Albumin powders (Sigma, AG-1653) were dissolved in the saline solution to prepare the human serum albumin (HSA) solution of 12.6 mg/ml. 6 mL albumin solution was poured in a capped vial and placed in a degree C constant temperature water bath for 5 minutes during a thermal process. The vial was then put in the room temperature (25 degree C) for another 5 minutes. The above procedures were repeated until the total period of 30 minutes in the 95 degree C water bath was reached. Fresh and thermal processed albumin solutions were sampled for protein analysis. The conformation of albumin in solution was monitored using a circular dichroism spectroscopy (CD, Spectropolarimeter J-810, Jasco).

Linear reciprocating friction tests of x-UHMWPE articulating 316 stainless steels were carried out with 20 mm/s speed, 5 mm stroke length for 50 cycles. Various compressive displacements between 300–600 μm were applied in the friction tests. Fresh and thermal processed albumin solution and saline solution were used as lubricants.

Results: Figure 1(a) indicates that the friction coefficient of x-UHMWPE sliding over steel in the thermal processed albumin solution is higher than the friction coefficients measured in fresh albumin solution under various compressive displacements ranging from 300-600 μm (p<0.05). Thermal processed albumin solution contains a measurable amount of unfolded albumin. Compared to native albumin, unfolded albumin has a less regular structure and exposes more hydrophobic side chains of amino acids, resulting in more hydrophobic interaction between the unfolded albumin and material surfaces. The unfolded albumin forms a compact layer of protein that tends to adhere to the hydrophobic x-UHMWPE surface and results in the increase of friction coefficient. However, the friction coefficients for thermal processed albumin solutions increase with increasing compressive displacements (loads). With increasing normal load, the unfolded albumin may be pressed onto surfaces to a greater amount, leading to increasing the friction coefficients. When the hydrophobic x-UHMWPE is replaced by a less hydrophobic oxidized x-UHMWPE, the friction coefficients are shown in Figure 1(b).

Discussion: In this study, the thermal unfolding of albumin molecules has been characterized. The interactions of the conformational change of albumin with x-UHMWPE and oxidized x-UHMWPE surfaces were investigated through a series of friction tests in order to point out their impacts on boundary lubrication. The effects of the relationship between the hydrophobicities of albumin and articulating materials on their frictional characteristics were also indicated. The results indicate that a decrease of α-helix content and an unfolding of the secondary structure of albumin were observed with increasing temperatures which may come from the frictional heat of joint articulation process. The conformational change of albumin differentiates the frictional characteristics for UHMWPE with different oxidation levels. A model describing that the properties of the lubricating molecules and articulating surfaces may affect the adsorption of the boundary lubrication thin film which is critical to the tribological behavior was proposed.

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