Effect of Concentrations of Bovine Serum Albumin on Tribological Response of Cobalt Chromium Femoral Head

INTRODUCTION:
Nano/micro-scale tribological properties (surface roughness and frictional coefficient of engineering and biological materials) have been investigated through Atomic Force Microscopy (AFM) [1]. At the macro-scale, previous studies in the literature have reported on the effect of lubricants on friction and wear through pin-on-disk tests and there has been the general agreement that albumin plays an important role as a lubricant in the tribological behavior of hip implant materials such as UHMWPE (ultra high molecular weight polyethylene)-on-coobalt chromium [2, 3], UHMWPE-on-stainless steel [2, 4, 5], and UHMWPE-on-alumina ceramic [2, 4]. At the micro-scale, however, the effect of lubricants on the tribological properties of hip implant materials has not been well identified, although micro-scale AFM measurements are highly suitable for exploring frictional effectiveness of boundary lubrication for diverse lubricants in diarthrodial joints. Therefore, the objective of the present study is to investigate the role of albumin as a boundary lubricant in the lubrication of cobalt chromium (CoCr) femoral head total hip arthroplasty (THA) by measuring its frictional coefficients with AFM techniques.

MATERIALS AND METHODS:
One sample with length, width, and thickness of 10 mm, 10 mm, and 5 mm, respectively, was machined from the main wear region of a CoCr femoral head after 10 years of usage which was retrieved from hip surgery for aseptic loosening of THA. The sample was cleaned in an ultrasonic bath for five minutes and glued on top of the cylindrical flat plates (1 mm thickness and 19 mm diameter) using a small amount of cyanoacrylate glue. In this study, two types of solutions were prepared as lubricants: PBS (Phosphate Buffered Saline, Sigma-Aldrich, No. P5493) as a control solution, and BSA (Bovine Serum Albumin, Sigma-Aldrich, No. A2153) at different protein concentrations (10 mg/ml, 20 mg/ml, and 30 mg/ml) in PBS. All lubricants were stored at a temperature of 4 °C. For AFM measurements with lubricants, the sample was imaged at room temperature using an AFM device (XE 70, Park Scientific Instruments, South Korea) which was placed in a sealed box and equipped with software (XEI version 1.6.5) for image processing and the calculation of the surface roughness. A rectangular silicon cantilever with a normal spring constant of $K_N=0.95$ N/m that was integrated with a square-pyramid conical tip (curvature less than 10 nm) was used. Friction force ($F_z$) was calculated by the multiplication of the lateral voltage signal ($V_{LFM}$) in V, lateral spring constant ($K_L$ in N/m), and lateral sensitivity ($S_L$ in mm/V). In the present study, the friction force was calculated from the whole image of 25$\mu$m×25$\mu$m scanned area, and the lateral sensitivity ($S_L$) is proportional to the normal sensitivity ($S_N=61.14$ nm/V) by the following equation $S_L=\frac{W}{2L} \frac{V_{LFM}}{V_{S_L}}$ [6], where $h$ is the tip height, $L$ is the cantilever length, and $V_{LFM}$ and $V_{S_L}$ are the lateral and vertical voltage signals of the scanned image, respectively. The lateral spring constant ($K_L$) for a rectangular silicon cantilever adopted in the experiments was calculated by the equation of $K_L=\frac{GW^3}{3Lh^2}=29.08$ N/m [7,9], where $G=6.17\times10^{11}$ Pa [7] is shear modulus of the cantilever, $W$ is the cantilever width, and $t$ is the cantilever thickness.

The measurements of the frictional forces were repeated for six values of normal loads in increment of 5 nN at each position. The values of surface roughness ($R_s$) (Fig. 1A), normal force (Fig. 1B), and lateral voltage signal images (Fig. 1C) were simultaneously measured over the same scanned area of 25$\mu$m×25$\mu$m, at a scanning frequency of 1 Hz. The plot of the frictional force against the normal force was fitted with a straight line, whose slope was the frictional coefficient (Fig. 2).

RESULTS:
The average values of surface roughness ($R_s$) over the 25$\mu$m×25$\mu$m scanned area of the CoCr femoral head were 58.506±18.896 nm (n=5). The frictional coefficients ($\mu$) through AFM were 0.241±0.044 with an $R^2$ of 0.993±0.005 (n=5) in PBS, 0.197±0.019 with an $R^2$ of 0.999±0.001 (n=6) in BSA of 10 mg/ml, 0.072±0.016 with an $R^2$ of 0.994±0.004 (n=6) in BSA of 20 mg/ml, and 0.064±0.005 with an $R^2$ of 0.997±0.001 (n=6) in BSA of 30 mg/ml. The Student t-test revealed statistically significant differences in $\mu$ of CoCr femoral head between PBS and BSA of 10 mg/ml (p<0.05) as well as between PBS and BSA of 20 mg/ml and between PBS and BSA of 30 mg/ml (p<0.0001). Similarly, between different concentrations of BSAs (between BSAs of 10 mg/ml, 20 mg/ml, and 30 mg/ml), there were statistically significant differences in $\mu$ in all cases except between BSAs of 20 mg/ml and 30 mg/ml (p<0.0001).

DISCUSSION:
The surface roughness and frictional coefficient of CoCr femoral head which was retrieved from hip surgery for aseptic loosening of THA were measured successfully through AFM techniques at six different locations of its main wear region with different lubricants. In the current study, the amount of BSA concentration significantly affected reducing $\mu$ of CoCr femoral head; $\mu$ was higher at smaller BSA protein concentration and smaller at higher BSA protein concentration. However, when BSA concentration is higher than 20 mg/ml, an increase in BSA concentration results in no further decrease in $\mu$ of CoCr femoral head. These results suggest that $\mu$ of CoCr femoral head is dependent on the concentration of BSA, but there is a maximum concentration of BSA to play a role as an effective boundary lubricant. These results could be explained by the fact that albumin in BSA enhances lubricity through adsorption on the surface of CoCr femoral head and also consistent with some studies at the macro-scale [2,5]. In future study, efficiencies of other lubricants such as globulin and hyaluronic acid for boundary lubrication of CoCr femoral head will be elucidated through AFM frictional measurements.

REFERENCES: