Effect of Concentrations of γ-globulin on Frictional Response of Cobalt-Chromium Femoral Head

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INTRODUCTION:
There has been the general agreement that γ-globulin plays an important role as the boundary lubricants in improving the frictional properties of the lubricated surfaces [1]. Through macroscopic pin-on-disk measurements, it was found that the frictional coefficient ($\mu$) between cobalt-chromium (CoCr) and UHMWPE was $\mu=0.25$ using γ-globulin as a lubricant [2], and wear between glass and polyvinyl alcohol (PVA) hydrogel was dependent on the protein concentration of γ-globulin [3]. AFM measurements has been reported to be very effective for exploring boundary lubricating ability of diverse lubricants without being affected by the surface roughness of rubbing materials [4], and, moreover, the effect of protein concentrations of γ-globulin has not been well identified on the boundary lubricating ability of hip implant materials until now. Therefore, the objective of the present study is to investigate the concentration-dependent role of γ-globulin as a boundary lubricant in the lubricating ability of CoCr femoral head 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, which was retrieved from revision surgery due to aseptic loosening ten years after total THA. Prior to the AFM measurements with diverse lubricants, the sample was first cleaned with the surgical cotton wool under distilled water. Then it was soaked in 99% ethanol for ten minutes in an ultrasonic bath to remove the remaining fine foreign substances. Finally, the sample was glued on top of the cylindrical flat plates. In the present study, PBS (Ref. P5493, Sigma-Aldrich) was used as a control solution, and bovine γ-globulin (Ref. 5009, Sigma-Aldrich) as a lubricant at concentrations of 2.5, 5.0, 7.5, and 12.5 mg/ml in PBS based on the physiological concentrations of human synovial fluid which was in the range of 1.4 to 4.2 mg/ml [5], by being stored at 4°C until ready for use. For AFM measurements, the sample was entirely submerged in PBS and γ-globulin and imaged at room temperature using an AFM device (XE 70, Park Systems, South Korea) which was placed in a sealed box and equipped with analysis software (XEI version 1.6.5).

A rectangular silicon cantilever with a normal spring constant of $K_r=95$ N/m that was integrated with a square-pyramid conical tip (curvature $\leq 10$ nm) was used. Frictional force was calculated from the whole image of 25μm×25μm scanned area by the multiplication of the lateral voltage signal ($V_{LSTM}$), the lateral spring constant ($K_l$), and the lateral sensitivity ($S_L$). Here, the lateral sensitivity ($S_L$) was computed from the equation which was proportional to the normal sensitivity ($S_N=61.141$ nm/V) [6], where $h$ is the tip height, $L$ is the cantilever length, and $V_{LSM}$ and $V_{LB}$ are the lateral and vertical voltage signals of the scanned image, respectively. The lateral spring constant ($K_l=29.084$ N/m) for the rectangular silicon cantilever was measured by the equation $K_l=GwK_l$, where $G=6317\times 10^{15}$ Pa [6] 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 an increment of 5 nN at each position. The values of surface roughness ($R_s$), normal force, and lateral voltage signal images were simultaneously measured over the same scanned area at a velocity of 50 μm/s (Fig. 1). The plot of the frictional force against the normal force was fitted with a straight line, whose slope yields the frictional coefficient (Fig. 2).

RESULTS:

Root mean squared (RMS) surface roughness ($R_s$) over the 25μm×25μm scanned area was measured for the main wear region of the CoCr femoral head implant in PBS (Fig. 1) and the average value of $R_s=10155$ by Hallym University Medical Center (01-2009-13).

In the current study, the frictional coefficient ($\mu$) of the CoCr femoral head statistically decreased when the protein concentrations of γ-globulin were 2.5 and 5.0 mg/ml, but statistically increased when the protein concentrations of γ-globulin were 7.5 and 12.5 mg/ml. This result indicates that there exists a certain range of γ-globulin concentrations which can optimize the frictional behavior of the bearing surfaces, and this range is similar to the range of γ-globulin concentrations (i.e., 1.4-4.2 mg/ml) within human synovial fluid [5]. However, γ-globulin showed that its protein concentrations out of the range of physiological γ-globulin concentrations of human synovial fluid led to a decrease in the effectiveness of boundary lubrication for the bearing surface of the CoCr femoral head; γ-globulin at a concentration of 0 mg/ml (control solution) and more than 5.0 mg/ml increased $\mu$ of the CoCr femoral head. This result could be explained by fact that stronger adsorption strength of γ-globulin at its higher protein concentration leads to higher adhesive force between the lubricated surfaces, and thus increases $\mu$. In future study, efficiencies of other lubricants such as dipalmitylophosphatidylcholine (DPPC) and hyaluronic acid (HA) for boundary lubrication of CoCr femoral head will be investigated through AFM measurements.

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