히알루론산의 농도가 코발트-크롬 인공 대퇴골두의 마찰 특성에 미치는 영향 분석

Effect of Hyaluronic Acid Concentrations on Frictional Response of a Cobalt-Chromium Femoral Head

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1. INTRODUCTION

Hyaluronic acid (HA) is one of the major components which plays an important role in determining viscosity properties of human synovial fluid [1]. In the literature, there were contradictory results reported on the effect of HA on friction and wear properties of natural and artificial joints [2-4]. Through macroscopic knee simulator for the bearing of metal-on-UHMWPE, Wang et al. reported no difference in wear of UHMWPE [2], while another study reported a significant increase in the wear of UHMWPE when HA was added to bovine serum [3]. Furthermore, Forsey et al. reported that frictional properties of human articular cartilage significantly reduced under the lubrication of HA through macroscopic pin-on-plate friction device [4]. At the micro-scale, however, the effect of HA concentrations on the frictional properties of hip implant materials has not been clearly identified, although micro-scale AFM measurements are highly suitable for exploring boundary lubricating ability for diverse lubricants in diarthrodial joints. Therefore, the objective of this study is to investigate the concentration-dependent role of HA in the lubricating ability of a cobalt-chromium (CoCr) femoral head implant, by measuring frictional coefficients with AFM techniques.

2. MATERIALS AND METHODS

One sample with dimensions of 10×10 mm^2 squared area and 5 mm thickness was machined from the main wear region of a CoCr femoral head, which was retrieved from a revision surgery due to aseptic loosening ten years after total hip arthroplasty (THA). The sample surface was cleaned with 99% ethanol for ten minutes in an ultrasonic bath and glued on the cylindrical plate (1 mm thickness and 19 mm diameter). In this study, two types of solutions were prepared as lubricants: PBS (P5493, Sigma-Aldrich) as a control solution and HA (53747, MW=1.63 MDa, Sigma-Aldrich) as a lubricating solution at diverse concentrations of 2.0, 3.5, and 5.0 mg/ml that was made by stirring at a temperature of 50°C in PBS, because HA was found in human synovial fluid ranging from 3.0 to 4.0 mg/ml.

For AFM frictional measurements, the sample was entirely submerged in lubricants and imaged at room temperature using an AFM device (XE 70, Park Systems), which was placed in a sealed box and equipped with analysis software (XEI 1.6.5) for image processing and the calculation of the applied normal force and surface roughness. A rectangular silicon cantilever with a normal spring constant of K_N=0.6 N/m that was integrated with a conical tip (curvature ≤10nm) was used. Frictional force (F_L) was calculated from the whole image of a 25μm×25μm scanned area by the multiplication of the lateral voltage signal (V_{LFM}), the lateral sensitivity (S_L), and the lateral spring constant (K_L). Here, the lateral voltage signal was obtained as half of the averaged value of the difference between forward and backward voltage signals from the scanned images. The values of the surface roughness (R_q), normal force, and lateral voltage signal were simultaneously measured over the same scanned area at a scan rate of 1.0 Hz (50 μm/s). The measurements of the frictional forces were repeated for six values of the normal forces at an increment of 5 nN at each location. The plot of the frictional forces against the normal forces was fitted with a straight line whose slope was the frictional coefficient (μ) (Fig. 2).

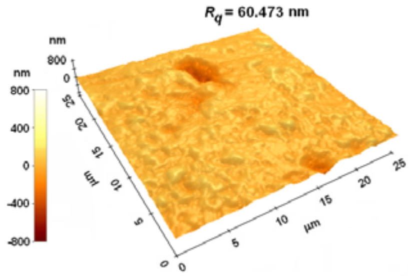

Fig. 1 Typical AFM image of the surface roughness (R_q) for the CoCr femoral head

3. RESULTS

Root mean square (RMS) surface roughness (R_q) 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_q was 58.801±14.277 nm (n=12). The frictional coefficients (μ) of the CoCr femoral head were 0.248±0.029 (n=12, R^2=0.997±0.005) in PBS. In the lubricant of HA, μ was 0.161±0.026 (n=12, R^2=0.991±0.011) at 2.0 mg/ml, decreased to 0.108±0.009 (n=12, R^2=0.996±0.012) at 3.5 mg/ml, and then increased to 0.149±0.008 (n=12, R^2=0.998±0.003) at 5.0 mg/ml. The one-way ANOVA exhibited statistical differences in μ between PBS and HA of all concentrations (p<0.0001). Similarly, between HA with different concentrations, there were statistical differences in μ in all cases except between HA of 2.0 and 5.0 mg/ml (p<0.0001).

4. CONCLUSIONS

In the present study, an increase in HA concentration significantly reduced μ of the CoCr femoral head when compared to PBS. μ statistically decreased when HA concentration increased from 2.0 to 3.5 mg/ml, but statistically increased when HA concentration increased from 3.5 to 5.0 mg/ml. This result indicates that a certain range of HA concentration exists that can optimize the frictional behavior of the CoCr femoral head surface, and this range is similar to the range of HA concentration within human synovial fluid (i.e., 3.0-4.0 mg/ml). In future study, the efficiencies of phospholipids on the boundary lubrication of CoCr femoral head will be investigated through AFM frictional measurements.

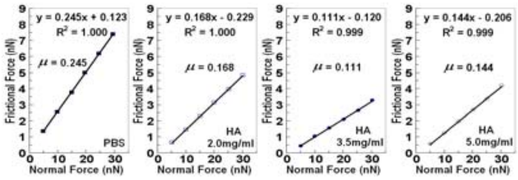

Fig. 2 Plots of the frictional force against the normal force in PBS and diverse HA concentrations

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REFERENCES

1. Kawai et al., “Influence of Additive Hyaluronic Acid on the Lubricating Ability in the Temporomandibular Joint,” Biomed Mater Res A., 70, 149-53, 2004.
2. Wang et al., “The Effects of Lubricant Composition on in Vitro Wear Testing of Polymeric Acetabular Components,” Biomed Mater Res B 68, 45-52, 2004.
3. DesJardins et al., “Increased Total Knee Arthroplasty UHMWP Wear using a Clinically Relevant Hyaluronic Acid Simulator Lubricant,” Proc IMechE H., 220, 609-23, 2006.
4. Forsey et al., “The Effect of Hyaluronic Acid and Phospholipid based Lubricants on Friction within a Human Cartilage Damage Model,” Biomaterials, 27, 4581-90, 2006.