EFFECTS OF TRIBOCHEMISTRY OF SYNOVIAL FLUIDS ON THE PERFORMANCE OF UNICONDYLAR KNEE ARTHROPLASTY - DEVELOPMENT OF THE TESTING MODEL

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Partial joint arthroplasty surgeries have been widely applied to the patients with unicompartmental knee joint osteoarthritis. Degeneration in the opposite compartment is a common cause of failure after unicompartmental arthroplasty. It is suggested that the decreased synovial fluid lubrication might be related to the cartilage damage. In the situations of partial joint arthroplasty, the influence of chemically conformed fluids released from the arthroplasty implant interface on the lubricating ability of the natural cartilage becomes one of the most critical issues. Once the association of the tribochemistry of biological lubricants due to the arthroplasty implant articulation and the degeneration of the cartilage is identified, further development can be made to enhance the durability of partial joint arthroplasty. In this study, in-vitro testing procedures have been successfully developed to investigate the effects of tribochemical reactions of biological lubricants on the friction change of articular cartilages. The results indicated that the lubricating ability for cartilages deteriorates after articulation by ultra-high molecular weight polyethylene (UHMWPE) and stainless steel.

Key words: cartilage, unicompartmental knee arthroplasty, synovial fluid, lubrication, tribochemistry, ultra-high molecular weight polyethylene, UHMWPE

INTRODUCTION

Unicompartmental knee arthroplasty (UKA) has been done for more than 30 years with variable results. Recent interest in minimally invasive techniques has made this procedure regained the popularity. Short-term results with respect to pain relief and function are equal to or better than those of total knee arthroplasty (TKA). However, with longer-term follow-up, the failure rate is higher than that of TKA. The most common mechanism of failure is component loosening, polyethylene wear and progression of disease in the un-resurfaced compartment. Some study indicated the durability of UKA declines after 5 years, and the results at 10 years are inferior to those of TKA. A recent follow up study showed 18% of the knees had progressive loss of joint space in the opposite compartment and 14% of the knees had progressive loss of joint space in the patellofemoral compartment. Degeneration in the opposite compartment is a common cause of failure after unicompartmental arthroplasty. Some authors have suggested that overcorrection of joint deformity results in the transfer of increased forces to the uninvolved compartment and accelerating degeneration. However, the complete explanation of the progression of patello-femoral arthritis is still not provided. In addition, Elsaid et al. further suggested that the decreased synovial fluid lubrication might be related to the cartilage damage.

As shown in Figure 1, under UKA design, the influence of chemically conformed fluids from the joint implant interface on the lubricating ability of the natural cartilage on the other side becomes one of the most critical issues. Once the association of the tribochemistry of biological lubricants due to the joint implant articulation and the osteoarthritis of the cartilage is identified, further development can be made to enhance the durability of UKA. Thus, the objective of this study to develop a series testing protocols to (1) quantify the tribochemical reactions of synovial fluid compositions (eg. proteins, hyaluronic acid) due to the tribological process of artificial joints, and to (2) evaluate the effects of chemically conformed fluids on the performance of the natural cartilages. By further performing systematic investigations with the testing model, the failure mechanism of UKA can be identified and the possible solution can be proposed.

MATERIALS AND METHODS

An in-vitro testing procedures have been developed to investigate the effects of tribochemical reactions of biological lubricants on the friction change of articular cartilages. Bovine serum was used as lubricants to simulate the synovial fluid and the individual

![Fig. 1: Schematic of the effect of tribochemistry of synovial fluid on the friction of cartilage: Interactions of articulations of joint implants and cartilage articulation.](image-url)
compositions. “Articulated” lubricants were prepared by the articulation of artificial joint materials (metal-ultra-high molecular weight polyethylene [UHMWPE]) in bovine serum. By further applying both “fresh” and “articulated” biological lubricants in cartilage-stainless steel friction tests, the coefficients of frictions under various loads were obtained.

**Preparation of articulated biological lubricants**

Raw GUR1050 UHMWPE materials obtained from United Orthopaedic Corporation, Taiwan were used in this study. 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. Bovine serum (AKH12367, HyClone) was used as the lubricant in the experiments. All UHMWPE pins were presoaked in the solution for at least 15 days so as to become completely saturation with the lubricants. A linear reciprocating wear test was designed to carry out the articulating of UHMWPE and 316 stainless steel. Linear reciprocating wear tests were run under a nominal contact pressure of 3 MPa, a stroke length of 19 mm, a frequency of 1.5 Hz, and an average sliding speed of 57.2 mm/s for 24 hours. After the wear tests, lubricants were collected and stored.

**Cartilage tissue sample**

Full-thickness articular cartilage was harvested aseptically from adult porcine knee joints within 12 h after slaughter. We used mosaïcplasty chisel to harvest osteochondral tissue. The diameter of the cylindrical tissue sample was 4.5 mm. Briefly, the chisel was hammered into the femoral condyle of the porcine knee joint with the depth of 5 mm. Then we gently shake the chisel to break the cancellous bone. The chisel was removed and the osteochondral tissue was pushed out from the chisel. The pusher was applied from the part of cancellous bone, to avoid injury to the cartilage surface. The cylindrical tissue was cut to a minimize the height of osteochondral bone and fixed on the top surface of a UHMWPE pin of 6.35 mm in diameter and 25.4 mm in length by epoxy glue as shown in Figure 2. During the sample preparation process, the cartilage tissue was immersed in the PBS solution.

**Measurement of friction of cartilage**

A multi-directional wear tester equipped with a three-axes force sensor has been set up. The picture of the system is shown in Figure 3. Three servo-motors and one piezo-electrical force sensor were integrated and controlled by a Labview software to synchronize the sliding motion and data acquisition. This configuration makes the simulation of any motion pattern possible. The cartilage tissue sample and the polished 316 stainless steel were mounted on the tester. Linear reciprocating wear tests of cartilages articulating 316 stainless steels were carried out with 20 mm/s speed, 5 mm stroke length for 20 cycles. Various initial penetration depths between 300-800 µm were applied in the friction tests. Fresh and articulated biological lubricants of bovine serum were used as lubricants. Normal forces and frictional forces were recorded and analyzed by the Labview software.

![Fig. 2: Retrieved cartilage tissue sample from adult porcine knee joints.](image-url)
RESULTS

Figure 4 shows an example plot of the normal load, frictional force, and friction coefficient for the linear reciprocating sliding between cartilage tissue and 316 stainless steel under fresh serum lubrication with an initial penetration depth of 600 µm. The positive and negative frictional force and friction coefficient indicate the opposite moving direction during the linear reciprocating process. It is seen that the normal force decays rapidly at initial linear reciprocating motions due the stress relaxation of the viscoelastic cartilage. Gradually the normal load approaches to a steady value around the 20th cycle.

The normal and frictional force during the sliding motion has been successfully recorded, and friction coefficients have been calculated. Figure 5 shows the friction coefficients under fresh and articulate serum solutions. The friction coefficients under articulated serum are higher than the friction coefficients under fresh serum. The results indicated that the lubricating ability of the biological lubricants deteriorates after being articulated by UHMWPE and stainless steel.

DISCUSSION

The results imply that after the tribological process of UKA system in vivo, the lubricating ability of synovial fluid deteriorates. It might affect the articulation of
natural cartilages near by. The resulting higher friction force between cartilages may lead to osteoarthritis. Therefore, further understanding of the tribochemical reactions of biological lubrication is necessary. Heuberger et al.5 had studied the adsorption of human serum albumin on the articulating surface that may affect the friction force. They indicated that the unfolded protein with less α-helix content tend to occupy a larger surface area of polyethylene than is the case with fresh protein. The adsorbed layer of denatured protein effectively passivates the surface and prevents adsorption of more proteins. Therefore, a larger friction force in polyethylene-ceramics articulation was observed with denatured protein. Our study also indicates that the α-helix content of albumin solution decreases with increasing time of the wear process4. In this study, we further provide evidence that the articulated biological lubricants also lead to the increase of friction force in a cartilage-steel sliding test. However, synovial fluids consist of a variety of compositions such as albumin, globulin, hyaluronic acid, lipids, etc. Each composition may behave differently while under an articulating process. Further experiments shall be carried out to investigate the mechanism of tribochemical reactions of individual composition. The transformation of the biological molecules during the process could be identified. By doing so, the combinational influence on the friction between natural cartilages can be understood. Currently, there remains difficulty on measuring the friction force with the curve surfaces of the natural cartilages. Efforts should be also made by contact mechanics analysis in order to precisely quantify and calculate the friction coefficients. Thus, identification of the failure mechanism of UKA can be expected based from the development of UKA simulation platform in this study.

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