Friction of articular cartilage surface lubricated with synovial fluid constituents in contact with glass and hydrogel

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1. INTRODUCTION

In recent years, various studies have produced differing results and conclusions regarding the boundary lubrication properties of albumin and γ-globulin [1–4]. This study aimed to clarify the effect of different sliding interface materials (opposing surfaces) on the lubrication ability of albumin and γ-globulin in cartilage. To achieve this, the friction properties of glass-cartilage and hydrogel-cartilage interfaces were measured.

2. MATERIALS AND METHODS

2.1 Bovine cartilage preparation

Fresh fetlocks from bovine approximately 20 months old were collected from a local slaughterhouse and dissected within 24 hours of sacrifice. Osteochondral blocks were obtained from the proximal end of the middle phalanx and cut into square plate specimens with a side length of 8 mm using a microcutter (MC-201, MARUTO, Japan). Special care was taken during sample preparation to avoid contact with or damage to the cartilage surface.

2.2 Friction tests

Rotating (angular) reciprocating tests were performed using a pin-on-disk configuration in a Nano Tribometer (Anton Paar NTR3, Austria). Two sliding pairs were tested: one with a circular (diameter: 2 mm) reciprocating upper specimen of copolymer hydrogel (GB55) as 0.4 mm thickness paired with cartilage, and the other with a smooth glass probe (diameter: 2 mm) paired with cartilage. This tribometer can apply and precisely control extremely low normal forces on soft material surfaces. The tribometer achieved precise measurements of the normal and friction forces by utilizing a uniquely designed elastic double-beam cantilever in conjunction with two high-resolution capacitive sensors. The piezoelectric actuator reads the normal force in real time and instantly adjusts its position to stabilize the normal force. The coefficient of friction (COF) was calculated as the ratio of friction and normal forces.

Friction tests were conducted under three contact loads of 5, 20, and 100 mN. For each contact load, the sliding speed was sequentially increased through six different speeds (0.05, 0.1, 0.2, 0.5, 1.0, and 2.0 mm/s). Each speed was tested with a radius of 1 mm and angular amplitude of 30° for five cycles. Test lubricants are phosphate buffered saline (PBS), 2.1 wt% albumin solution, 2.1 wt% γ-globulin solution, protein solution (1.4 wt% albumin and 0.7 wt% γ-globulin), fresh synovial fluid (SF). SF was extracted from healthy bovine metacarpal phalangeal joints. The friction measurement process is schematically summarized in Fig. 1.

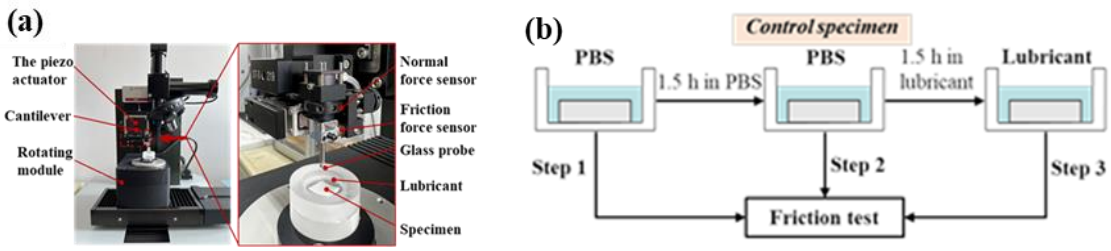

Fig. 1 (a) Photograph of the tribometer. (b) Schematic representation of the overall experimental design.

3. RESULT

The three-step COFs of two counterfaces in PBS, albumin, γ-globulin, the albumin and γ-globulin mixture solutions and fresh SF are plotted versus sliding speed under various normal loads in Fig. 2. The GB55-cartilage friction pair exhibits a lower COF compared to the glass-cartilage friction pair. In all lubricants, the COF is significantly influenced by the sliding speed, with the COF decreases as the sliding speed increases, except for the GB55-cartilage friction pair at 5 mN. At 5 mN, the COF for the GB55-cartilage friction pair initially decreases and then increases with rising sliding speed. This indicates that the transition speed of the GB55-cartilage friction pair to mixed lubrication shifted to the slower side compared to the glass-cartilage friction pair.

For the glass-cartilage friction pair, in PBS (Step 2), an increase in contact load resulted in a decrease in the COF. Conversely, in PBS (Step 1), albumin, γ-globulin, the albumin and γ-globulin mixture solutions and fresh SF, the COF remained approximately

constant despite the increase in contact load. In all lubricants, the GB55-cartilage friction pair showed obvious dependence on the contact load. Moreover, the highest COF was observed at the lowest sliding speed and contact load.

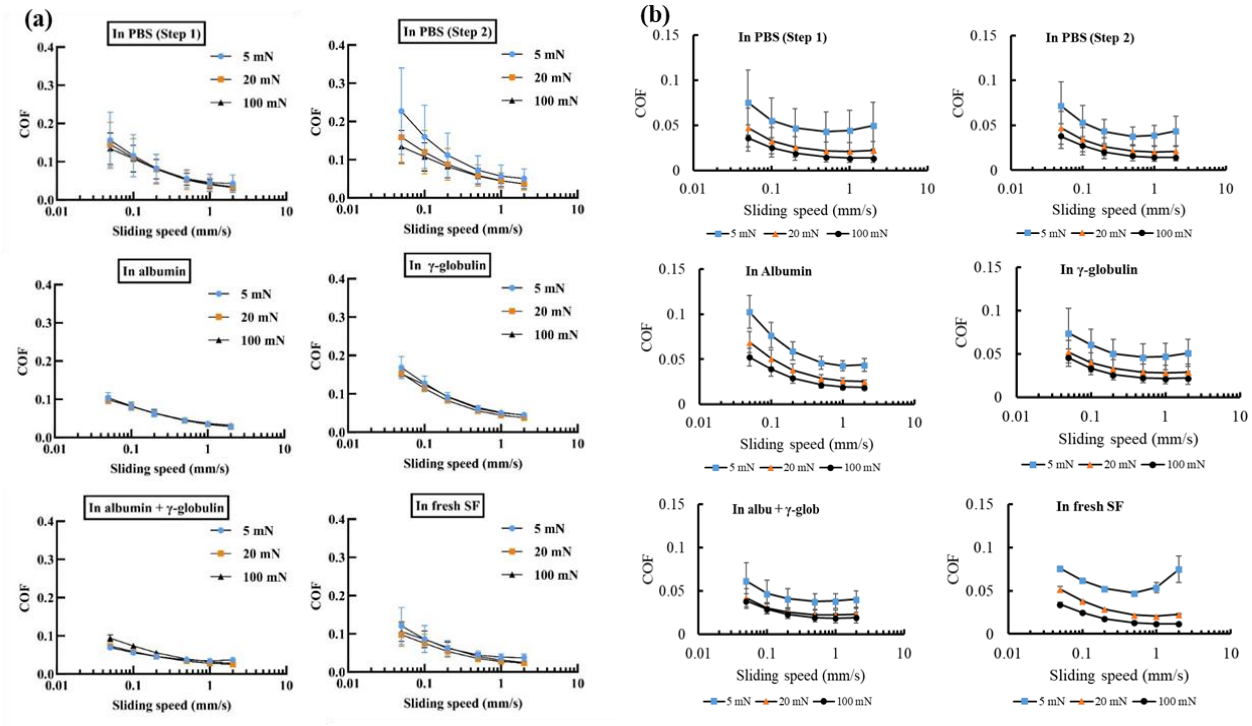

Fig.2 The three-step COFs of two counterfaces as a function of the sliding speed in PBS, albumin, γ-globulin, the albumin and γ-globulin mixture solutions and fresh SF under normal loads of 5, 20, and 100 mN. (a) glass-cartilage, (b) hydrogel-cartilage.

Fig. 3 shows the COF for the two counterfaces in three steps at 5 mN, 0.05 mm/s. In the glass-cartilage pair, the COF is significantly higher in step 1 compared to step 2. Conversely, in the hydrogel-cartilage pair, the COFs in both steps are nearly identical, indicating insensitivity to the initial state of the cartilage. In the glass-cartilage pair, all lubricants demonstrate lubricating ability. The solution containing albumin and γ-globulin shows the lowest COF, even compared to fresh SF. However, in the hydrogel-cartilage pair, lubrication is only observed with the solution containing albumin and γ-globulin; other lubricants do not exhibit similar effects.

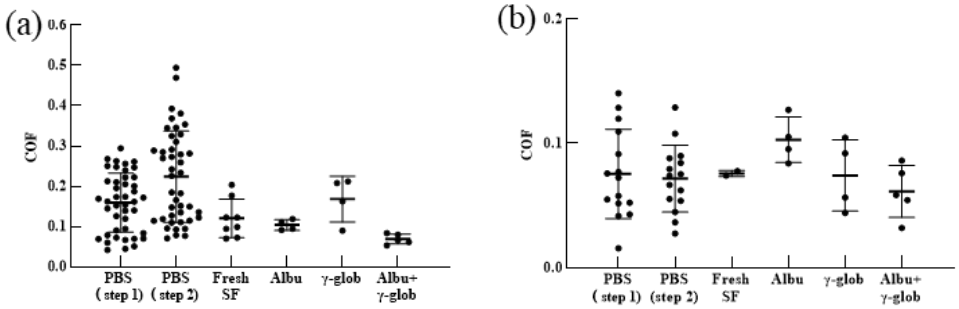

Fig. 3 Friction coefficient of two counterfaces tested at 5 mN, 0.05 mm/s. (a) glass-cartilage, (b) hydrogel-cartilage.

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