Migrating versus Stationary Applied Pressure Changes Lubricity of Hydrogel Surfaces

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Statement of Purpose: Hydrogels used as prosthetic or drug delivery devices possess surfaces which often directly contact and move against tissues at rates determined by physiological processes such as vascular pumping, breathing, blinking, and large muscle contraction. Therefore the lubricity of hydrogel surfaces and its interaction with other highly-tunable surface properties may influence the success of the device. For example, lubricity has been shown to be a predictor of soft contact lens comfort [1]. As stress is applied to a hydrogel surface in relative sliding, the surface can readily change dimension due to its biphasic composition and water content. The specific scaling laws and effects of hydrogel water content on surface lubricity are yet unknown. Tribological measurements of hydrogels typically use a hard polished surface sliding against the hydrogel sample, but the influence of the experimental setup, that is, which material is held stationary, has not been explored or discussed. In lubricity work on fluid pressure load support in articular cartilage, Caligaris et al referred to this difference as stationary versus migrating contact[2,3]. In very recent work, the motion of the contacting area in lubricity measurements has been performed both ways[4,5]. We hypothesize that lubricity measurements with such conditions may lead to dramatically different responses because of the propensity of the hydrogels to concentrate polymer at the surface under stationary contacting conditions[6]. The purpose of this work is to clearly define the motion profiles, and demonstrate the sensitivity of hydrogel lubricity to stationary versus migrating contacts.

Methods: Polyacrylamide hydrogels were molded into both flat sheets and hemispherical tips (Figure 1) in order to test both migrating and stationary contact conditions.

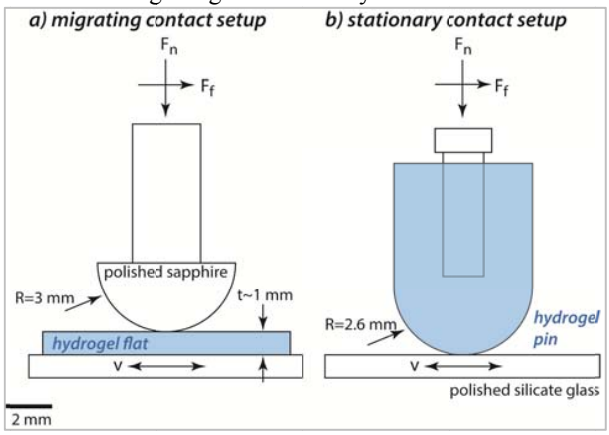

Figure 1. Friction testing experimental setup

Polyacrylamide at high water content (~92% water) and low modulus was used to magnify the effects of applied stress. Hydrogels were crosslinked with N,N'-Methylenebisacrylamide (MBAm) 0.5% over the course of 30 minutes by ammonium persulfate (APS) and tetramethylethylenediamine (TEMED). Lubricity experiments were performed in ultrapure water under an applied force, F_n = 400 μN. The friction forces were measured over 30 reciprocating sliding cycles for stroke length of 3 mm, and experiments were performed at 3 different sliding speeds (v=300, 500, and 1,000 um/s). The reported friction coefficients were calculated by averaging the ratio of the friction force over the normal force for each reciprocating cycle; both the mean and standard deviations were plotted over the course of the experiments (see Figure 2).

Results: The dramatic effect of migrating contact areas as opposed to stationary contact area experiments is clearly demonstrated in Figure 2, where the friction coefficient is plotted versus the number of reciprocating sliding cycles. For the migrating contact area at a sliding speed of v=1,000 um/s, the friction coefficient after 30 cycles was below μ=0.02. For the same sliding conditions under stationary contact, the friction coefficient approached μ=0.25. As sliding speed was reduced to v=300 um/s both the stationary and migrating contact experiments gave similar values of friction.

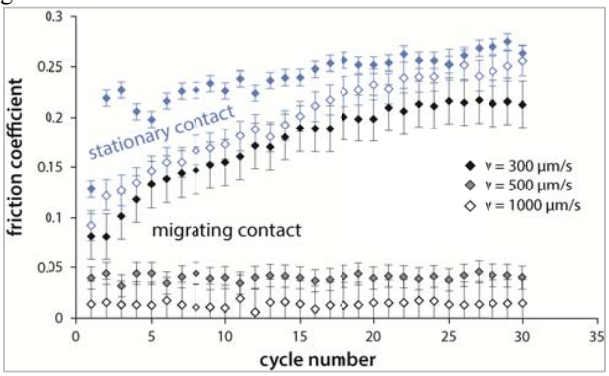

Figure 2. Migrating contact on a polyacrylamide hydrogel provided lower friction than stationary contact.

Conclusions: The hypothesis that friction coefficient is dependent upon the motion of the contact area was confirmed. This work demonstrates lubricity measurements of the same high water content polyacrylamide material in both stationary and migrating contact over a range of sliding speeds. The migrating contact condition showed a significantly lower friction coefficient and greater measurement sensitivity to sliding speed. Further work will investigate the effects on lubricity of local dehydration kinetics due to the motion of the contact area.

References: (1) Brennan NA. AAO Ann Meeting Abstr. 2009 (2) Caligaris M. Osteoarthr Cartilage. 2008;16(1):1220-1227. (3) Bonnevie ED. Tribol Lett. 2011;41(1):83-95. (4) Roba M. Tribol Lett. 2011:44(3):387-397 (5) Dunn AC. Tribol Lett. 2013: in press. (6) Chen XM. J Biomech Eng-T ASME. 2007;129(2):156-163.