Effect of Counterface Surface Roughness on Tribological Rehydration of Articular Cartilage

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Introduction: Articular cartilage comprises the load-bearing tissue of synovial joints and, in the absence of injury or degradation, can support smooth articulation over decades of use. A major interest in cartilage biomechanics is to understand how cartilage can maintain low friction values ($\mu<0.02$) under repetitive loading conditions.[1-3] Recently, our team rediscovered a unique *ex vivo* tribological testing configuration, the convergent stationary contact area (cSCA) that allows assessment of cartilage biomechanics under fully-sustainable and physiologically-consistent cartilage strain, strain recovery, hydration, and lubricity over hours of testing; through a mechanism we have termed 'tribological rehydration.'[4] Our Previous studies have used standard glass microscope slides as the sliding counterface. In order to further characterize cartilage biomechanics in the cSCA configuration, *the goal of this study was to investigate the effect of glass counterfaces of different surface roughnesses on cartilage tribomechanical outcomes.*

Methods: Tissue Specimens and Tribological Testing: ∅19mm osteochondral cores were removed from the femoral condyle centerline of mature bovine stifle joints. Explants were stored in PBS + protease inhibitors[5] and tested using a custom-built tribometer[6] in which explants were compressed and slid against a reciprocating glass slide. Glass Surfaces: Glass slides of three different roughness and asperity heights were tested in this study: super-polished quartz microscope slides (SPI Supplies, West Chester, PA), plain microscope slides (Fisher Scientific), and frosted microscope slides (Fisher). Testing Protocols: A tribological rehydration characterization scheme, with a repeated-measures design, was used for each testing group. It consisted of 30 min of static compression at 7N (~0.25 MPa), followed by 30 min of reciprocal sliding at 80 mm/s (~walking speed) under 7N compression. Characterization was first performed against a plain microscope slide, then repeated against polished, plain, and frosted slides, sequentially. Between sliding tests, explants free-swelled in PBS for two hours. After testing, damage was assessed using stereomicroscopy, and explant were bisected to measure cartilage thickness (h). Data Analysis: Deformation (δ), normal force (F_N), and friction coefficients (μ) recorded by the tribometer were analyzed using MATLAB. Measures of tissue strain ($\varepsilon = \delta/h$) were calculated, strain and friction magnitudes were analyzed at the beginning and end of active sliding, and strain recovery (i.e. tribological rehydration) during sliding was measured. Characteristic deformation rates were obtained from the time-dependent deformation data. Friedman's Test was used to identify statistically significant changes between the repeated tests.

Results: Deformation and friction responses were similar with sliding against regular and polished slides, and strain recovery (i.e., tribological rehydration) was observed under both of these conditions. The most pronounced changes occurred when explants were tested against 'rough' glass, where tribological rehydration was not observed.

When sliding against rough glass, strain and deformation recovery were significantly impaired ($p<0.0001$).

Equilibrium coefficients at the end of sliding were similar for all three surfaces (μ = 0.04 - 0.07). However, there was a significant increase in start of sliding friction coefficient for rough glass ($\mu = 0.5288$, $p<0.0001$) compared to regular and polished surfaces (μ= 0.288 and 0.289, respectively; $p=0.9996$). Surface roughness had no effect on the static deformation time constant ($p>0.1$); however, increased surface roughness had a significant effect on the sliding deformation time constant relative to regular and polished glass surfaces ($p<0.0001$), consistent with the lack of strain recovery observed (positive; **Fig. 1**).

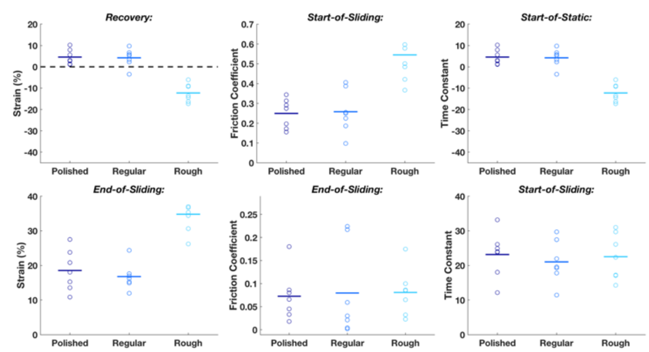

Figure 1: Sliding-induced strain recovery occurs with both polished and regular, but not rough glass; the static compression time constants were similar for polished and regular glass while explants reached characteristic deformation faster when compressed against rough glass; end-of-sliding deformation time constants show that strain recovery occurred for polished and regular glass while sliding against rough glass resulted in continued deformation

Conclusions: The results of this study illustrate that decreasing surface roughness of the glass counterface has no appreciable effect on the tribomechanical response of articular cartilage under the cSCA testing configuration. These findings suggest that regular microscope slides are adequate for assessing the tribological behavior of articular cartilage in the cSCA and that ultrapolished glass is not necessary for these experiments. Conversely, the use of frosted glass, which is of a greater asperity height, and thus, surface roughness, prevents cartilage from sustaining tribological rehydration, and induces clear tissue wear.

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