Role of Biphasic Tissue Properties in Regulating Articulation-Induced Cartilage Rehydration

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Introduction: Articular cartilage's primarily function is to provide a lubricated, near-frictionless bearing surface in diarthrodial joints. Prior work using the convergent stationary contact area (cSCA) configuration demonstrates that sliding alone serves to recover cartilage interstitial fluid lost under compressive loading through *tribological rehydration (TR)*. We recently showed that TR exhibits largely conserved speed-dependent characteristics across mammalian species, despite known variation in biphasic properties (stiffness, permeability). Here, we aim to identify relationships between these tissue properties and cartilage cSCA lubrication outcomes across species.

Materials and Methods: Osteochondral cSCA explants were extracted from the centerline of femoral condyles from five model species (shown in **Fig. 1A**). Contact radii and characteristic strain time constants were used to establish normal loads and static compression times that generated similar contact stresses (0.25±0.05 MPa) and target strains (~15%) across species. Each specimen was compressed for the noted time (dotted line, **Fig. 1B**), driving fluid exudation and enabling facile measurement of TR (tissue thickening via fluid recovery). Specimens then were slid at 80-0 mm/s, with sliding bouts at different speeds separated by exudation to the initial target strain. Representative tribological data is shown in **Fig. 1B**. Rate-controlled indentation with Hertz biphasic theory analysis was used to calculate tissue moduli (E_{y-} & E_{y+}) and permeability constants (k_0 & M). Pearson correlations were calculated among all parameters with significance set at $p < 0.01$ ($|r| > 0.50$).

Results and Discussion: As biphasic theory predicts, E_{y+} and k_0 were negatively correlated (r = 0.61, **Fig. 1C**). Under slow sliding speeds, greater k_0 was associated with faster fluid exudation (r = 0.80, **Fig. 1D**) and greater end-of-sliding strains (r = 0.57). At 10 mm/s, net fluid exudation (negative recovered strain) was observed for all samples; however, exudation magnitude strongly correlated with k_0 (r = -0.69). In contrast, TR outcomes at fast sliding speeds, which promote high fluid load support, were insensitive to biphasic material properties; no meaningful association between strain recovery and k_0 (r = -0.13, **Fig. 1E**) or E_{y+} (r = 0.15, **Fig. 1F**) were seen at 80 mm/s across species. Finally, tribological responses strongly covaried among sliding speeds. End-of-sliding strains at 80 mm/s was strongly correlated with those at 10 mm/s (r = 0.93, **Fig. 1G**), and a similar relationship was observed between end-of-sliding friction coefficients (r = 0.61, **Fig. 1H**).

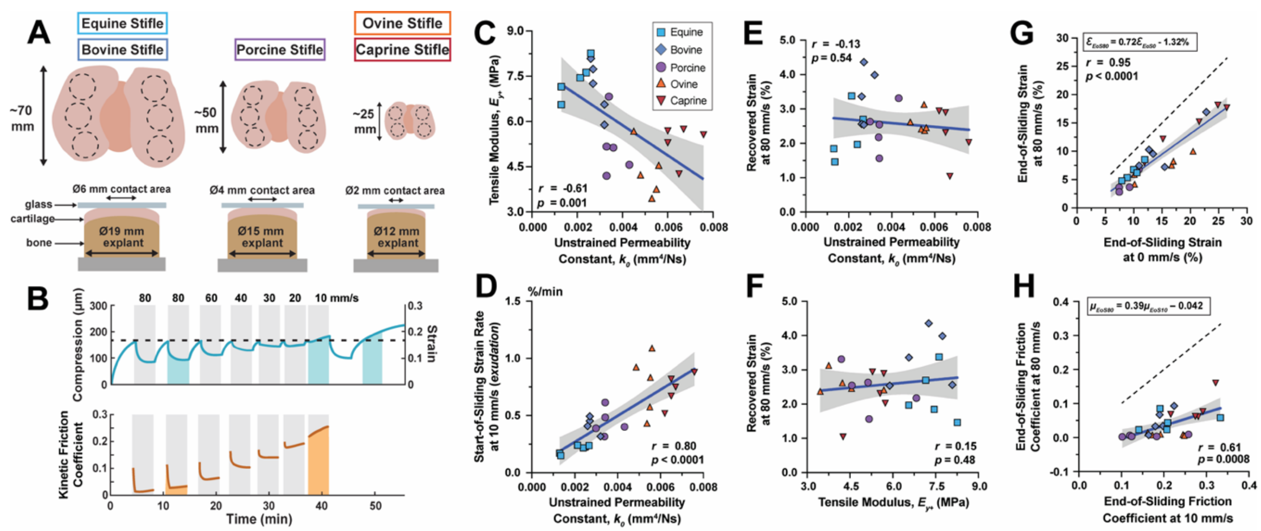

Figure 1. A) Relative sizes of femoral condyles and cSCA explants used herein. B) Representative tribological characterization data (from a bovine sample). C-H) Bivariate correlation plots showing relationships between representative biphasic parameters (C), slow sliding strain rates and k_0 (D), high-speed sliding strain recovery and biphasic properties (E-F), and tribological outcomes between speeds (G-H).

Conclusions: Our results reveal differential influences of tensile stiffness and permeability on strain and friction under conditions of high vs. low fluid load support. For slow speeds, where sliding-induced hydrodynamic pressurization is presumed less effective, greater cartilage compliance and permeability were associated with greater, and more rapid, exudative strain. In contrast, no analogous relationships were found at high speed. Nonetheless, high-and slow-speed tribological outcomes were strongly covariant, suggesting cartilage's 'recovery' response to hydrodynamic conditions can be surmised from its behavior in other widely used, 'non-hydrodynamic' testing configurations and predictable upon easily measured biphasic theory informing tissue properties.