Comparative Tribology: Articulation-Induced Rehydration Across Species

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The cSCA configuration & Tribological Rehydration

- **Convergent stationary contact area (cSCA)** = a curved-on-flat contact between convex cartilage explant and a flat counterface (**Fig. 1A**)
- High-speed sliding of the cSCA promotes hydrodynamic pressurization in the convergent wedges and facilitates cartilage fluid and interstitial lubrication recovery (i.e., **tribological rehydration**; **Fig. 1B**)
- The cSCA drives physiologically-consistent and informative sliding environments
  - High fluid load support (>90%)
  - Low tissue strains
  - Low interfacial friction ($\mu_k \sim 0.02$)
  - Near indefinitely
- Tribological rehydration is highly titratable and reproducible in our bovine cartilage model

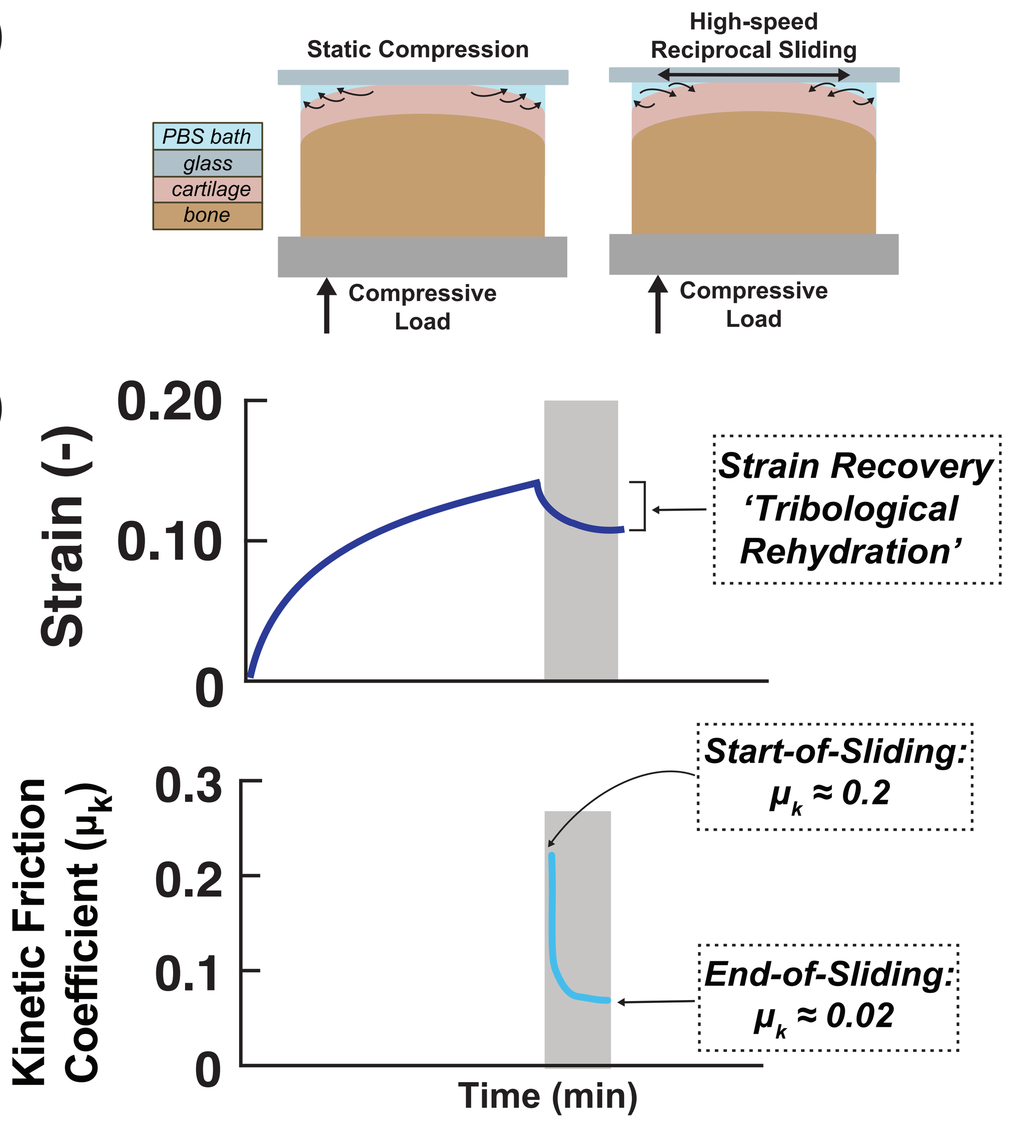

Figure 1: The cSCA configuration **(A)** promotes tribological rehydration during high-speed sliding, facilitating compression/strain recovery **(B, top)** and low equilibrium friction coefficients **(B, bottom)**

Comparative Tribology Approach

Research question: *Is tribological rehydration a universal cartilage behavior?*

- Osteochondral explants from stifle joints of five common animal models (equine/horse, bovine/cow, porcine/pig, ovine/sheep, and caprine/goat)
- Explant diameters chosen to maintain cSCA geometries and normal loads scaled to generate 0.25 ± 0.05 MPa contact stresses (**Fig. 2**)
- Sliding speed-dependent tribological characterization: intermittent bouts of 0-80 mm/s sliding separated by compression to initial target value (**Fig. 3**)
- Material properties determined from microindentation using Hertz Biphasic Theory

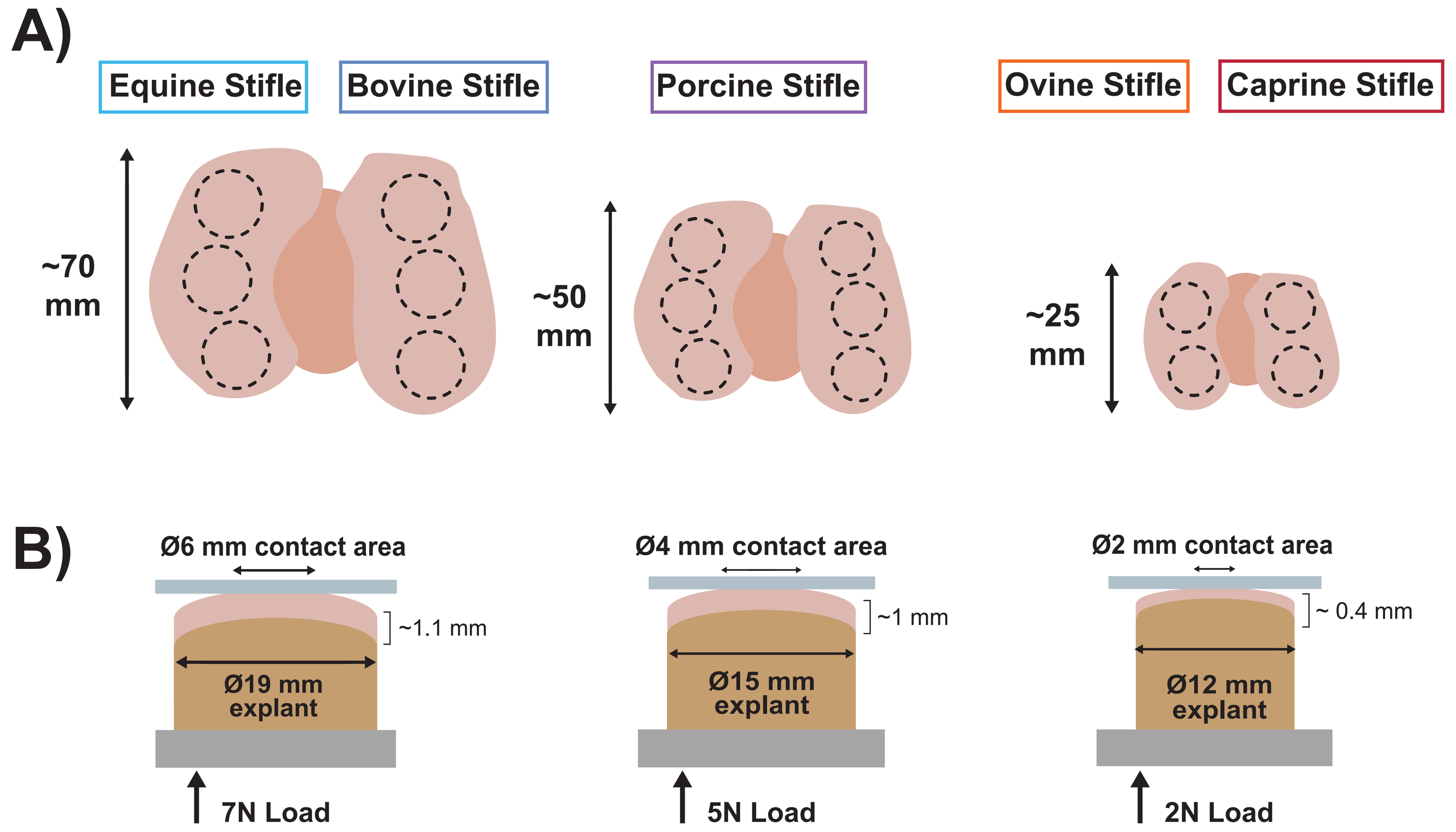

Figure 2: Relative sizes of mammalian stifle joints used in this study **(A)** and corresponding cSCA explant geometries **(B)**. Normal loads were scaled based on explant contact area to produce ~0.25 MPa contact stresses.

Sliding Speed-Dependent Tribological Characterization

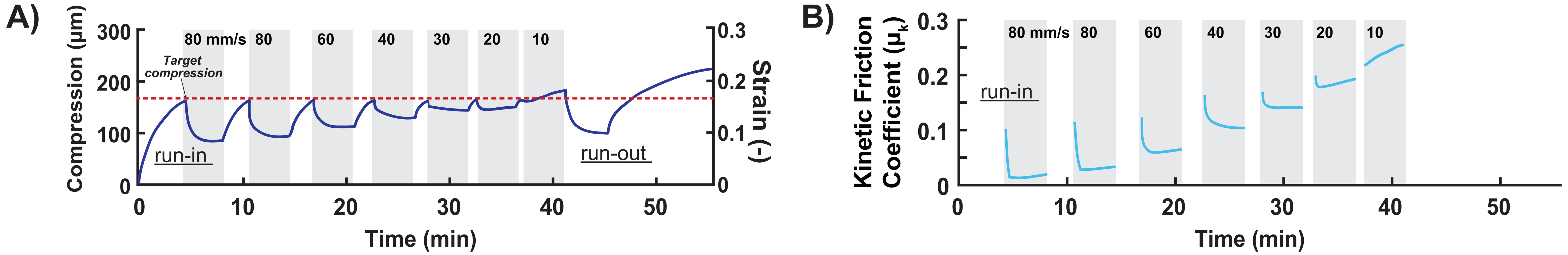

Figure 3: Sliding speed-dependent compression/strain **(A)** and kinetic friction **(B)** response for a representative bovine stifle explant. Each test began with a run-in period to a target compression value (**A**, red dotted line). Intermittent bouts of 4 minutes of sliding were separated by static compression to the target compression value.

Results

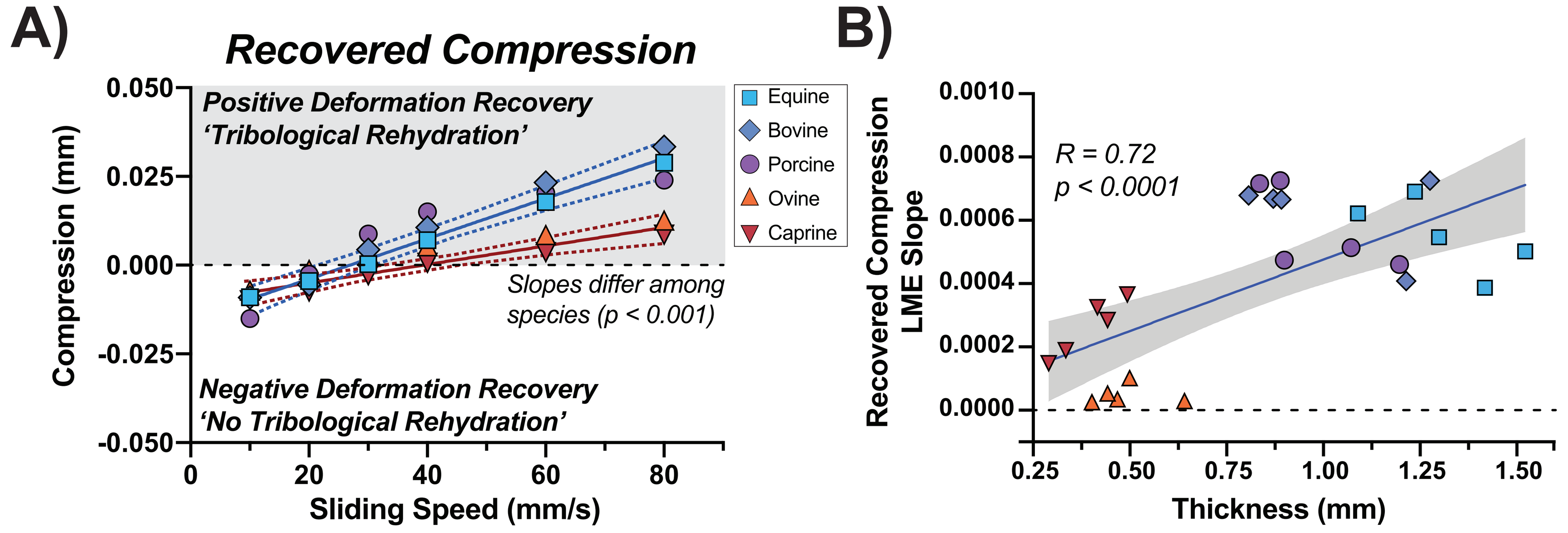

Figure 4: Sliding speed-dependent compression recovery responses segregated based on animal size. (A) Deformation recovery increased linearly with sliding speed; however, the relative increase in recovery per unit increase in sliding speed was greater for equine, bovine, and porcine specimens ($p < 0.001$). **(B)** The slope of this speed-dependent compression reocvery response was strongly correlated with cartilage thickness ($R = 0.72$, p = < 0.0001).

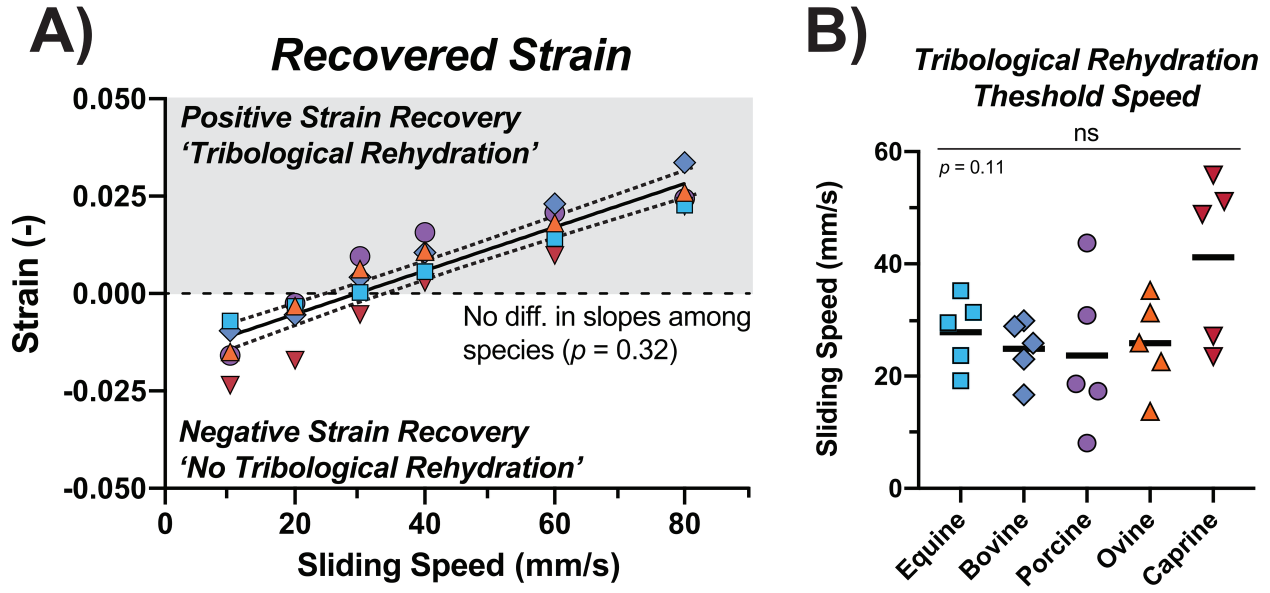

Figure 5: Slidng speed-dependent strain recovery responses were remarkably consistent among species. (A) Strain recovery increased linearly with sliding speed, and the slope of this relationship did not vary among species ($p = 0.32$). **(B)** Sliding speeds required to balance exudation and rehydration ('tribological rehydration threshold speeds') were statistically indistinguishable ($p = 0.11$).

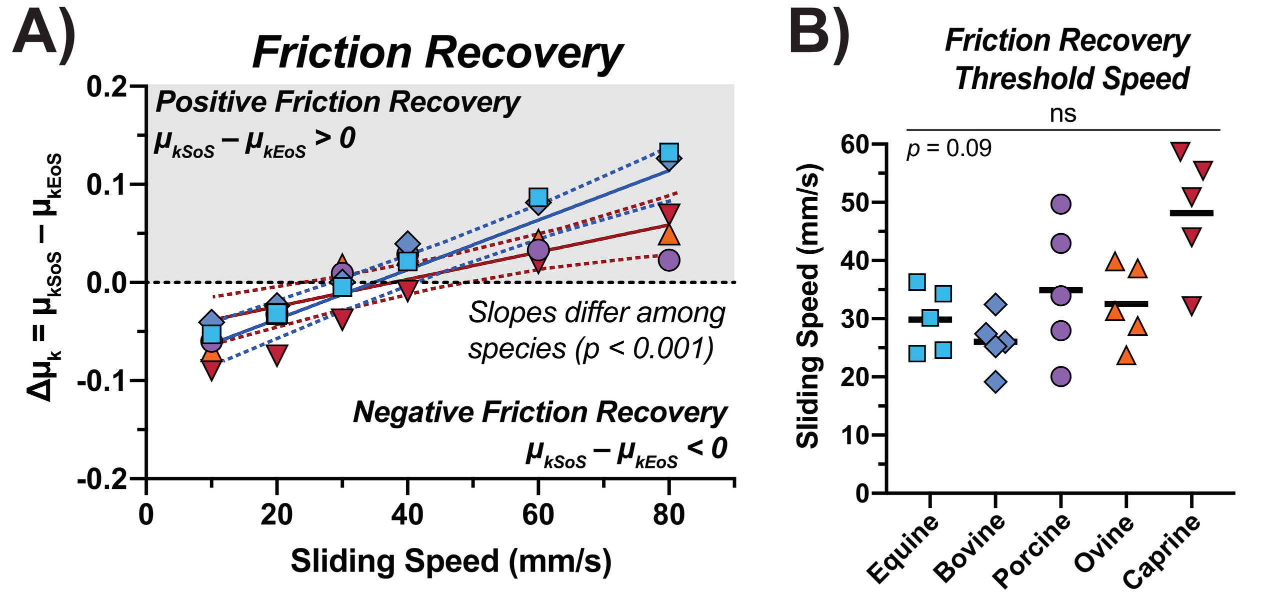

Figure 6: Species-specific friction responses. (A) Friction recovery increased linearly with sliding speed; proportionally greater recovery was observed in equine, bovine, & caprine explants than porcine & ovine specimens ($p < 0.001$). **(B)** Sliding speeds at which no net change in friction would occur did not differ among species ($p = 0.09$).

References

1. Moore & Burris, *OA&C*, 2017. 2. Graham, *OA&C*, 2017.
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Conclusions

- Articular cartilage from all species tested supported robust sliding-induced strain recovery and lubrication at speeds ≥ 30 mm/s
- Sliding speed-dependent strain recovery behavior was remarkably consistent among species, while the speed-dependent compression response was strongly correlated with tissue thickness, suggesting the magnitude of sliding-induced recovery is related to path length
- Ongoing analyses aim to determine predictive relationships among cartilage material properties and cSCA tribomechanics
- ***The conservation of tribological rehydration across mammalian species suggests it is a universal cartilage behavior and an important contributor to cartilage mechanics***

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