EVALUATING FRICTIONAL FORCES AT THE TENDON-IMPLANT INTERFACE WITH AND WITHOUT A LUBRICIOUS NON-FOULING COATING

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Objectives & Motivations

Objectives: Investigate frictional forces at the tendon-implant interface of novel force amplifying implants with lubricious non-fouling coatings.

Motivation: Cervical spinal cord injuries can cause incomplete tetraplegia, affecting extremity functions[1]. Tendon transfer surgeries, like the brachioradialis (BR) to flexor pollicis (FPL) procedure, aim to restore thumb key pinch grasp. However, current procedures only restore 2 kg-f of grasp strength compared to 9 kg-f in healthy individuals[2,3]. Novel force-amplifying implants show promise in increasing force[4], but their physiological effects need consideration. This study evaluates frictional forces at the tendon-implant interface using rabbit forearm tendons and three medical-grade titanium rods, including one uncoated and two coated rods. These non-fouling coatings are designed to improve foreign body integration in biological systems while also adding lubriciousness due to their hydrophobic properties. The two coatings are molecularly identical but are applied to the surface using two different processes. We hypothesize that the two coated rods will see reduced resistance forces and coefficients of friction compared to the uncoated rod.

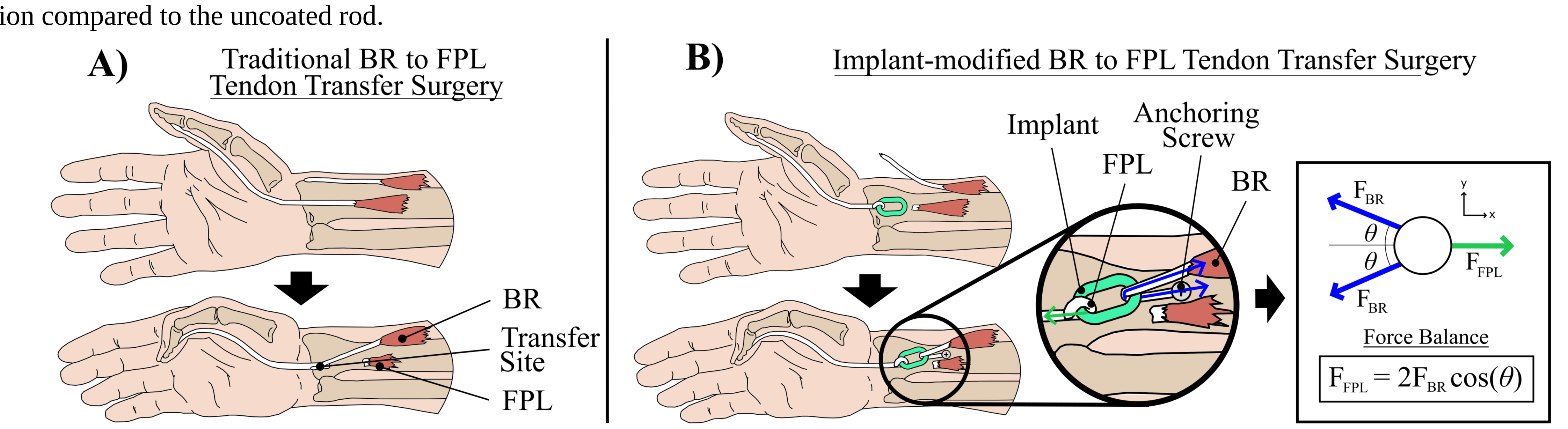

Figure 1. Illustrations of (A) a traditional BR to FPL tendon transfer surgery and (B) the implant-modified procedure. The mechanical advantage generated by the implant amplifies flexor pollicis longus tendon force according to the equation shown on the bottom-right.

Experimental Methodology

- Two extensor digitorum communis (EDC) tendons from a single New Zealand white rabbit (n = 2) were excised for use in this study.
- Each tendon was clamped on either end to Kevlar string and a 5lb Futek load cell and routed through a series of pulleys mounted on a custom testbed developed to measure the frictional forces between the tendon and a titanium rod. One end of the tendon is attached to a precision Faulhaber motor while the other end is connected to a counterweight that maintains a constant tension in the system.
- This methodology is based on previous work that utilizes the theoretical relationship between arc of contact, cable tension, and coefficient of friction defined by wrapping a cable around a mechanical pulley[5]. Specifically, the coefficient of friction, μ, is calculated using: $\mu = ln(F2/F1)/\phi$, where *F2* is the tension of the cable pulled away from the pulley, *F2* is the tension of the cable pulled toward the pulley, and ϕ is the arc of contact. The EDC tendon is routed under a titanium rod (L = 25.4mm, ⌀ = 3.175mm) that imitates the surface of the force-amplifying implant, and the motor was programmed to job the tendon 10mm at a rate of 1mm/s.
- In total each tendon was jogged back-and-forth four times across four loading conditions (120°+200g; 120°+500g; 160°+200g; 160°+500g) and all three titanium rods (Uncoated, Coating 1, Coating 2), for a total of 48 excursions per tendon. The loading conditions are unique combinations of two different arc of contacts with two tension weights that were chosen to imitate best- and worst-case tendon-implant configurations. Resistance forces are defined as the difference in force readings between the load cells on either side of the tendon and coefficients of friction are calculated using the aforementioned equation.

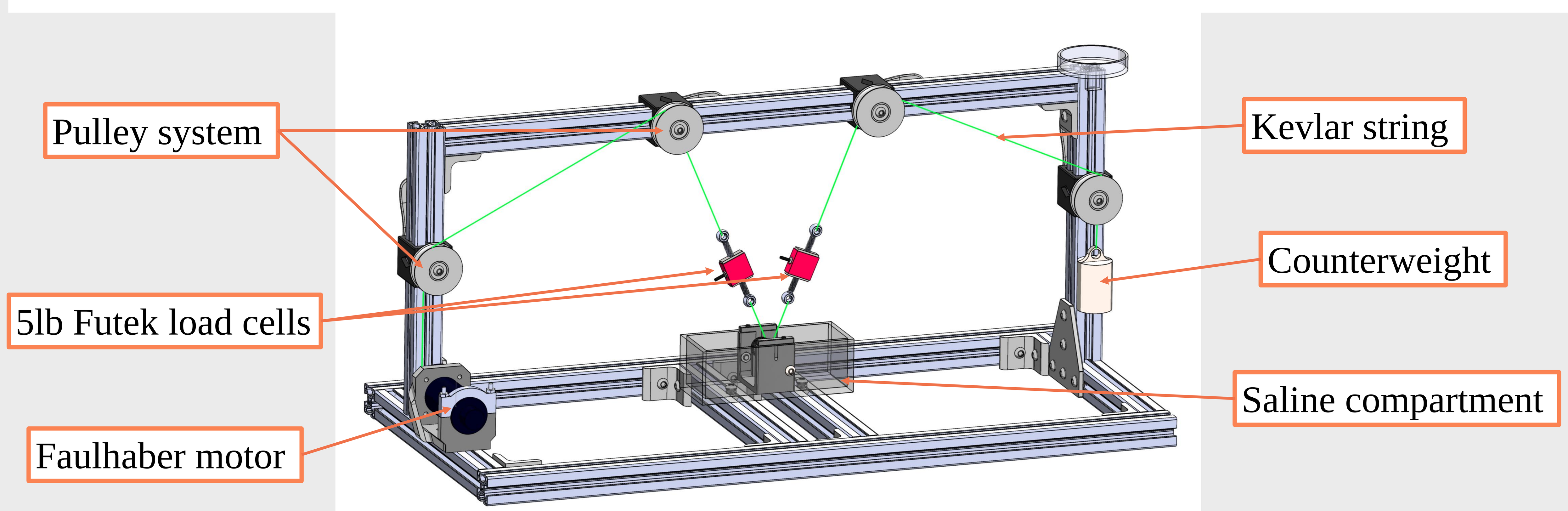

Figure 2. Custom testbed designed specifically to measure the frictional forces at the tendon-implant interface.

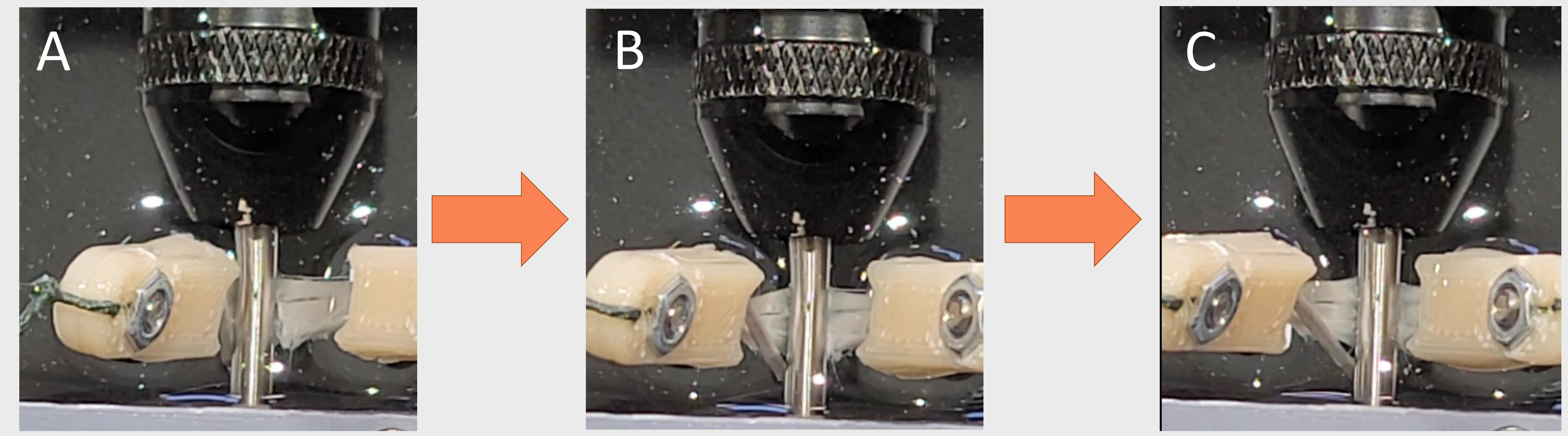

Figure 3. Top-down view of the tendon-rod interaction in the (A) initial position, (B) middle and (C) final position within the saline compartment.

Results

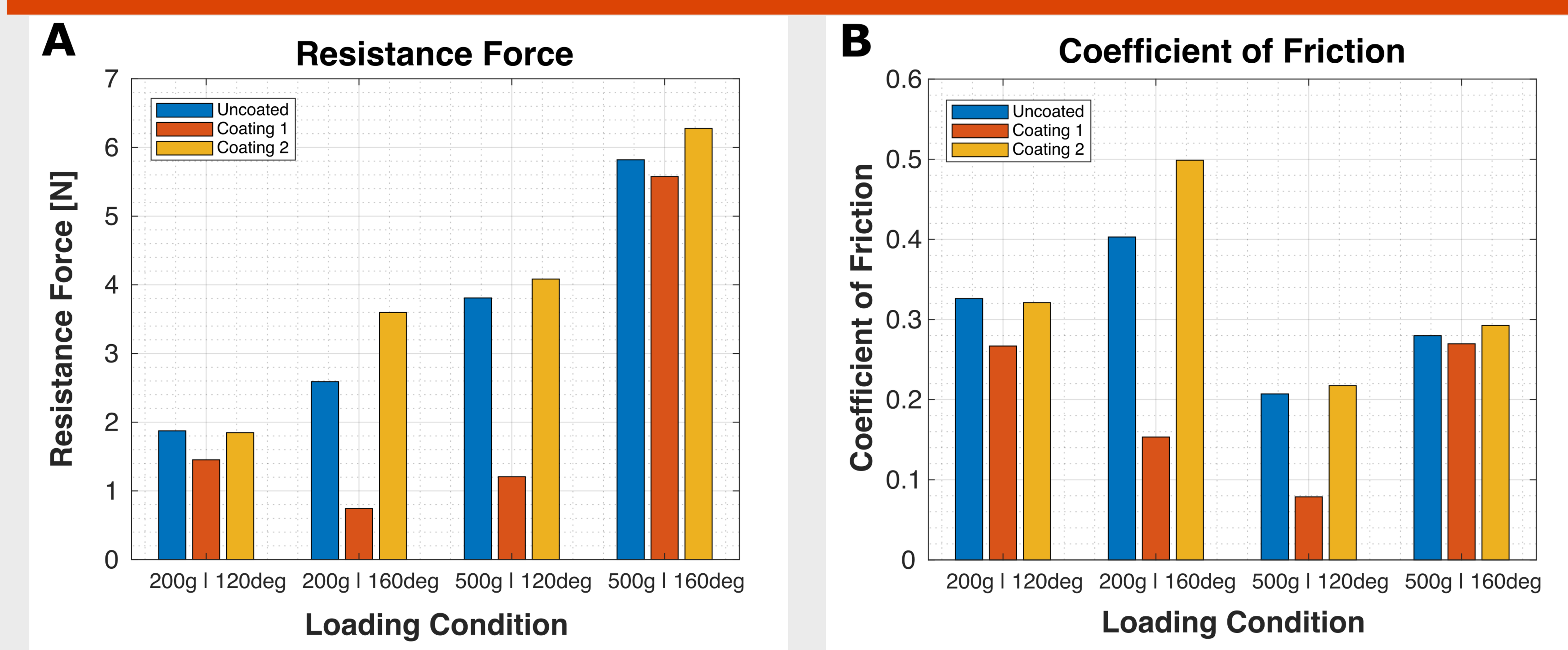

Figure 4. Calculated (A) resistance forces (B) and coefficients of friction for the interaction between rabbit tendon and uncoated and coated titanium rods.

- As seen in Figure 4A, resistance force generally increased as loading increased. Coating 1 (0.74N–5.5N) consistently drastically outperformed the Uncoated (1.87N–5.82N) and Coating 2 (1.85N–6.27N) rods in the middle two loading conditions (200g+160° and 500g+120°) and only marginally outperformed the other two conditions at the extreme loading conditions (200g+120° and 500g+160°).
- As seen in Figure 4B, a discernible pattern emerges, indicating that the coefficient of friction exhibited an upward trajectory in instances characterized by lower tension levels (200g), while it displayed a downward trend in scenarios marked by higher tension levels (500g). Such observations align with prevailing theoretical frameworks pertaining to coefficient of friction investigations involving flexible materials.

Conclusions

- The friction at the tendon-implant interface plays a significant role in tendon abrasion and the efficacy of a force-amplifying implant. By fully understanding this interaction, we enhance the capabilities of a force-amplifying implant that can advance the field of tendon transfer surgery and improve functional outcomes for patients of spinal cord injury.
- Frictional forces exert a significant influence on both the effectiveness of the implant and the health of the tendon. Enhanced friction levels yield diminished force amplification, heightened abrasion, and an elevated fibrotic response.
- Larger sample sizes are needed to more accurately describe the force-amplifying capabilities of the implant.

References

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