Implantable Passive Mechanism for Improved Restoration of Key Pinch Strength in a Human Forearm Model

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Introduction

Implantable mechanisms are capable of amplifying muscle force and provide a novel surgical option for treating muscle weakness conditions[1,2,3,4]. By routing tendons around a pulley to take advantage of fundamental principles of mechanics, implant-modified tendon transfer surgeries produce improved functional strength. Importantly, the implant enables a patient to use their own muscle to generate larger forces to overcome weakness.

The brachioradialis (BR) to flexor pollicis longus (FPL) tendon transfer for restoring key pinch grasp is an exemplar procedure for demonstrating the efficacy of such an implant. Most commonly, the BR-to-FPL tendon transfer is conducted to partially restore the loss of key pinch strength associated with spinal cord injuries. For the tetraplegic population, restoring full key pinch function is vital for improving autonomy and quality of life[5].

In the traditional procedure, the donor BR tendon is directly sutured to the host FPL tendon to restore key pinch grasp[6]. However, only 2 kg-f of the 9 kg-f produced in a healthy key pinch is restored[7,8]. In the proposed implant-based procedure, a pulley implant is attached to the FPL tendon. The BR tendon then loops through the implant and is anchored back proximally onto the radius. The BR tendon now slides on the implant as its muscle contracts, which can theoretically amplify the force transferred to the FPL up to 2x. In a previous study in the rabbit wrist extensor model, the implant produced a force-amplifying multiplier of 1.63x[3]. The objective of this pilot study was to evaluate the feasibility and efficacy of this force-amplifying implant in a human forearm model.

Methods

A single human cadaver forearm (n=1) was used to evaluate the force-scaling capabilities of a novel implantable mechanism in a control and an implant group. The control group reflected a standard BR-to-FPL tendon transfer where a fixed coupling between the tendons is created by suture. In the implant condition, the implant-based tendon transfer was conducted, which introduces a sliding coupling between the tendons via the pulley-like implant. In both groups, the BR tendon was transected at the muscle-tendon junction, attached to Kevlar rope, and connected to a load cell and torque-controlled motor with the same line of action. The thumb was also fixed to a second load cell to measure key pinch forces.

The cadaver arm was fixed to a custom testbed at the heads of the radius bone and the palm such that there was 0^{o} wrist deviation and 45^{o} thumb abduction. A K-wire was inserted through the thumb to isolate movement of the basal carpometacarpal joint.

For each of the two groups, four trials were conducted where the torque-controlled motor ramped from a force of 4 N to 22 N in 8 even steps, resulting in a total of 64 measurements. The first trial of each group was used to eliminate slack in the system and were omitted from the final results.

Force amplification ratios were calculated by dividing the thumb key pinch forces generated in the implant group by the same forces produced in the control group.

Results and Discussion

The results from this study indicate that the implant-based procedure amplified thumb pinch force by an average of 1.70x ± 0.08x when compared to the traditional tendon transfer procedure (see Figure 1). This average was calculated using only the final six data points because there was still slack in the system below 9 N of input force. This is indicated by the large error bars at the first force step and the steep increase in force amplification ratio between the second and third force steps.

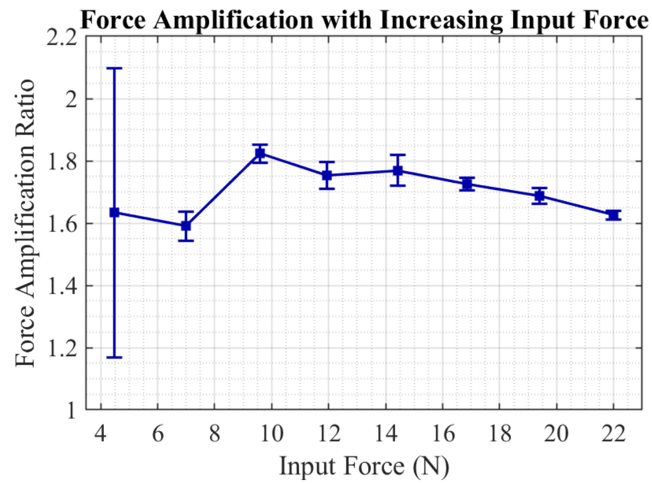

Figure 1: Force amplification ratio during BR tendon tensioning (3 trials, n=1).

When compared to the traditional procedure, the implant-modified procedure improves key pinch strength by 70% through simply modifying the routing of the tendons. This result indicates that implantable mechanisms may provide a promising new option for spinal cord injury patients for restoring strength in thumb pinch grasp beyond what is currently achievable.

This experiment is limited by the sample size of one cadaver. Larger sample sizes are needed to validate the force-amplifying capabilities of these implants.

Significance

Implantable mechanisms introduce a new concept into the traditional surgical approach of connecting and routing tendons in orthopaedic surgery. The successful development of force-amplifying implants has the potential to drastically improve functional outcomes for patients with muscle weakness. This would enable these patients to return to more activities of daily living and improve the current level of care.

References

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