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

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INTRODUCTION: Implantable mechanisms present a novel surgical option for treating muscle weakness conditions by passively amplifying muscle force[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 without any external power, control signals, or electronic components. Importantly, the implant enables a patient to use their own muscle to generate the force and movement necessary 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 grasp function associated with cervical 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 typically restored[7,8]. In the proposed implant-based procedure, a pulley-like 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, depending on the line of action of the tendons and the anchoring location of the BR tendon. 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 two experimental groups: a control group and an implant group. The control group represented a standard BR to FPL tendon transfer procedure where a fixed coupling between the tendons is created by suture. In the implant condition, the implant-modified tendon transfer procedure 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. The thumb was then 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 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. The cadaver arm remained fixed in this anatomical position between throughout both surgical interventions to reduce positioning error between the two experimental groups.

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 was 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: The results from this study indicate that the implant-based procedure increased key pinch force by an average of 1.70x ± 0.08x across input forces ranging from 9-22 N when compared to the traditional tendon transfer procedure (n = 1). This average was calculated using only the final six force-amplification ratios 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 first and second force steps.

DISCUSSION: The objective of this study was to explore the force-amplifying efficacy of the implantable mechanism in a BR to FPL tendon transfer conducted in a human cadaver forearm. When compared to the traditional procedure, the implant-modified surgery improves key pinch strength by 70% by 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. Furthermore, since only patients with a minimum threshold of muscle strength qualify for tendon transfer procedures, this implant-modified tendon transfer may expand the qualifying patient pool by essentially providing additional strength. While the findings of this study are promising, the experiment is limited by the sample size of one cadaver. Larger sample sizes are required to validate the force-amplifying capabilities of these implants.

SIGNIFICANCE/CLINICAL RELEVANCE: Spinal cord injuries can cause debilitating life-long functional weakness that can only be partially restored with current tendon transfer practices. Implantable mechanisms introduce a new concept into the traditional surgical approach of connecting and routing soft tissue in orthopaedic surgery and could drastically improve rates of return to activities of daily living.

REFERENCES: [1] Mardula et al. 2015, HAND; [2] Homayouni et al. 2015, TBME; [3] Ling et al. 2019, ORS; [4] Pihl et al. 2016, JOR; [5] Smaby et al. 2004, JRRD; [6] Hentz et al.1992, JHS; [7] Hamou et al. 2009, JHS; [8] Mathiowetz et al. 1985, APMR.

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IMAGES AND TABLES:

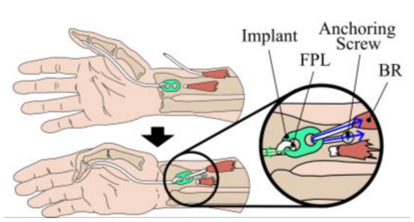

Figure 1. Illustration of a force-scaling implantable passive mechanism in a modified BR to FDL tendon transfer.

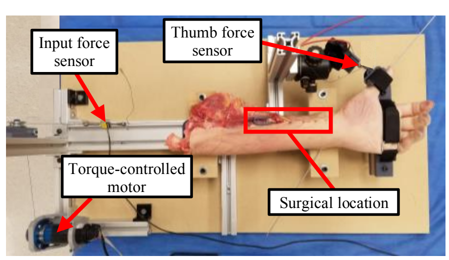

Figure 2. Custom testbed setup used to measure key pinch force in a human cadaver forearm.

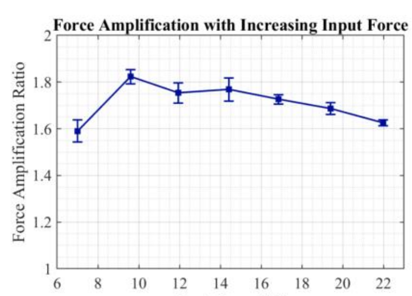

Figure 3. Force amplification ratio created by the implant-based tendon transfer surgery with increasing input force (n = 1).