EVALUATING EFFICACY OF A FORCE-AMPLIFYING IMPLANTABLE MECHANISM IN A LIVE RABBIT FOREARM MODEL USING ELECTRICAL STIMULATION TO GENERATE MUSCLE TWITCHES

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INTRODUCTION

In the United States, 58.7% of the 17,700 spinal cord injuries that occur each year result in some degree of tetraplegia[1], which leads to reduced control of upper limb muscles. Tendon transfer surgeries are often necessary to restore upper limb functions and decrease an individual's dependence on caregivers and family members[2]. To restore thumb key pinch grip, a brachioradialis (BR) to flexor pollicis longus (FPL) tendon transfer surgery is often conducted. We propose the use of a novel modification to the standard tendon transfer procedure by introducing a pulley-like implant between the BR and FPL tendons that amplifies the force transferred from the BR muscle to the FPL tendon by up to 2X. The trade-off for the force amplification effect is a proportional increase in the muscle contraction length to create the same output tendon excursion. In this work, we electrically stimulate the common digital extensor (CDE) muscle in an analogous BR tendon transfer procedure in a live New Zealand white rabbit forearm model. Specifically, the purpose of this study is to evaluate the efficacy of such a force-amplifying implant by generating muscle twitch forces in a standard and implant-modified tendon transfer surgery at varying tendon lengths while measuring output tendon forces.

METHODS

The right forelimb of a single New Zealand white rabbit (n=1) was used in this preliminary study, and both tendon transfer surgeries were conducted in the same leg of the anesthetized rabbit. After the implant-modified surgery was first conducted, the forelimb was fixed at the elbow and wrist joints in a custom testbed, and fine-wire electrodes were inserted into the CDE muscle. A load cell attached to a micrometer head was then connected to the distal end of the pulley implant via Kevlar string to measure the force of the output tendon. The custom testbed enabled muscle length adjustments within 0.01 mm.
The CDE muscle was initially set to 0.25 N of passive tension, and 5 muscle twitches were generated at 1 second intervals using electrical stimulation (3 mA, 40 Hz). The muscle length was incrementally increased by 0.25 mm and stimulated again using the same protocol until there was an equal number of data points on either side of the estimated active muscle force curve plot. During data collection, custom MATLAB code was used to actively calculate active muscle forces from raw data and fit an active muscle force-length curve[3] onto the raw data. Following data collection, the surgery was modified to a standard tendon transfer procedure. The CDE muscle was initially set to 0.125 N of passive tension and the output tendon length was increased by 0.50 mm between muscle twitches to account for the change in force-amplification effect and output tendon excursion lengths between the two surgeries.

RESULTS AND DISCUSSION

The force-length curves for the implant-modified and standard tendon transfer surgeries were aligned on the horizontal axis using the estimated optimal muscle length and can be seen in Figure 1. The peak muscle twitch force for the implant-modified surgery was 1.51 N while the peak force in the standard surgery was 0.86 N. However, the curve for the implant-modified procedure is noticeably narrower than the standard procedure.

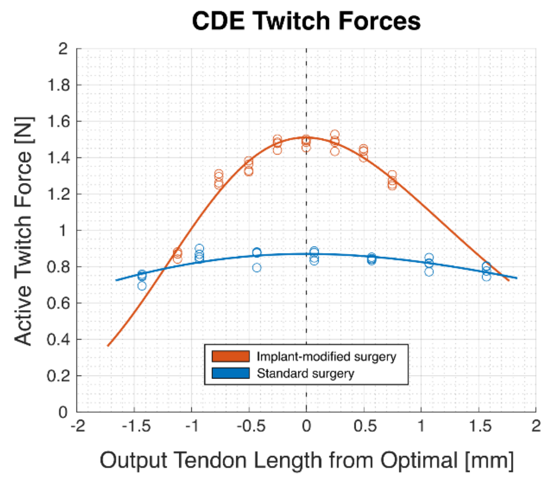

Figure 1: CDE muscle twitch forces from a rabbit forearm in an implant-modified and standard tendon transfer surgery.

The objective of this study was to explore the efficacy of force-amplifying implant in a live rabbit model across varying muscle lengths. When compared to the standard surgery, the implant-modified surgery produced a peak force 1.74X times greater but this force amplification diminishes as you move away from the optimal muscle length. This is due to the narrower force-length curve for the implant-modified surgery, which is caused by the difference in excursion transmission between the two surgeries. This study is limited by having a sample size of one. A larger sample size is needed to validate the results that were achieved.

CONCLUSIONS

This study demonstrates some of the characteristics of a force-amplifying implant used in tendon transfer surgeries. While the implant has the potential to improve functional strength of tendon transfer surgery, the force amplification may not be constant over the joint range of motion. Using the implant will ultimately require more precise tendon tensioning during surgery but has the potential to drastically improve outcomes for spinal cord injury patients.

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REFERENCES

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