Artificial Tibialis Cranialis Tendon Enables Normative Hindlimb Biomechanics During Hopping Gait in Rabbits

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INTRODUCTION: Critically sized tendon injuries are devastating since they prevent transmission of muscle forces to limb segments during movement. Such injuries are currently repaired surgically using autologous and allogenic tendon grafts, which are limited due to donor site morbidity and biosafety concerns, respectively [1]. Artificial tendons may be an effective alternative to tendon grafts for critically sized tendon defects. While there have been some studies on artificial tendons of varying designs and materials, the effect of artificial tendons on movement biomechanics has not been rigorously studied. Filling this knowledge gap is a critical step toward establishing the clinical efficacy of artificial tendons. Therefore, the goal of this study was to quantify in vivo hindlimb biomechanics during hopping gait of rabbits in which the biological tibialis cranialis tendon was surgically replaced with a polyester artificial tendon [2]. We hypothesized that hindlimb ground contact pressures and joint kinematics would be closer to baseline in rabbits with the artificial tibialis cranialis tendon than in rabbits with no tibialis cranialis tendon (surgical tendon excision).

METHODS: All animal procedures were approved by our Institutional Animal Care and Use Committee. In ten female New Zealand White rabbits (17-19 weeks old), the tibialis cranialis tendon was surgically excised. In five rabbits (polyester tendon (PET) group), the excised tendon was replaced with a polyester, silicone-coated artificial tendon as previously described [3]. In the other five rabbits (tendon excision (TE) group), the artificial tendon was not implanted. Prior to surgery, the rabbits were trained to hop along a walkway. Ground pressure data (Tekscan VH4 Walkway) and sagittal plane motion (high speed video cameras) of the operated (left) limb only were collected at 240 Hz once before surgery and every other week from 2 to 8 weeks post-surgery. Three trials were selected from each of three timepoints (baseline, 2- and 8-weeks post-surgery) for further analysis. The independent variables from ground contact pressure data were peak vertical force, vertical impulse, vertical impulse distribution, average ground contact area, and stance percent of stride; and from videos were range of motion and maximum, minimum, and average angle for the knee, ankle, and metatarsophalangeal (MTP) joints during the stance and swing phases of gait. Peak vertical force and vertical impulse were normalized by body weight. For each independent variable, we performed a two-factor (group, timepoint, and their interaction) ANOVA with repeated measures (rabbit) using statistical analysis software (SAS 9.4); least-squared means with a Tukey-Kramer adjustment was used for post-hoc pairwise comparisons. We used statistical parametric mapping (SPM [4])-based ANOVA and two-tailed paired t-tests to compare kinematic curves among timepoints; Bonferroni correction was used to account for multiple comparisons. Differences were considered significant for $p < 0.05$.

RESULTS SECTION: There were no significant differences in age, weight at time of surgery, weight at euthanasia, or length of the biological tendon between the two groups. Radiographs showed that the artificial tendon-anchor-bone interface remained stable throughout the study for all PET rabbits. Across groups, both peak vertical force (p=0.0002) and vertical impulse (p=0.0180) were significantly less at 2- and 8-weeks post-surgery compared to baseline (Figure 1A,B). In addition, peak vertical force was significantly less at 8-weeks post-surgery compared to baseline for the TE group (p=0.0215), but not the PET group (p=0.0621). From SPM ANOVA, there was a significant difference in joint angle among the three timepoints between ~44-58% of swing for the knee and ~38-80% of swing for the ankle. Post-hoc paired t-tests showed that, compared to baseline, the knee was significantly more extended during stance and swing at 2-weeks post-surgery and 2 and 8-weeks post-surgery, respectively, for the TE group. Ankle angle was also greater (i.e., more plantarflexed) during swing at 2- and 8-weeks post-surgery for the TE group (Figure 2). There were no significant differences among timepoints in the PET group for the knee or ankle.

DISCUSSION: The results supported our hypothesis that the artificial tendon would enable hindlimb biomechanics that more closely matches baseline values compared to rabbits with tendon excision only. These findings suggest that the artificial tibialis cranialis tendons effectively performed the biomechanical function of the native tendons they replaced. Interesting, peak vertical force at 8-weeks post-surgery was significantly less than at pre-surgery for the TE group and nearly so for the PET group. It is possible that the rabbits shifted weight from the operated limb to the sound limb, potentially due to discomfort or perceived functional impairment. Further analysis of bilateral pressure data is needed to confirm this. There were several limitations to the study. First, the study did not include a control group of healthy, non-operated rabbits to account for potential changes in biomechanics as the rabbits aged or gained more experience with our experiment protocol. Second, we replaced a healthy biological tendon with an artificial tendon in a single surgery; future studies should model the more likely clinical scenario that a tendon defect is present for some period prior to surgical replacement with an artificial tendon.

SIGNIFICANCE/CLINICAL RELEVANCE: Polyester, silicone-coated artificial tendons could potentially be an effective alternative treatment option for critically sized tendon defects and other severe tendon pathologies.

REFERENCES: [1] Jimenez-Carrasco C, et al., J Clin Med, 12(3), 2023. [2] Melvin AJ, et al., J Orthop Res, 30(7), 2012. [3] Hall PT, et al., J Biomech, 151, 2023. [4] Pataky TC, J Biomech, 43(10), 2010.

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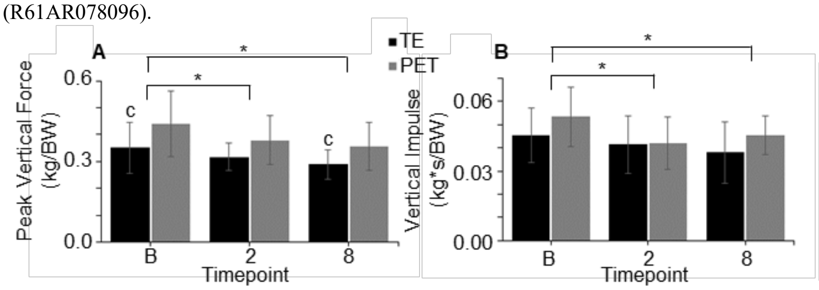

Figure 1: Mean and standard deviation at baseline, and 2- and 8-weeks post-surgery for A) Normalized peak vertical force; B) Normalized impulse. *p< 0.05

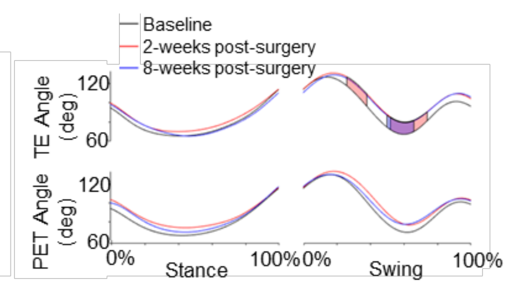

Figure 2: Mean ankle joint angles during gait for the TE (top) and PET (bottom) groups. Red, blue, and purple shaded areas indicate significant differences (p<0.05) between baseline and either 2-week, 8-week, or both post-surgery timepoints, respectively.