Passive Engineering Mechanism Enhancement of a Flexor Digitorum Longus Tendon Transfer Procedure

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Introduction/Purpose: Adult acquired flatfoot deformity (AAFD) associated with posterior tibial tendon (PTT) dysfunction remains a common orthopaedic problem for which a definitive solution has yet to be identified. Controversy has surrounded the diversity of treatment approaches utilized in current practice, which collectively fail to restore physiologic posterior tibial tendon function. In this proof-of-concept study we proposed a novel passive engineering mechanism (PEM) enhanced flexor digitorum longus (FDL) tendon transfer to address this deficiency. The objective of this study was to determine if PEM-enhancement would better restore physiologic PTT function and gait using a biomechanical flatfoot model. We hypothesized that compared to standard treatment, PEM-enhancement would increase applied FDL tendon force and improve pedobarographic and kinematic gait parameters.

Methods: An AAFD model consistent with stage II PTT dysfunction was induced in 8 cadaveric lower-limb specimens. Specimens were tested using a robotic gait simulator (RGS) under conditions in randomized order simulating flatfoot, standard treatment, and PEM-enhanced treatment. Three trials were performed for each condition per specimen for a total of 120 trials. In PEM conditions, a custom pulley was fixed in series to the PT tendon along its normal line of action to provide biorealistic passive mechanical advantage (Fig. 1). Pedobarographic (plantar pressures and CoP) and foot bone kinematics during the stance phase of gait were assessed with a RGS-integrated pressure mat and motion capture system respectively. Twenty-five independent RGS trials were completed to measure PEM force scaling using a custom load cell. For statistical analysis, a linear mixed-effects regression was used to determine if mean biomechanical outcome differed by condition. Significance was set at p = 0.05.

Results: Cadaveric flatfoot induction and robotic gait simulation produced a statistically validated biomechanical AAFD model. Throughout stance phase, PEM-enhancement significantly increased applied FDL tendon forces while reflecting physiologic tendon action, with mean FDL force increased 32.6 ± 10.7% at the physiologic force peak. Pedobarographic data demonstrated that PEM-enhancement consistently increased lateral pressure and decreased medial pressure during stance phase, with significantly decreased hindfoot pressure (-21 to -24 kPa) and laterally shifted CoP (3.9 to 4.8mm) observed in comparison to standard treatment. Kinematic data generally showed that PEM-enhancement caused adduction, inversion, and elevation of the medial longitudinal arch during stance phase, with significant joint motion differences (~1 to 2 degrees) observed from standard treatment for the tibiotalar, naviculocuneiform, and first MTP.

Conclusion: Using a well-documented biomechanical flatfoot model, we demonstrated that an innovative PEM-enhanced FDL tendon transfer better restored physiologic PTT force and gait characteristics compared to standard treatment. Further, PEM-enhancement enabled desired gait changes not previously observed in the literature for a modeled tendon transfer procedure, changes which compared to those found by other investigators who applied combined tendon transfer and bony procedures to achieve such results. These findings establish PEM-enhancement as a potential solution to PTT muscular imbalance following current surgical methods, and suggest that it may be a valuable feature of novel approaches to improve outcomes in AAFD treatment.
Figure 1. Specimen mounted on the robotic gait simulator with a passive engineering mechanism (PEM). (I) PEM-enhanced treatment condition with pulley [white arrow] and representative kinematic marker quad-cluster [black arrow]. (II) Close-up of pulley attachment to posterior tibialis tendon (PTT). (III) Independent PEM force scaling test configuration with load cell [white arrowhead] attached in series with pulley and PTT.