

FORCE- AND MOMENT-GENERATING CAPACITY OF FLEXOR DIGITORUM LONGUS FOLLOWING TENDON TRANSFER

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INTRODUCTION: Posterior Tibialis Tendon Dysfunction is a common condition that leads to significant morbidity of the foot (Mann et al., 1985). In conjunction with surgical lengthening of the lateral column of the foot or with calcaneal osteotomies, the flexor digitorum longus (FDL) muscle is often transferred to the medial cuneiform or navicular bones to augment the function of the deficient posterior tibialis muscle (Wacker et al., 2002). The functional success of this and other tendon transfers relies, among many factors, on the post-surgical production of appropriate muscle moments which in turn depends on donor muscle architecture, joint mechanics and transfer technique. However, knowledge of the functional capacity of native and transferred extrinsic foot muscles including the FDL is limited. The purpose of this research was to quantify the maximal isometric forces and moments that FDL is capable of producing following tendon transfer. It was hypothesized that in comparison to the native state, the hindfoot moment arm, force and moment produced by FDL would increase following tendon transfer to either the medial cuneiform or navicular bones.

METHODS: In six cadaveric specimens free from musculoskeletal disease, muscle moment arms for FDL and posterior tibialis (PT) were determined using the tendon-excursion method (An et al., 1984). Moment arms were measured with both muscles in their native state and with FDL transferred to either the plantar aspect of the navicular

or medial cuneiform bones. PT remained intact and served as a control.

To estimate the force FDL can produce in its native and transferred states, surgical simulations were performed in a specimen-specific musculoskeletal (MS) model of the talocrural, subtalar (STJ) and talonavicular joints. The kinematic structures of these joints were determined from the same cadaver from which bone geometry was obtained. Cardinal plane rotations and translations were measured using a joint coordinate system approach (Cole et al., 1993) and introduced into the MS model. The model was actuated by muscle-tendon units represented as three-element Hill-type muscles in series with elastic tendons. Reported muscle fiber lengths, maximal isometric forces, tendon lengths and pennation angles specified the force-producing properties of each muscle (Wickiewicz et al., 1983). Muscle paths were defined by MRI collected from the same cadaveric specimen. Via points and wrapping structures were added to maintain physiological muscle paths during joint rotations. Simulations in which muscles were maximally and isometrically activated as the STJ was rotated from -10° of eversion to $+15^{\circ}$ of inversion were used to examine the force- and moment-generating capacity of the PT and FDL muscles.

ANOVA was used to compare cadaveric moment arm magnitudes in the native and transferred states ($p=0.05$).

RESULTS AND DISCUSSION: The FDL hindfoot moment arm magnitude measured in cadaveric specimens decreased by up to 40% when transferred from its native state (Table 1). These differences were not significant ($p=0.122$) due to variability within specimens. Post hoc power analyses indicated that over 20 specimens would be required to detect statistical significance.

FDL muscle moment arms also decreased during the simulated transfer surgeries. FDL produced more force in both transferred conditions than in the native state when the hindfoot was inverted. However, force production for foot positions representative of the stance phase of gait (0 - 10° eversion)

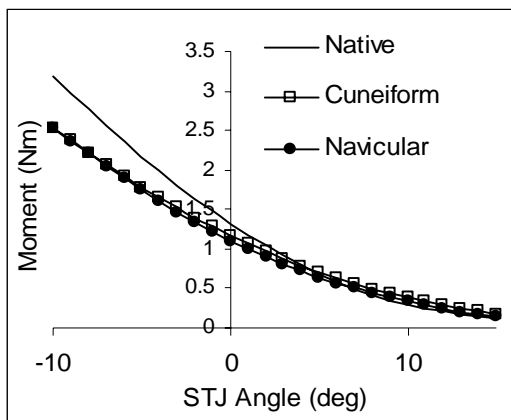


Fig 1: Simulated maximal isometric FDL muscle moments about the hindfoot for FDL tendon transfers. Eversion 0° to -10° ; inversion 0° to $+15^\circ$.

Table 1: Individual (S1–S6) and group mean moment arms magnitudes (mm) for FDL calculated in hindfoot neutral position for the native and transferred FDL.

	S1	S2	S3	S4	S5	S6	Mean
Native	19.7	15.5	10.2	18.7	23.4	15.6	17.2
Cuneiform	16.7	15.4	7.6	16.8	5.0	8.1	11.6
Navicular	13.6	17.3	9.7	16.6	1.8	8.4	11.2

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was unchanged. Due to decreased moment arm magnitudes and no change in muscle force, the transferred FDL produced lower inversion moments about the hindfoot compared with its native condition for neutral to everted STJ positions (Fig 1.).

CONCLUSIONS: Transfer of the FDL tendon to the navicular or medial cuneiform did not increase the capacity of the FDL muscle to invert (or resist eversion of) the hindfoot. In contrast, the transferred FDL tended to be less effective in this role suggesting little functional advantage is gained through its transfer to these sites. Because muscles were fully activated and the subtalar and talonavicular joints were moved in isolation, the current simulation results cannot be directly applied to predict muscle forces or to analyze muscle function during gait. However, combined with appropriate in vivo measurements of joint kinematics, ground-reaction forces and muscle activity, the model described herein may be used to estimate muscle-tendon forces during gait.