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

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Disclosures

Individual disclosures can be found in the AOFAS Mobile App

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Adult Acquired Flatfoot Deformity (AAFD)

- Common orthopaedic problem for which a definitive solution has yet to be identified
- Associated with dysfunction of the posterior tibial tendon (PTT), the primary stabilizer of the medial longitudinal arch (MLA)
- Characterized by symptomatic gait dysfunction secondary to:
  - Collapse of MLA
  - Hindfoot eversion
  - Forefoot abduction
AAFD: Current Treatment

- Diversity of treatment approaches utilized
- Common method involves:
  - Flexor Digitorum Longus Tendon Transfer (FDLTT)
  - Ligamentous repair
  - Bony realignment
- General Outcomes:
  - Moderate symptomatic relief
  - Moderate functional improvement
- General Limitations:
  - Fail to restore physiologic PTT force to MLA
- Applicable innovative methods?
  - Passive engineering mechanism (e.g. pulley) enhanced tendon transfer procedure
Proof-of-Concept Study

• Objective:
  - Determine if a novel passive engineering mechanism (PEM) enhanced FDLTT procedure would better restore physiologic PTT force to the MLA and improve pedobarographic and kinematic gait parameters using a biomechanical AAFD model.

• Hypothesis:
  - PEM-enhancement would cause relative:
    • Increased applied tendon force to MLA
    • Laterally shifted peak plantar pressure and center of pressure (CoP)
    • MLA elevation, hindfoot inversion, and forefoot adduction
Eight cadaveric AAFD model specimens tested using robotic gait simulator under five conditions (n = 120):

- AAFD control (FF), FDL tendon transfer (FDLTT), hypertrophic FDLTT (hFDLTT), PEM, and hypertrophic PEM (hPEM)
Results: PEM-Enhanced FDLTT

- Validated biomechanical AAFD model
- PEM-Enhancement:
  - Increased applied FDL tendon forces to MLA
  - Reflected physiologic FDL action
  - Increased lateral peak plantar pressure and decreased medial and hindfoot peak plantar pressures
  - Laterally shifted CoP
  - Reflected MLA elevation, hindfoot inversion, and forefoot adduction
Results: PEM-Enhanced FDLTT

PEM-Enhanced Peak Plantar Pressure

Center of Pressure

- hPEM
- PEM
- hFDLTT
- FDLTT

Medial Shift | Lateral Shift Compared to FF

90%
75%
25/50%
# Results: PEM-Enhanced FDLTT

## Relative Motion and Stance Phase Interval of Significant Pair-Wise Mean Kinematic Differences for Joints or Bony Relationships of the Foot

<table>
<thead>
<tr>
<th>Joint or Relationship</th>
<th>Cardinal Plane</th>
<th>Differences from FF (% SP, Relative Motion)</th>
<th>Treatment Differences (% SP, Relative Motion)</th>
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<tr>
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</table>

† Significant omnibus association and pair-wise difference (p < 0.05 continuous for > 5% SP).

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**Talonavicular Joint Kinematics**

![Talonavicular Joint Kinematics](image-url)
A PEM-enhanced FDLTT may be a valuable feature of novel approaches to improve outcomes in AAFD treatment.

- More closely restores physiologic PTT forces to the MLA
- Uniquely enabled desired gait changes previously realized only with combined tendon transfer and bony procedures

Several limitations affected this proof-of-concept study:

- Biomechanical model approximates in vivo conditions
- PEM device was not suitable for surgical use

Future work:

- Engineer biocompatible pulley and tendon sheath system
- Define optimal position for surgical implantation
References

PASSIVE ENGINEERING MECHANISM ENHANCEMENT OF A FLEXOR DIGITORUM LONGUS TENDON TRANSFER PROCEDURE

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INTRODUCTION

Adult acquired flatfoot deformity (AAF D) associated with posterior tibial tendon dysfunction (PTTD) remains a common orthopaedic problem for which a definitive solution has yet to be identified.2,3 The condition is characterized by symptomatic gait dysfunction secondary to the insidious collapse of the medial longitudinal arch (MLA), hindfoot eversion, and forefoot abduction.3,4

Standard treatments of AAFD, such as a flexor digitorum tendon transfer (FDLTT), generally provide symptomatic relief and moderate clinical improvement, but fail to restore physiologic PTT function.5,7 In this proof-of-concept study we proposed an innovative passive engineering mechanism (PEM) enhanced FDLTT procedure to address this deficiency.

Objective: Determine if a novel PEM-enhanced FDLTT procedure would better restore physiologic PTT force to MLA and improve pedobarographic and kinematic gait parameters using a biomechanical AAFD model.

Hypothesis: PEM-enhancement would increase applied FDL tendon force and produce a lateral shift in peak plantar pressure and center of pressure (CoP), MLA elevation, hindfoot inversion, and forefoot adduction when compared to standard FDLTT treatment.

METHODS

A radiographically confirmed AAFD model was induced via ligament attenuation and cyclic physiologic force loading in eight cadaveric lower limb specimens.8,11

Specimens were tested using a robotic gait simulator (RGS), which accurately reproduces the stance phase of gait.12,13 Three trials were collected for five randomized conditions: flatfoot (FF), FDL tendon transfer (FDLTT), hypertrophic FDLTT (hFDLTT), PEM, and hypertrophic PEM (hPEM) (n = 120). In PEM conditions, a custom pulley was fixed in lower-limb specimens.8,11

In PEM conditions, a custom pulley was fixed in lower-limb specimens.8-11 Attenuation and cyclic physiologic force loading in eight cadaveric specimens was collected for five randomized conditions: flatfoot (FF), FDL tendon transfer (FDLTT), hypertrophic FDLTT (hFDLTT), PEM, and hypertrophic PEM (hPEM) (n = 120). In PEM conditions, a custom pulley was fixed in lower-limb specimens.8-11

RESULTS

Statistical analysis was performed using paired t-tests (radiographic measures, PTT force scaling) and linear mixed-effects regression with omnibus and pairwise comparisons (pedobarographic and kinematic parameters). Significance was set at p < 0.05.

Figure 1: (A) PEM concept design. (B) Specimen mounted on RGS with PEM (arrow).

Figure 2: PEM force scaling. Mean ± SD in vitro PEM-enhanced FDL force and in vitro applied FDL force compared to target in vivo applied FDL tendon force and in vivo PTT force.

Figure 3: Peak plantar pressure. [Left] Representative radiograph-aligned plantar pressure data with resultant CoP line. (Right) Mean difference (mm) for standard (FDLTT, hFDLTT) and PEM-enhanced (PEM, hPEM) treatment conditions compared to flatfoot (FF).

Figure 4: Center of pressure (CoP). [Left] Representative radiograph-aligned plantar pressure data with resultant CoP line. (Right) Mean difference (mm) for standard (FDLTT, hFDLTT) and PEM-enhanced (PEM, hPEM) treatment conditions compared to flatfoot (FF).

Figure 5: Talonavicular joint kinematics. Mean joint angle in the coronal plane, reflecting motion of navicular with respect to talus. Significant omnibus association between mean joint angle and condition is depicted by x-axis tic. (Significance: p < 0.05 continuous for > 5% stance phase)

DISCUSSION

Using a validated biomechanical AAFD model, we demonstrated that a novel PEM-enhanced FDLTT procedure better restored physiologic PTT force and gait in comparison to standard treatment. Uniquely, our innovative procedure enabled desired gait changes not seen in comparable studies, changes which corresponded to those found by other investigators who required combined tendon transfer and bony procedures to achieve such results.14,15

Several limitations affected this proof-of-concept study, as our biomechanical model approximated in vivo conditions and the PEM device was not suitable for surgical use. Future work will apply our results to engineer a biocompatible pulley and tendon sheath system, as well as define an optimal position for surgical implantation to achieve loading directions that provide maximal scaling. Conclusively, this study validates PEM-enhancement as an efficacious tendon force scaling method and suggests that a PEM-enhanced FDLTT procedure may prove to be a valuable feature of future approaches targeting improved AAFD treatment outcomes.

REFERENCES


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