CARBON FIBER FOOTPLATE(S) TO ENHANCE FOOT ORTHOSES AND GAIT REHABILITATION

Shashank Sharma, MBA[1], Dr. Shridhar Yarlagadda[1], Dr. Elisa Arch[2], Adrienne Henderson, MS[2], Dr. Dustin Bruening[3]
University of Delaware | Center for Composite Materials[1] | Department of Kinesiology & Applied Physiology[2] | Brigham Young University[3]

Introduction

- Collaborative work being done as part of the NSF Award # 2032155 "Collaborative Research: Don't forget the foot! Exposing foot energetics to enhance foot orthoses and gait rehabilitation"
- *Overall Objective:* To reveal critical understandings of the mechanisms governing the energetics of the human foot and apply this understanding to probe and modulate the energetics of the ankle-foot systems using a novel foot orthosis

Key Questions to Answer:

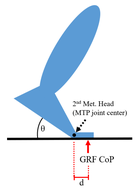
1. How is energy used and transferred throughout the typical (unimpaired) foot?
2. How does energy usage and transfer throughout the ankle-foot system change when typical individuals walk while wearing deformable foot orthoses that alter forefoot stiffness?
3. For individuals with ankle-foot impairments, can a deformable foot orthosis with customized forefoot stiffness be used to enhance ankle-foot energetics?

Background & Motivation

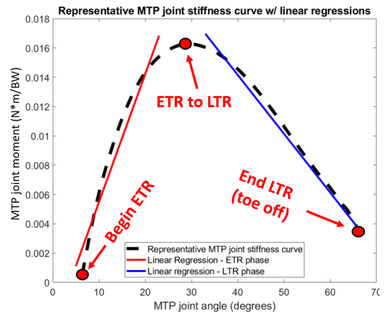
- It is widely agreed that the ankle-foot system plays a major role in achieving efficient gait
- Given the emerging insights **into how important a role the foot plays in gait energetics**, we contend that the key to positively **transforming ankle-foot assistive devices** (orthoses, prostheses) and the associated user benefits lies within the foot

Key Parameters

- Rotational "stiffness" about metatarsophalangeal (MTP) joint center
  - Slope of Moment vs Angle curve

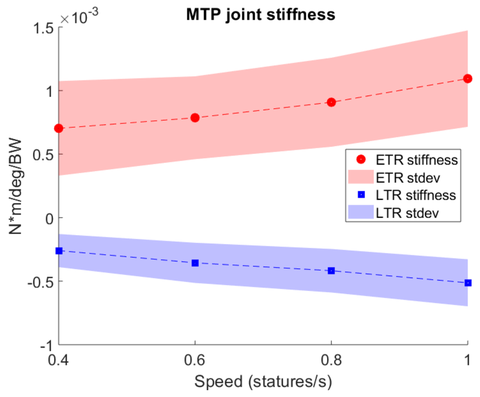


- Function of:
  - Ground reaction force (GRF) : Angle of foot relative to ground (only normal forces used in stiffness calculation)
  - Distance from center of pressure (COP) to MTP joint center (d)
- MTP joint moment and angle analyze during late stance
  - Curve divided in to two phases: Early Toe Rocker (ETR) and Late Toe Rocker (LTR)
  - Slope of moment-angle curve during phase of interest calculated to determine MTP joint stiffness



Typical MTP Joint Stiffness:

- Range of walking speeds: 0.4 (slow) to 1.0 (fast) statures/sec



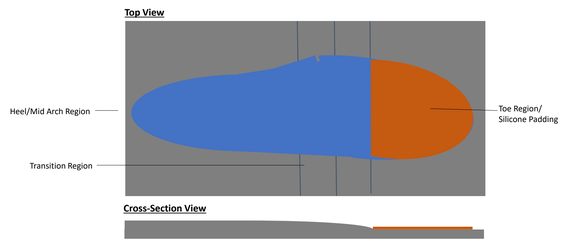
- This data give an initial measurement, but a lot of variability even in typical individuals. Still exploring other ways to calculate MTP joint stiffness

Design and Manufacturing

- The footplate design in a manner that would enable streamlined manufacturing process
- Process is scalable and doesn't require the use of any specialized molds or equipment, and enables simple customization based on individual footplate requirements

Design Features	Sizing and Stiffness	Material
• Customized Stiffness: Need to be able to tailor the stiffness based on individual subject's parameters • Comfort: One of the most important aspects of the DFO is the comfort while being worn	• Obtain data on the subject including: ➢ Anatomical data on subject's foot, including geometry of insole ➢ Stiffness range based on MTP joint assessment	T700/G83C prepreg manufactured by Toray Out of Autoclave manufacturability with 250 F oven cure cycle Full material characterization, including fatigue performance done previously

- The footplate geometry is cut from a rectangular carbon fiber baseline plate manufactured with variable thickness (stiffness) in different regions
- Designed to target specified energy absorption and release during walking motion

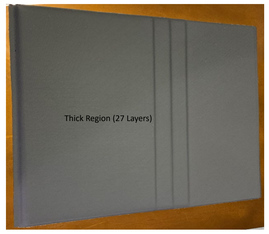


Footplate Regions:

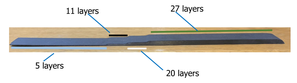
- Heel/Mid Arch Region: Heel and mid arch area where the foot plate thickness is relatively high. Approximately 25 plies of carbon fiber prepreg
- Transition Region: Area where the thickness is reduced via ply drops to avoid stress concentration at desired deflection point during motion
- Rocker/Thin Region: Area where the thickness is low, can be determined based on foot data approximates for population. Range 5 - 9 plies.
- Toe Region: Thickness is roughly 1/5 of the thickness in heel/mid arch region, and stays consistent post transition region

Prototype Manufacturing

- First prototype was built to do trials and determine the stiffness profile(s)
- Instron testing will be done to analyze the stiffness profile of the footplate and characterize footplate stiffness based on number of carbon fiber layers used in different regions



Prototype Carbon Fiber Baseline Plate



1" Width Beam from First Prototype Built

Current and Future Work

- First prototype was built to do trials with a healthy subject to access the stiffness response, comfort and general footplate performance
  - Determine if the transition region is appropriate
  - Thickness in various regions
  - Performance over time
- Establish the process to determine the layup configurations based on bending stiffness requirements for each footplate
- Develop a process to establish safe use limits for each footplate (DFO) based on individual footplates construction

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