Modeling Foot Invertor and Evertor Muscle Tendon Lengths with Milwaukee Foot Model Kinematics in OpenSim

*Maxine L. Olson[1,2,3], Christina M. R. Garman[2], Joseph J. Krzak[2,4], Philip A. Voglewede[1], Gerald F. Harris[1,2], Karen M. Kruger[1,2]
[1]Marquette University, Milwaukee, WI, [2]Shriners Children's Chicago, Chicago, IL [3]Rosalind Franklin University, North Chicago, IL
[4]Midwestern University, Downers Grove, IL *maxine.olson@rosalindfranklin.edu

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INTRODUCTION: *In-vivo* modeling of muscle tendon length (MTL) change helps explain the influence of soft tissue on motion and stability. Specifically, MTL change of foot invertors (tibialis anterior and posterior muscles) and evertors (peroneus brevis and longus muscles) during gait will allow clinicians to identify the primary contributor(s) to characteristic pediatric foot and ankle deformities with a goal of providing more informed and individualized treatment recommendations. Musculoskeletal modeling to compute MTL has historically been used with a single segment foot, limiting its accuracy and use.

The purposes of this study were to: 1. Create an OpenSim multi-segment foot model based on the validated kinematic Milwaukee Foot Model (MFM). This model will more accurately capture MTL changes during gait for foot invertor and evertor muscles due to the inclusion of within foot joint kinematics. 2. Calculate normal bands of MTL across the gait cycle in a sample of typically developing (TD) children. 3. Show differences in MTL in participants with foot pathology (PFP) when compared to the normal bands.

METHODS: Instrumented gait analysis was performed bilaterally with 10 TD (5 female) and 10 PFP (3 female) with a variety of pathologies resulting in but not limited to severe equinovarus and planovalgus deformities, in this ethics board approved study. Kinematic gait data was captured with the Vicon Plug-in-Gait Model for knee and hip motion, and the MFM for ankle, midfoot, and metatarsophalangeal (MTP) joint motion [1]. The 8 degree-of-freedom (DOF) KU Leuven OpenSim multi-segment foot model was adapted to match the 9 DOF MFM joint motions and foot segments [1-2]. Three DOF were allowed at the ankle (1 DOF (sagittal) at the talocrural joint, 2 DOF (transverse and coronal) at the subtalar joint), 3 DOF at the midfoot/Chopart joint, the Lisfranc joint was locked with midfoot and forefoot segments combined into a single forefoot segment, and 3 DOF at the MTP joint.

An inverse kinematic analysis based on marker position was performed in OpenSim 4.5 on our unscaled OpenSim base model allowing for direct comparison of MTL between participants based on individual kinematics regardless of participant height or muscle size (Fig. 1) [3]. Bone-based MFM kinematics were substituted for ankle, midfoot, and MTP OpenSim kinematics. TD MTL bands (mean ±1 standard deviation) were created and scaled so that the maximum and minimum of the average muscle length during gait were equal to ±1. PFP MTL were overplot and compared to TD bands.

RESULTS: Normal bands were developed for foot invertor and evertor muscles (Figure 2: grey bands). When PFP MTL were compared to TD bands, differences of more than 1 SD were seen in many cases and varied greatly by individual pathology and walking pattern. As an example, Figure 2 red lines show plots of 6 PFP limbs with equinovarus deformity. While there is variation within this equinovarus group, as a whole, tibialis muscles are shorter than typical, and peroneus are longer than typical, congruent with expectations of an inverted hindfoot.

DISCUSSION: A model was created to more accurately process MTL by accounting for midfoot and MTP motion. Not unexpectedly, TD MTL bands were wider (larger standard deviation) than is seen in knee or hip muscles due the large range of TD foot types and associated varied kinematics [4]. Invertor/evertor MTLs were congruent with pathologies observed; invertors were shorter than TD for an inverted hindfoot and longer for an everted and/or plantarflexed hindfoot. For example, equinovarus deformity in Figure 2 show shorter tibialis and longer peroneus MTL compared to the TD band. Variation within this pathology was seen and was expected due to the muscles' complex dual task nature of both inversion/eversion and plantar flexion/dorsiflexion function and additional wide variation in forefoot deformities [5]. Future study with larger pathology specific groups would add to this work. Limitations of the study include modeling the collection of midfoot joints as a single joint and assumptions of normal bony structures, joint motions, and muscle insertion points in PFP.

SIGNIFICANCE/CLINICAL RELEVANCE: The ability to show how MTL of the tibialis and peroneal muscles vary with pathology will benefit clinicians and influence treatment by increasing understand of specific musculotendon contributions to various foot deformities. In this first step of modelling foot invertors and evertors with a multi-segment foot, a difference in PFP from TD MTL bands was shown in participants with foot pathology.

REFERENCES: [1] Long et al. *J Exp Clin Med* 2011;3(5), [2] Malaquias et al. *Computer Methods in Biomech and Biomed Eng* 2017:20(2), [3] Arnold et al. *J Biomech* 2006;39, [4] Kruger et al. *J Biomech* 2019;94, [5] Krzak et al. *Gait & Posture* 2015;41(2).

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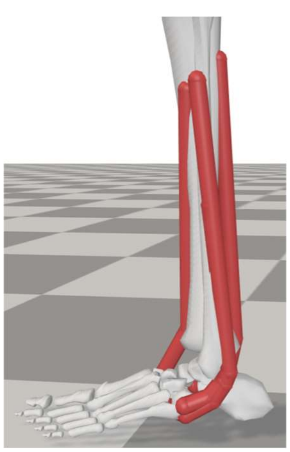

Figure 1: OpenSim model with tibialis and peroneal muscles highlighted.

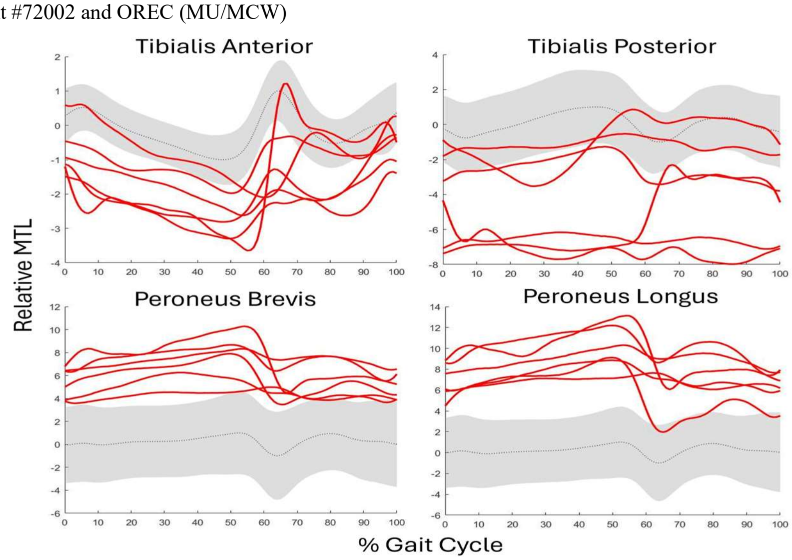

Figure 2: Grey band: TD mean ±1 standard deviation. Red lines: PFP with equinovarus pathology. Relative MTL: +1 = max length of averaged TD. -1 = min length of averaged TD.