Medial Arch Load and Redistribution of Foot Forces in Flexible Flatfoot Deformity Associated with Posterior Tibial Tendon Dysfunction

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Summary

Under conditions of Posterior Tibial Tendon Dysfunction (PTTD), simulated by reducing Tibialis posterior (TP) muscle strength by 50%, our forward dynamics simulation of a musculoskeletal model with eight ligaments per foot revealed a pronounced increase in hindfoot eversion and Chopart joint inversion, along with compensatory activation of the flexor hallucis longus during walking. Simulations incorporating muscular adaptations to PTTD demonstrated partial adaptations in the foot muscles and ligaments.

Introduction

Posterior Tibial Tendon Dysfunction (PTTD), a leading cause of adult-acquired flatfoot, results from a weakened or torn posterior tibial tendon collapsing the medial arch [1]. Although studies show this collapse causes pain [2] and may lead to arthritis [3], they often focus on the tendon or static measures, neglecting muscle activity and load distribution in surrounding structures [2,3]. Understanding these factors is essential because muscles and ligaments play an important role in foot stability and force redistribution [4]. The objective of this study is to investigate the effects of PTTD on joint kinematics and load distribution during walking using a multi-segment foot model and forward dynamic simulations.

Methods

This research is approved by the Institutional Review Board at KAIST. An anatomical foot model was integrated into an existing musculoskeletal model with 25 degrees of freedom (DOF) and 92 muscles [5]. The Chopart and Lisfranc joints (1 DOF each) were added, along with eight ligaments (Anterior & Posterior tibiotalar, Tibiocalcaneal, Tibionavicular, Anterior & Posterior talofibular, Calcaneofibular, Spring ligament) on each foot. Ligament properties were based on existing literature [6]. Joint kinematics were collected from a healthy male participant (Age: 21, 179.4 cm, 63.9 kg) during walking. A gait controller replicated joint kinematics, and PTTD was simulated by reducing tibialis posterior (TP) muscle strength by 50% and retraining the controller. Joint kinematics, muscle, and ligament forces were compared across healthy, PTTD, and post-adaptation conditions using statistical parametric mapping.

Results and Discussion

Changes in joint kinematics and muscle and ligament forces for the three different conditions are shown in Figure 1 and Table 1. Our simulation showed increased hindfoot eversion and Chopart joint inversion in the foot with PTTD, which conforms to previous studies [2, 7]. The simulation revealed increased force of flexor hallucis longus at PTTD condition to compensate the weakened TP muscle [8]. Post-adaptation showed partial recovery of joint kinematics and ligament forces, emphasizing the impact of targeted interventions on PTTD.

Table 1: Maximum differences of the injury (PTTD and Adapted) models against the healthy models. (Sub. Inv.: Inversion of subtalar joint, Cho. Inv.: Inversion of Chopart joint, FHL: Flexor hallucis longus, PTTL: Posterior tibiotalar ligament)

	Sub. Inv.	Cho. Inv.	TP	FHL	PTTL	Spring
PTTD	-5.4°	12.1°	-41.9N	17.7N	-56.4N	29.8N
Adapted	-1.3°	4.2°	-77.2N	-4.8N	14.7N	-2.2N

Conclusions

In conclusion, simulating PTTD revealed altered joint kinematics and load redistribution in surrounding structures, emphasizing the need for targeted interventions for better clinical treatment.

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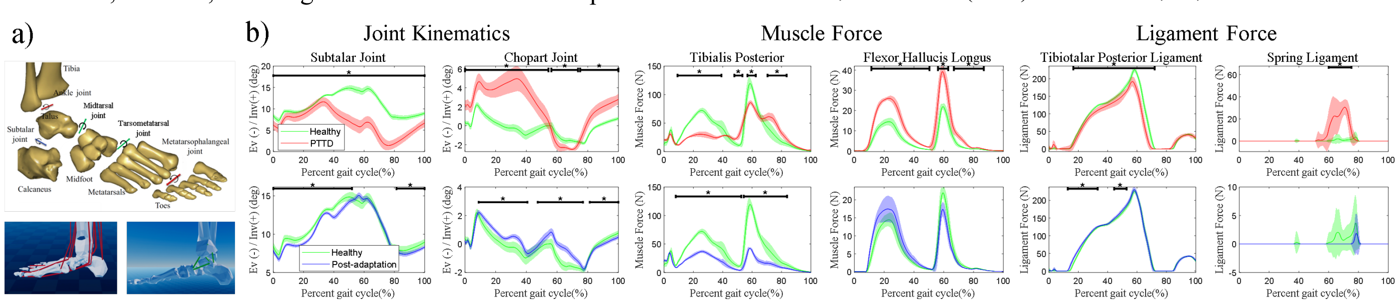

Figure 1: Foot model (red: muscles, green: ligaments) (a), joint kinematics, and muscle and ligament forces under three different conditions (b)