The Broken Windlass: Lower-limb Biomechanics in Patients with Plantar Fasciitis

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INTRODUCTION: Plantar fasciitis (PF) is one of the most common causes of foot pain. It is estimated that one million Americans seek medical care every year to treat symptoms of PF[1]. Despite the high incidence, the pathophysiological mechanism is not completely understood. Recently, importance has been placed on the metatarsal-phalangeal joints and tension of the plantar fascia—the Windlass mechanism[2]. The goal of this study was to evaluate differences in gait measurements in patients with plantar fasciitis as compared to healthy subjects using a multi-segment foot model[3] to focus on the motion of the first metatarsal-phalangeal joint. Considering the plantar fascia anatomy, with its insertion on the base of the proximal phalanx of lesser toes as well into both sesamoids and consequently, to the hallux[4], we hypothesized that patients with plantar fasciitis present greater dorsiflexion of the hallux.

METHODS: Data from an ongoing, prospective, IRB-approved study were analyzed from six individuals (4 with PF and 2 healthy subjects). Individuals underwent gait analysis using a 20-camera OptiTrack motion capture system (NaturalPoint, Inc., Corvallis, OR) and an embedded force plate system within a 12ft walkway. All subjects underwent repeated (n=5) walking trials at self-selected speed and fast speed (30% increase). All motion data was labeled and tracked in Motive and further processed using Visual 3D. A multi-segment foot model[3] was used to calculate maximum and minimum joint angles, as well as range of motion (ROM), for the hallux, medial forefoot (1st metatarsal-proximal phalanx), midfoot, hindfoot, and tibia during the stance phase of gait. Lower limb range of motion was measured manually (using a standard goniometer).

RESULTS: Kinematic results can be found in tables 1 and 2**.** The angle of hallux dorsiflexion during standing was 76,08º for the PF group (SD 26,12), while the control group showed 93,83º (SD 14,85). Regarding the manual measurement, the ROM of hallux for the subject group was 105,5º (SD 3,12) (the maximum 82,5º and minimum 23º, SD respectively 0,71 and 7,54). For the control group, the hallux ROM was 94º (SD 30,17) (the maximum 78º and minimum 16º, SD respectively 15,56 and 14,61).
Considering the force for plantarflexion of the hallux, the PF group showed a force of 67,39N (SD 35,04) while the control group 69,83N (SD 16,26).

DISCUSSION: Contradictory to our hypothesis, the ROM of the hallux during gait was greater in the control group in comparison to the PF group (37,89º and 55,49º respectively). This finding was also present in previous studies[5]. One possible explanation for this finding is the possible mechanism of adaptation that the patient develops to avoid pain in the late stance phase[5]. The hallux ROM during standing also contributed to this finding, where the PF group showed lower ROM compared to the control group. Our findings should be taken in the context of our limitations. The multi-segment foot model used also showed several technical limitations including collinearity between segments which influenced the data quality and its analysis. Addressing the foot motion during gait using multi-segment foot models is of high importance for better understanding PF, its pathophysiological mechanism, and also for the development of treatment strategies. Future studies with more patients, which can overcome the challenges faced in the present study are required for improved conclusions.

SIGNIFICANCE/CLINICAL RELEVANCE: The present study contributes to a better understanding of the biomechanics of the foot during normal gait for patients with PF. Especially for analyzing the foot in six different segments and considering the relation between each of them. The main hypothesis could be questioned bringing focus to the pathologic mechanism of the disease. Another important achievement was to find technical barriers that can limit the research using the multi-segment foot models. Bringing those limitations into discussion is of main importance for future studies.

REFERENCES: [1] Riddle et al., FAI, 2004. [2] Hicks et al., J. of Anatomy, 1954. [3] de Mits et al., J. of Orthopaedic Research, 2010. [4] Wearing et al. Sports Med, 2006 [5]Pazhooman et al,. Gait Posture, 2023.

Table 1. Joint kinematics during normal walking. PF=plantar fasciitis group››

	Subject Groups	Minimum angle, ° (Mean±SD)	Maximum angle, ° (Mean±SD)	ROM, ° (Mean±SD)
Hallux vs Medial Forefoot (dorsiflexion / plantarflexion)	PF (n=4)	24.7±8.2	62.6±17.8	37.9±21.1
	Controls (n=2)	23.9±1.6	79.4±5.8	55.5±4.2
Medial Forefoot vs Midfoot (dorsiflexion / plantarflexion)	PF	-16.7±4.2	11.8±16.6	28.5±12.7
	Controls	-24.4±9.7	4.9±4.1	29.3±13.8
Hindfoot vs Tibia (inversion / eversion)	PF	-0.4±8.5	12.4±9.3	12.9±3.1
	Controls	2.26±3.2	13.6±4.2	11.3±7.5

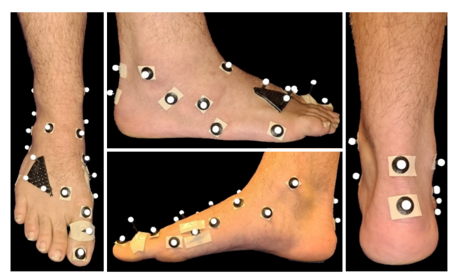

Figure 1 – Marker set for Multi-segment foot model (Ghent)

Table 2. Joint kinematics during normal and fast walking. PF=Plantar fasciitis group

	Subject Groups	Minimum‹3 angle, ° (Mean±SD)		Maximum angle, ° (Mean±SD)		ROM, ° (Mean±SD)	
		Normal	Fast	Normal	Fast	Normal	Fast
Hallux vs Medial Forefoot (dorsiflexion / plantarflexion)	PF (n=4)	24.1±8.2	25.3±8.3	62.6±17.3	62.6±18.3	38.5±20.8	37.4±21.5
	Controls (n=2)	25.1±3.6	22.8±0.5	80±4.7	78.6±7.2	54.9±1	55.8±8.3
Medial Forefoot vs Midfoot (dorsiflexion / plantarflexion)	PF	-17.2±5.1	-16.1±3.5	11.3±17.6	12.3±15.7	28.4±12.7	28.5±12.7
	Controls	-24.1±9.3	-26.9±7.1	5.1±4.4	3.1±6.2	29.2±13.6	29.9±13.3
Hindfoot vs Tibia (inversion / eversion)	PF	0.61±7.3	-1.5±9.6	12.38±9.3	12.4±9.3	11.8±3.6	14±3.1
	Controls	2.08±2.6	2.4±3.7	14±4.5	13.2±3.9	11.9±7.2	10.8±7.6