Multi-Segment Foot Kinetics

Chang R, Rodrigues PA, Van Emmerik RE, Hamill J.(2014) "Multi-segment foot kinematics and ground reaction forces during gait of individuals with plantar fasciitis."

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BACKGROUND: Clinically, plantar fasciitis (PF) is believed to be a result and/or prolonged by overpronation and excessive loading, but there is little biomechanical data to support this assertion. The purpose of this study was to determine the differences between healthy individuals and those with PF in (1) rearfoot motion, (2) medial forefoot motion, (3) first metatarsal phalangeal joint (FMPJ) motion, and (4) ground reaction forces (GRF).

METHODS: We recruited healthy (n=22) and chronic PF individuals (n=22, symptomatic over three months) of similar age, height, weight, and foot shape ($p>0.05$). Retro-reflective skin markers were fixed according to a multi-segment foot and shank model. Ground reaction forces and three dimensional kinematics of the shank, rearfoot, medial forefoot, and hallux segment were captured as individuals walked at 1.35 ms(-1).

RESULTS: Despite similarities in foot anthropometrics, when compared to healthy individuals, individuals with PF exhibited significantly ($p<0.05$) (1) greater total rearfoot eversion, (2) greater forefoot plantar flexion at initial contact, (3) greater total sagittal plane forefoot motion, (4) greater maximum FMPJ dorsiflexion, and (5) decreased vertical GRF during propulsion.

CONCLUSION: These data suggest that compared to healthy individuals, individuals with PF exhibit significant differences in foot kinematics and kinetics. Consistent with the theoretical injury mechanisms of PF, we found these individuals to have greater total rearfoot eversion and peak FMPJ dorsiflexion, which may put undue loads on the plantar fascia. Meanwhile, increased medial forefoot plantar flexion at initial contact and decreased propulsive GRF are suggestive of compensatory responses, perhaps to manage pain.

Bruening DA, Cooney KM, Buczek FL.(2012) "Analysis of a kinetic multi-segment foot model. Part I: Model repeatability and kinematic validity."

Gait Posture. 2012 Apr;35(4):529-34.

Kinematic multi-segment foot models are still evolving, but have seen increased use in clinical and research settings. The addition of kinetics may increase knowledge of foot and ankle function as well as influence multi-segment foot model evolution; however, previous kinetic models are too complex for clinical use. In this study we present a three-segment kinetic foot model and thorough evaluation of model performance during normal gait. In this first of two companion papers, model reference frames and joint centers are analyzed for repeatability, joint translations are measured, segment rigidity characterized, and sample joint angles presented. Within-tester and between-tester repeatability were first assessed using 10 healthy pediatric participants, while kinematic parameters were subsequently measured on 17 additional healthy pediatric participants. Repeatability errors were generally low for all sagittal plane measures as well as transverse plane Hindfoot and Forefoot segments (median<3°), while the least repeatable orientations were the Hindfoot coronal plane and Hallux transverse plane. Joint translations were generally less than 2mm in any one direction, while segment rigidity analysis suggested rigid body behavior for the Shank and Hindfoot, with the Forefoot violating the rigid body assumptions in terminal stance/pre-swing. Joint excursions were consistent with previously published studies

Bruening DA, Cooney KM, Buczek FL.(2012) "Analysis of a kinetic multi-segment foot model part II: kinetics and clinical implications."

Gait Posture. 2012 Apr;35(4):535-40.

Kinematic multi-segment foot models have seen increased use in clinical and research settings, but the addition of kinetics has been limited and hampered by measurement limitations and modeling assumptions. In this second of two companion papers, we complete the presentation and analysis of a three segment kinetic foot model by incorporating kinetic parameters and calculating joint moments and powers. The model was tested on 17 pediatric subjects (ages 7-18 years) during normal gait. Ground reaction forces were measured using two adjacent force platforms, requiring targeted walking and the creation of two sub-models to analyze ankle, midtarsal, and 1st metatarsophalangeal joints. Targeted walking resulted in only minimal kinematic and kinetic differences compared with walking at self selected speeds. Joint moments and powers were calculated and ensemble averages are presented as a normative database for comparison purposes. Ankle joint powers are shown to be overestimated when using a traditional single-segment foot model, as substantial angular velocities are attributed to the mid-tarsal joint. Power transfer is apparent between the 1st metatarsophalangeal and mid-tarsal joints in terminal stance/pre-swing. While the measurement approach presented here is limited to clinical populations with only minimal impairments, some elements of the model can also be incorporated into routine clinical gait analysis.

Dixon PC, Böhm H, Döderlein L.(2012) "Ankle and midfoot kinetics during normal gait: a multi-segment approach."

J Biomech. 2012 Apr 5;45(6):1011-6.

Multi-segment foot models are increasingly being used to evaluate intra and inter-segment foot kinematics such as the motion between the hindfoot/tibia (ankle) and the forefoot/hindfoot (midfoot) during walking. However, kinetic analysis have been mainly restricted to one-segment foot models and could be improved by considering a multi-segment approach. Therefore, the aims of this study were to (1) implement a kinetic analysis of the ankle and theoretical midfoot joints using the existing Oxford Foot Model (OFM) through a standard inverse dynamics approach using only marker, force plate and anthropometric data and (2) to compare OFM ankle joint kinetics to those output by the one-segment foot plugin-gait model (PIG). 10 healthy adolescents fitted with both the OFM and PIG markers performed barefoot comfortable speed walking trials over an instrumented walkway. The maximum ankle power generation was significantly reduced by approximately 40% through OFM calculations compared to PIG estimates ($p<0.001$). This result was not caused by a decrease in OFM computed joint moments, but by a reduction in the angular velocity between the tibia/hindfoot (OFM) compared to the tibia/foot (PIG) ($p<0.001$). Additionally, analysis revealed considerable midfoot loading. One-segment foot models overestimate ankle power, and may also overestimate the contribution of the triceps surae. A multi-segment approach may help quantify the important contribution of the midfoot ligaments and musculature to power generation. We therefore recommend the use of multi-segment foot models to estimate ankle and midfoot kinetics, especially when surgical decision-making is based on the results of three-dimensional gait analysis.

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