

Midfoot and Ankle Gait Kinetics Assessed Using a Single Force Plate

Maxine L. Olson^{1,2,3}, Philip Voglewede¹, Joseph J. Krzak^{2,4}, Steven A. Miller³, Christina M.R. Garman², Gerald F. Harris^{1,2}, Karen M. Kruger^{1,2}

¹Marquette University, Milwaukee WI, ²Shriners Children's Chicago, Chicago IL, ³Rosalind Franklin University of Medicine and Science, North Chicago IL

⁴Midwestern University Physical Therapy Program, Downers Grove IL, E-mail: maxine.olson@rosalindfranklin.edu

Disclosures: The authors have no conflicts of interest to disclose.

INTRODUCTION: Understanding segmental foot kinetics is crucial for providing more appropriate treatments of foot pathologies, identifying and tracking deformities across time, and quantifying outcomes. However, kinetic analysis of gait (i.e., joint moments, power) is typically conducted only at the ankle, knee, and hip joints, neglecting joints within the foot itself. Equipment in a standard gait lab generates a single ground reaction force vector (GRF) when the foot strikes a force plate. This GRF vector is currently insufficient to calculate kinetics at multiple foot joints. While additional instrumentation or procedures (pressure plates and/or multi-plate targeted walking) have been employed to solve this issue, these approaches are not feasible in most gait labs [1-3]. Our novel mathematical force distribution algorithm (mFDA) decomposes the single GRF from a single force plate into hindfoot and forefoot vectors. It is hypothesized that midfoot (forefoot with respect to hindfoot) and ankle (hindfoot with respect to tibia) moments calculated from the mFDA will be found valid when compared to moments calculated from a gold standard RScan pedobarographic pressure plate force distribution.

METHODS: Ten typically developing pediatric subjects gave informed consent and were enrolled in our IRB approved cohort validation study (14.1 ± 2.1 years, 5 female). Bilateral multi-segment foot kinematics were collected using the validated Milwaukee Foot Model (MFM) for shank, hindfoot, forefoot, and hallux segments [4]. A minimum of 5 clean foot strikes per limb were captured for a total of 102 trials. GRF data was simultaneously obtained with an RScan pedobarographic pressure plate overlaid and synced with the AMTI force plate. RScan data was mapped into hindfoot and forefoot segments resulting in respective segment RScan GRF vectors.

Segmented force plate GRF vectors were obtained from our mFDA using custom MATLAB code. Our algorithm calculated hindfoot and forefoot GRF vectors as a function of the location of the center of pressure (COP) and phase of stance. Three phases of stance were defined:

- **Heel Strike:** All GRF was assigned to the hindfoot segment.
- **Foot Flat:** Heel in contact with the ground and the COP located between Boundary 1 (calcaneal markers) and Boundary 2 (metatarsal heads). GRF was divided proportionally between hindfoot and forefoot segments based on the location of the COP with respect to the Boundaries (Fig 1).
- **Heel Off:** All GRF was applied to the forefoot segment until **Toe Off** when GRF was zero.

Angular properties (i.e., speed, acceleration) were calculated with the defined MFM series of kinematic Euler rotations and local coordinate axes. Segmental inertial properties were estimated as elliptical cylinders. Triaxial midfoot and ankle joint moments were calculated with an inverse dynamic approach using Newton-Euler equations [5] and were normalized by mass and time (100% gait cycle). Statistical analyses were performed with statistical parametric mapping (SPM) in R, assessing differences in midfoot and ankle moments calculated from the RScan and algorithm-derived GRF distributions.

RESULTS: Figure 2 illustrates the close match of triplane midfoot and ankle moments computed from the two force distributions. Using $\alpha=0.05$, a familywise error Bonferroni adjusted alpha of $7.8e-4$ was computed. No significant difference was found in coronal or transverse moments. A statistically significant difference was found in 3-8% of gait cycle in the sagittal plane moments at the midfoot and ankle joints.

DISCUSSION: The mFDA provides adequate GRF input for accurate midfoot and ankle moment calculations in all three planes of motion (Fig 2. If only one line is visible, the two lines are overlaid). While there was a statistical difference found between the average moments at 3-8% of gait cycle in midfoot and ankle sagittal planes, this is not necessarily a clinically meaningful difference due to the very small number of frames and maximum average moment difference of only 0.04 Nm/kg. Known limitations include the absence of a shear force distribution with use of the RScan plate and as such shear forces are distributed based on the vertical pressure map. While not yet tested extensively in a clinical population, an equinovarus case subject, using the same data collection and modeling methods, shows minimal moment differences (Fig 3). Future direction involves validating the mFDA on subjects with multiple pathologic foot/ankle conditions so that the mFDA can be implemented to identify and track pathology, inform decision making, and quantify outcomes following intervention.

SIGNIFICANCE/CLINICAL RELEVANCE: Discovery of abnormal joint kinetics within the foot can point medical professionals to appropriate diagnoses and interventions. Development of a force distribution algorithm is the first step in making midfoot kinetic analysis feasible with standard gait lab equipment.

REFERENCES: 1. MacWilliams, B. (2003) Gait & Posture 17(3): 214-224. 2. Saraswat, P. (2010) J Biomech 43(9): 1645-1652. 3. Bruening, D. (2012) Gait & Posture 35(4): 535-540. 4. Kidder, S. (1996) IEEE Trans Rehab Eng 4(1): 25-32. 5. Vaughan, C. (1999) Dynamics of Human Gait.

ACKNOWLEDGMENTS: Shriners Hospital Grant #72002 and OREC (MU/MCW)

