Comparison of Tibiotalar and Subtalar Joint Moments Across Models of Healthy and Pathological Ankles

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Introduction: There are approximately 2 million acute ankle sprains in the United States every year, and up to 60% of patients experience long term disability [1]. Chronic ankle sprains can even lead to painful osteoarthritis that must be treated through surgery. Models and simulations are useful tools for analyzing how injuries or surgeries affect the ankle. However, the utility of current models is limited by the fact that the most widely used ankle models include motion at only the tibiotalar joint; the subtalar joint is "locked" meaning it provides no motion. This is particularly problematic when using inverse dynamic simulations to quantify ankle joint moments. Joint moments define the total moment muscles must generate to create movement. However, the calculated joint moments are sensitive to the underlying joint model. The aim of this study was to examine how different ankle joint models, representing both healthy and pathological states, influence joint moments.

Materials and Methods: A musculoskeletal gait model (OpenSim v. 3.3, Gait2354 [2, 3]) was modified to create three models: the anatomical model had no locked joints to imitate *in vivo* conditions, the pathological model had a locked tibiotalar joint to imitate a common ankle surgery, and the standard model had a locked subtalar joint to imitate a widely used gait model. Inverse kinematics and inverse dynamics were performed using reference gait data describing 2.5 s of walking by a healthy adult [2]. Inverse kinematics used skin-marker data to define joint angles of the tibiotalar and subtalar joints over time for each model. Inverse dynamics used the calculated joint angles and force-plate data to estimate joint moments at the tibiotalar and subtalar joints. Data was normalized to percent gait cycle by identifying heel-strikes from the ground reaction force data. To enable comparison, a transformation matrix was applied in MATLAB to define all output variables relative to an anatomical coordinate system that was equivalent across the three models. Analyses included comparisons of peak joint moments and root mean square error (RMSE) between each model and the standard model. Tibiotalar and subtalar moments were also summed to examine total ankle moment.

Results and Discussion: The tibiotalar dorsiflexion/plantarflexion moment of the standard and anatomical models are almost identical throughout the gait cycle, while the pathological model has a smaller peak magnitude around 75% of the gait cycle (Fig 1A). The fact that the dorsiflexion/ plantarflexion moment is insensitive to the model is further supported by the sum of the tibiotalar and subtalar moments, which shows an RMSE of 0.39 Nm between the standard and anatomical models and an RMSE of 2.51 Nm between the standard and pathological models. In contrast, there is a large range in the peak subtalar inversion/eversion moments across the three models, and each model is at a different percentage of the gait cycle at its maximum point (Fig 1B). This large range, which spans 13.4 Nm, is problematic because it suggests that given the same data each model results in a different conclusion regarding how much torque the ankle muscles must generate during the recorded activity. Thus, even though the tibiotalar joint moments are nearly equal across the three models, if a researcher used any of the models to interpret gait data, the conclusions would be different because of the large difference between subtalar joint moments.

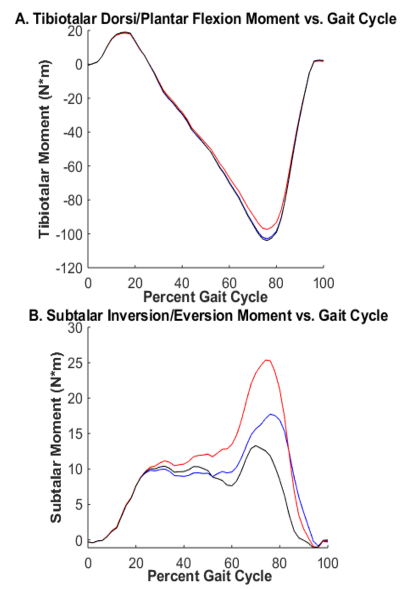

Figure 1: Tibiotalar (A) and subtalar (B) joint moments for the anatomical (black), standard (blue), and pathological (red) models.

Conclusions: This study highlights the importance of modeling both the tibiotalar and subtalar joints when studying ankle biomechanics. Future work will use experimental skin-marker and dual-fluoroscopy data [4] to evaluate the accuracy of each modeling approach for replicating healthy and pathological gait.

References: [1] Waterman et al. 2010. *J. Bone Joint Surg Am.* 92(13):2279-84 [2] Delp et al. 2007. *IEEE Trans Biomed Eng.* 54(11):1940-50 [3] Delp et. al 1990. *IEEE Trans on Biomed Eng*., 37:757-67. [4] Lenz et al. 2018 *ASB Conference Abstract*