EXCLUSION OF THE SUBTALAR JOINT AFFECTS SIGNIFICANTLY THE CALCULATED ANKLE MUSCLE FORCES DURING GAIT.

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INTRODUCTION

In routine clinical gait assessment, the foot segment is often defined as a line segment between a marker on the forefoot and a marker on the heel. Such a 2 D model allows the calculation of dorsi- and plantarflexion movement at the ankle but does not account for movements in the subtalar joint, i.e. inversion and eversion. Consensus exists that for the description of the gait pattern in terms of kinematics and kinetics, a 2D ankle model suffices, especially if no gross foot deformities are present.

Based on the measured kinematics and kinetics, the muscle force contribution underlying the observed gait pattern can be calculated using dynamic simulations of gait, using either an inverse or forward approach. The current work focuses on the question whether exclusion of a subtalar joint significantly alters the muscle force production in the muscles crossing the ankle joint, calculated using an inverse dynamics analysis.

METHODS

Gait kinematics were measured at 250 Hz in 10 adult control subjects, walking at their self-selected walking speed (1.2 ±0.1 m/s) using Vicon system (Oxford Metrics). A modified Cleveland marker placement protocol was used. At the foot, the marker placement protocol was extended to four markers attached to the calcaneus and three markers attached to the forefoot. Ground reaction forces were measured simultaneously using an AMTI force plate.

Kinematics are calculated through an inverse kinematics procedure (SIMM, Motion Analysis Corp) based on a scaled musculoskeletal model, matching the subject's weight and height. Two distinct models were used: The first one (16 DOF) represented the foot as a line segment between the marker on the forefoot and heel. The second model (18 DOF) incorporated the subtalar joint as defined by Inman. In this model, ankle and subtalar kinematics were calculated using the postition of the four markers on the calcaneus and three markers on the forefoot.
For both models, joint moments were calculated for the generalized coordinates in each of the models using SIMM dynamics pipeline.

In a second analysis, muscle force distribution was calculated during stance phase of gait (Matlab). An optimization problem was solved to calculate the muscle moments and hence muscle forces that constitute the external joint moments while minimizing the overall muscle activity. Input were the moment arms and maximal force generating capacity of 43 muscles, given the kinematics of the generalized coordinates during stance. Additional constraints were imposed to the solver to constrain the rate of muscle activation raise and decay within physiological limits and limit the level of maximal activation.

This analysis was repeated for the kinematics and kinetics calculated using the model with a 2D ankle, as well as the model incorporating the subtalar joint axis. To account for the anatomical variation of the subjects in the study population, the muscle force was expressed as a fraction of body weight (Force/BW). Muscle force production profiles were compared with reference data on muscle activation. The differences in the forces of the muscles crossing the ankle joint were compared statistically using a Wilcoxon Signed Rank test.

RESULTS

We found no significant differences in maximal dorsiflexion angle and maximal plantarflexor moment in stance, using both models. The 2D ankle model significantly overestimates maximal plantarflexor power generation (2D:1.53 - 3D:1.39; $p<0.05$), but underestimates maximal plantarflexor power absorption (2D:-0.34 - 3D:-0.55; $p<0.01$).

Figure1 presents the average difference in maximal muscle force production of 12 muscles crossing the ankle, using both models.

The 2D ankle model significantly under-estimates the muscle force production in M. peroneus longus, brevis and tertius, M. tibialis posterior and M. soleus. M. peroneus longus shows the largest difference in maximal force production up to 0.4 BW. M. tibialis posterior and M. Peroneus Brevis differ up to 0.1 BW. Although similar in magnitude, the overestimation of muscle force production for M. tibialis anterior using a 2D model, is not significant. The differences in maximal muscle forces for M. gastrocnemius medialis and lateralis are smaller than 0.1 BW and not statistically significant.

DISCUSSION AND CONLUSION

Estimation of individual muscle force production during gait is crucial in several applications, especially in evaluating the effectiveness of therapeutic interventions. We show that the calculated maximal force production in muscles that provide medio-lateral control of the foot position is significantly under- or overestimated when a 2D ankle model is used. Measurement and modelling of subtalar joint kinematics are crucial for reliable muscle force estimates during gait.

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