

AN EMG-DRIVEN FORWARD SIMULATION OF SINGLE SUPPORT PHASE DURING GAIT

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INTRODUCTION

Simulations based on forward dynamics have been used to study the relationship between joint torques (Kepple et al., 1997), muscle forces (Anderson and Pandy, 2001; Neptune et al., 2001; Thelen and Anderson, 2006) and the resulting movement. In these models, dynamic optimization and a computed muscle control algorithm were used to determine a set of muscle excitations that generate a simulation to best reproduce experimental data. However, these models cannot account for different neural control strategies that may be used by different people, and may have difficulty predicting different muscle recruitment patterns during various tasks. This may be resolved by using electromyography (EMG) as input.

In this report we describe for the first time a forward dynamics model that incorporates an EMG-driven model, and we apply this approach in a pilot study to estimate joint moments, muscle forces and measured kinematics during single support phase of gait.

METHODS

Two healthy young subjects who gave informed consent were included in this study. EMGs, joint positions and force plate data were collected from 4 walking trials. EMGs were collected from the major muscle groups of the right leg (MG, LG, Sol, TA, RF, VM/VL/VI, BFL/BFS, SM/ST) using surface

electrodes. Kinematics of the lower extremity, pelvis and trunk were determined using a Qualysis System. Maximum voluntary contraction trials were collected for normalization of EMG. The subjects were required to strike the force plate using their right feet. In this study we simulated the single support phase of the walking trials.

An inverse dynamics model was developed using SD/FAST (Symbolic Dynamics, Inc., Mountain View, CA). The musculoskeletal model was constructed using SIMM (Motion Lab Systems, Inc., Baton Rouge, LA). It includes 12 segments: femur, tibia/fibula, talus, calcn and toes of both limbs, pelvis, back. Here the back segment includes the mass and inertial properties of the torso, head and arms. This model has 10 DOF in sagittal plane: lumbar rotation, horizontal and vertical position of pelvis, pelvis rotation, hip, knee and ankle extension/flexion of both limbs. Our model solved the equations of motion of the whole body, and was different from the traditional bottom-to-up approach. The measurement of the upper body's movement is relatively inaccurate and may influence the results of our full-body model, so we implemented an optimization algorithm to calibrate the kinematics of the pelvis and back, reducing the residual forces and torques there.

An EMG-driven model (Buchanan et al., 2004) was used to estimate the muscle forces of the right leg to match the calculated inverse dynamic joint moments.

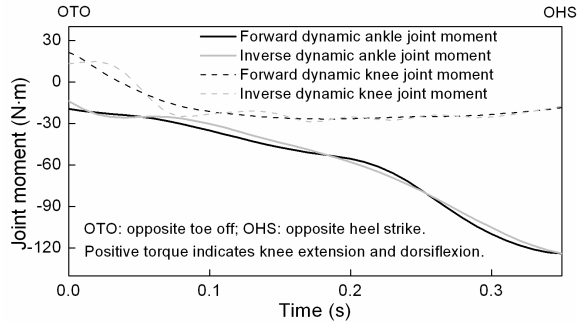


Figure 1. Forward and inverse dynamic right knee and ankle joint moment profile.

The forward dynamics model was developed using the same musculoskeletal model described above. Muscle forces, F_M , calculated from our EMG-driven model were used to drive the model spanning the right ankle and knee joint. For the other joints, the model was driven by the joint torques calculated using inverse dynamics, T_{inv} . The dynamical equations of motion were derived and solved using SD/FAST. We only included hip flexor, RF, and hip extensors, BFL, SM and ST, and did not include the other flexor/extensors and ligaments across the hip, so the right hip joint moment applied to the model was calculated as the term T_{others}^{hip} .

$$T_{others}^{hip} = T_{inv}^{hip} - T_{RF}^{hip} - T_{BFL}^{hip} - T_{SM}^{hip} - T_{ST}^{hip} \quad (1)$$

Ground reaction forces during the simulation were prescribed to the experimental values and a couple of translational and rotational spring-dampers were applied under each foot to account for the variance between calculated kinematics and experimental kinematics (Thelen and Anderson, 2006). The stiffness and damping of the spring-dampers were tuned using dynamic optimization to accurately track the measured kinematics.

RESULTS

The forward dynamic knee and ankle joint moments calculated from the EMG-driven model matched the inverse dynamic joint moments (Figure 1). The calculated right hip,

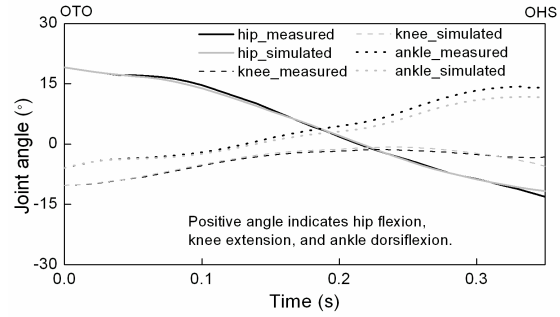


Figure 2. Simulated joint kinematics and measured kinematics.

knee and ankle joint kinematics matched the measured kinematics (Figure 2).

DISCUSSIONS AND SUMMARY

We have developed a forward dynamics model that uses EMGs as input. It successfully tracked measured kinematics during single support phase of gait. It demonstrated for the first time that muscle forces calculated from an EMG-driven model can be used to drive forward modeling of kinematics. This technique has great potential in study of the inter relationships between muscles and the resulting movements in healthy and impaired subjects.

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