SINGLE JOINT VERSUS MULTIPLE JOINT MODELING USING A HYBRID-EMG DRIVEN APPROACH

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INTRODUCTION

When one is interested in modeling the forces in a joint it is tempting to focus only on that joint. The disadvantage of this approach is that it may not provide a sufficiently powerful representation of the way biarticular muscles contribute to single joints. In this study, our previous single joint model was expanded to include multiple joints. Specifically, we compared estimation of ankle joint moments and muscle forces with results from a combined ankle and knee model.

METHODS

The data collection for this preliminary comparison of modeling methods was conducted on a subject with healthy gait. The subject performed gait and maximum voluntary contraction trials. The data collected were kinematics, muscle specific electromyography (EMG), and ground reaction forces. Muscles chosen were the semitendinosus, biceps femoris, rectus femoris, vastus lateralis, vastus medialis about the knee (Lloyd & Besier, 2002), the tibialis anterior and soleus about the ankle, and the gastrocnemii as biarticular muscles that span both the ankle and knee.

After the data collection, we averaged the EMGs from the vasti estimating activation for the vastus intermedius. In addition, EMG for the biceps femoris was assumed to be the same for both the long and short head. EMG data were processed by relieving bias, rectifying, high and low-pass filtering, and finally normalizing by the maximal activation for each muscle. The kinematic data were used to obtain joint angles for the hip, knee, and ankle and subsequently muscle-tendon lengths and muscle moment arms using SIMM. Also, inverse dynamic joint moments were calculated for the knee and ankle from the kinematic data and the ground reaction forces.

Our EMG-driven model is built on a forward dynamic approach using a Hill-type model which includes active, passive, and damping components (Figure 1) (Buchanan et al., 2005). The processed EMG data were passed through a history-dependent recursive filter and then non-linearized to

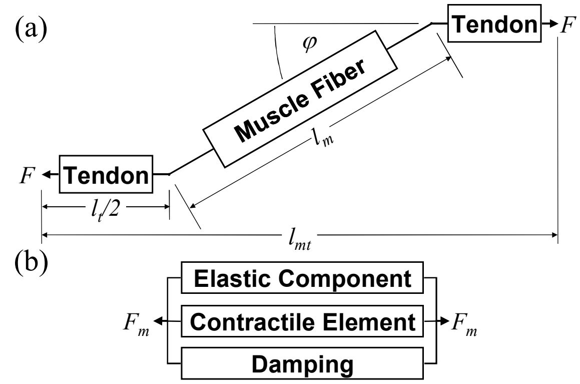

Figure 1: Hill-type model: a) muscle-tendon unit, b) muscle fiber unit. Where F is force, l_t tendon length, l_m muscle fiber length, l_{mt} muscle-tendon length, φ pennation angle, and F_m muscle force.

give muscle activation. The equation relating components of our Hill-type model was integrated to calculate fiber length and tendon length. Tendon force was interpolated from the force-length relationship, which combined with muscle moment arms gave joint moments (Buchanan et al., 2004).

Due to the difficulty of *in vivo* measurement of subject specific muscle parameters, such as tendon slack length, we used a hybrid model. In the tuning process, these parameters were adjusted according to an optimization algorithm (Goffe et al., 1994) using the inverse dynamic joint moments as the standard. Our model was tuned to the ankle and then to the ankle and knee combined for the first trial. The tuned models were then used to predict ankle joint moments for other walking trials.

RESULTS AND DISCUSSION

The model's ability to predict joint moments was consistent between single and multiple joint calibrations (R^2 = 0.97 and 0.96 respectively). RMS values of 7.7% and 8.1% showed a moderate increase in error when the knee was included in the tuning process (Figure 2). The RMS difference between the two predictions was 1.3%, and a 5% reduction in peak error was found by using the multi-joint model. The differences found between our models are seen in the muscle forces. The predictions for the soleus and tibialis anterior varied less than 5% between the two calibrations. On the other hand, the forces were estimated to change up to 20 percent for the gastrocnemii in the combined model.

The study showed consistency in joint moment predictions. More importantly, the deviations in muscle force predictions were more pronounced for the biarticular muscles,

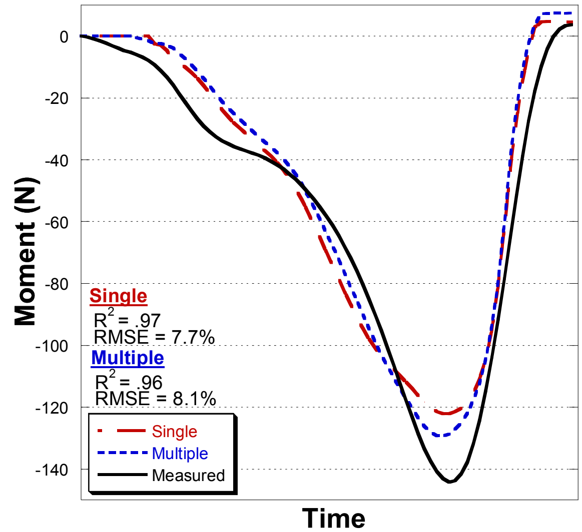

Figure 2: Ankle joint moment comparison

as expected. Single joint modeling of the ankle neglects contributions of the gastrocnemii at the knee. Multiple joint modeling accounts for more complex and physiological kinetics.

CONCLUSIONS

The performance of our multiple joint model was consistent with our previous work. The differences found in muscle force estimation are most likely due to increased physiological accuracy of the model.

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