MUSCLE ACTIVITY AND THE QUANTIFICATION OF CO-CONTRACTION AT THE KNEE DURING WALKING GAIT

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INTRODUCTION

It is commonly agreed that one of the greatest challenges in the study of human motion is the development of accurate, non-invasive methods to calculate individual force-time histories during movement [1]. Furthermore, in the field of medicine it is widely advocated that in surgical decisions for the management of such orthopedic conditions as cerebral palsy, muscle balance must be precisely defined if serious physician-caused errors are to be avoided [2].

It was the purpose, therefore, of this study to construct an EMG-driven neuromusculoskeletal model for the prediction and quantification of co-contraction, i.e., muscle balance and imbalance among the individual musculotendon units that comprise the synergistic and antagonistic muscle groups involved in knee flexion/extension during normal walking gait.

METHODS

The Model

The equations describing the mechanical response of the muscle model were based on Hill's [3] and Zajac's [4] original work, but incorporated individual muscle length, velocity, and excitation considerations for muscle contractions. Processed EMG represented the neural input to the muscle. A musculoskeletal model defining joint kinematics, and line of action and architecture of the musculotendon units of the left lower limb, was developed by modifying a previously introduced model [5], and using a software for interactive musculoskeletal modeling (SIMM).

Muscle kinematics were then calculated using the musculoskeletal model in conjunction with three dimensional cinematography. Individual muscle force as a function of length and level of excitation was also inquired as input to the model, and was established from a series of isokinetic calibration contractions and computer simulations. Co-contraction was measured in the form of a co-contraction index (CCI) using the following relationship:

$$\frac{\sum F^M_{Total}}{\sum F^M_{Agonists}} - 1 = CCI \qquad (1)$$

where $\sum F^M_{Total}$ represents the total muscle force acting at the joint, whereas $\sum F^M_{Agonists}$ represents the total muscle force of the agonist muscle groups. The output of the model was validated using the predicted and measured joint moments.

Experimental Procedures

Individual muscle force profiles were predicted for selected muscles of the left lower limb crossing the knee joint (Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedialis, Biceps Femoris –long head-, Biceps Femoris –short head- Semimembranosis and Semitendinosis, and Gastrocnemius –medial and lateral heads). Muscle activity was monitored using bipolar surface electrodes over the bellies of the afore mentioned muscle groups, except for the Vastus Intermedialis that was monitored as a function of the other two Vasti. The EMG signals were processed and normalized using activity levels collected from maximum voluntary contractions performed during the calibration contractions [6].

Retro reflective markers positioned on specific anatomical landmarks were used to obtain joint kinematics. Ground reaction forces were obtained using one force plate, AMTI (Advanced Medical Technology, Inc. Newton, Massachusetts). Joint kinetics, i.e., joint moments, were obtained using inverse dynamics [7].

Three subjects were tested during their normal walking gait at the Ohio State University Gait Analysis Laboratory. Isokinetic calibration contractions, of knee flexion and extension, were performed on a KinCom isokinetic dynamometer (KinCom, Chattecx Corporation) using eight different joint angular velocity conditions (+/-5, +/-60, +/-120, and +/-190 degrees/sec). To account for the biarticular muscle groups, such as the Gastrocnemius, which crosses both the ankle and the knee joints, the angle at the ankle joint during the calibration contractions was controlled. The angle at the hip was also controlled by having the subject sitting with the back at forty five degrees.

RESULTS AND DISCUSSION

Preliminary results indicate that the knee moment curves, predicted and measured, matched closely in shape (see Figure 1 for an example).

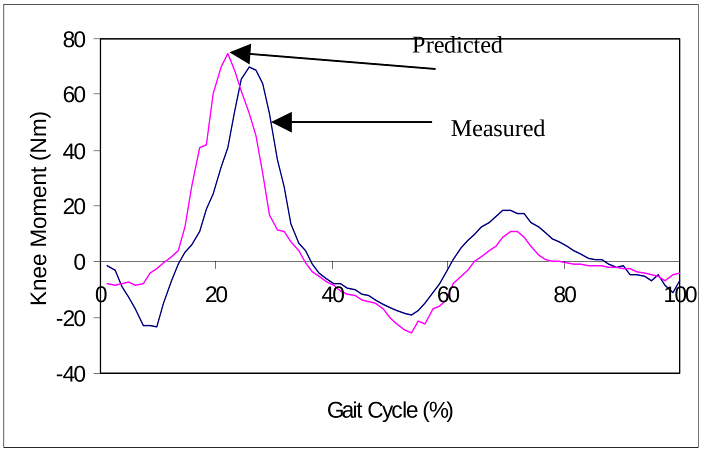

Figure 1. Comparison between the knee joint moment predicted by the EMG-driven model and the one measured from the inverse dynamics.

The correlation between moments derived from the two approaches ranged from r = 0.73 to r = 0.91 for the gait trials. The root mean square (RMS) difference between moment curves over one walking stride ranged between 5.3 N.m and 6.8 N.m at the knee. Expressed as a percentage of the RMS of the moments calculated using the inverse dynamics solution, the differences ranged from 28.3 to 34.6 percent at the knee. The results of this study were, in general, similar or better than those previously reported from similar studies [1].

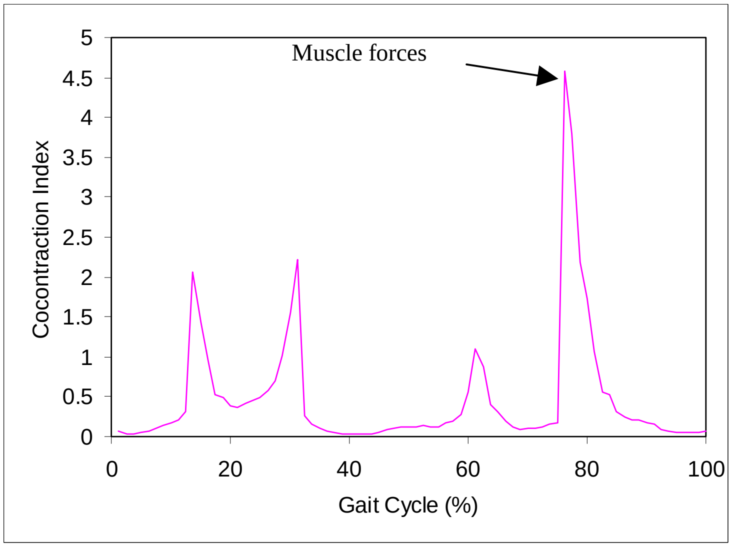

Figure 2. Co-contraction index at the knee during a complete gait cycle based on EMG-driven model the output.

From a qualitative point of view, the timing of co-contraction at the knee is in agreement with previous studies [8]. However, to the best of our knowledge, no other studies in the past have presented the quantification of co-contraction at the knee during walking gait by implementing the estimation of an index, which might allow comparison. Thus, from a functional perspective the results of the model suggest that co-contraction at the knee during gait occurs at the time when stability requirements are the greatest for the joint. Previous studies have demonstrated such a pattern for the ankle joint [9].

While this study is limited by the number of subjects, the nature of the moment curve differences suggests that the present EMG-driven model, even at its infant stages, is essentially correct. However, there is room for improvement. For example, the temporal inconsistencies between the measured and predicted moments can be attributed to a variety of factors, such as the placement of the electrodes [10] or the contribution of the passive structures at the joint. Thus, in the future there maybe the need to better account fro the contribution of passive structures at the joint, while maintaining the simplicity of the model.

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