The Muscular Function for Human Knee Movement Revealed from Electromyography: A Preliminary Study

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Abstract: The electromyography (EMG) of a male teenager performing isokinetic exercise is conducted to realize the characteristics of femoral muscles in human knee movement. The raw EMG data of rectus femoris muscle and biceps femoris muscle are full-wave rectified to demonstrate the electromechanical delay that ranges from 50 to 100 ms. The mean of biceps femoris EMG in isokinetics knee flexion is approximately 3-4 times as much as that of rectus femoris EMG in isokinetics knee extension. The rectified EMG signals are smoothed by using moving average method to receive a linear envelope that outlines the mean trend of EMG signals. It gives a clear perspective to observe the relation between the micro-scale EMG signal and the macro-scale kinetic data. This paper presents an important basis to establish a mechanical model of muscle for human knee movement.

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1. Introduction

Electromyography (EMG) represents the electrical activity of muscle. The study of muscle activity from EMG provides valuable information for the dynamics and control of human movement. The EMG of the muscles during a particular task can indicate which muscles are active and when the muscles initiate and cease. More importantly, the qualitative and quantitative assessments can be obtained from EMG and give an important understanding of the muscular function under tasks and exercises [1].

Piper [2] was the first investigator to study EMG signals. Basmajan and De Luca [3] wrote a milestone reference book to explore the interdisciplinary potential for EMG. Merletti and Parker [4] bridged a gap between engineering and physiology. Lloyd and Besier [5] provided an EMG-driven musculoskeletal model to estimate muscle forces and knee joint moments. Kiguchi and Imada [6] presented a muscle-model-oriented EMG -based control method to activate a lower-limb power-assist robot according to the users motion intention. Sun et al. [7] studied the effects of aging on knee joint movement by comparing the rectus femoris and biceps femoris EMG of different ages in isokinetic and isometric exercise. Yen, Tsai and Chang [8] used integral EMG to investigate muscular performance of applying different vibration and plyometric training.

In this paper, an isokinetic exercise for knee movement is performed by an individual subject. The EMG data of rectus femoris muscle and biceps femoris muscle are recorded. For the stand alone EMG is difficult to interpret, the kinetic data including the angle, angular velocity, and torque of knee are recorded too. By rectification of the raw EMG signal, the electromechanical delay between the onset of muscle and the onset of knee movement is clearly shown. The mean of the rectified EMG data during knee extension and flexion in isokinetic exercise is presented. Finally a linear envelope is determined by moving average method to produce a smooth curve that gives an important understanding of muscle activity for the control of knee movement.

2. Method

The subject is a healthy male teenager, age 15, height 171.1 cm, and weight 65.77 kg. An isokinetic exercise for knee extension and flexion is performed by the subject on the Biodex isokinetic dynamometer at a controlled angular velocity with varying resistance. The functions of isokinetic dynamometer is to isolate a lower limb, stabilize the adjacent segments, and control the speed of knee joint movement, typically in this study at 60°/s.

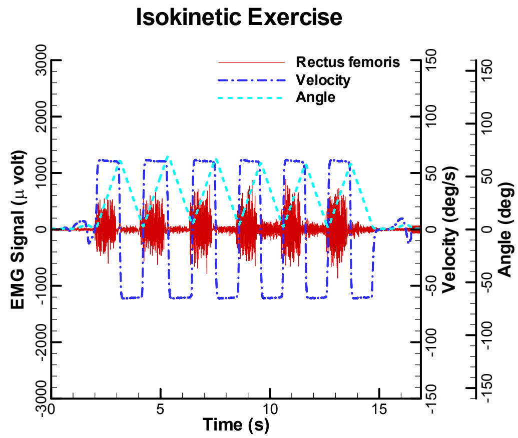
The muscular actions are considered to determine which muscle to be observed. The quadriceps femoris muscle group, the producer of knee extension, consists of the rectus femoris, vastus lateralis, and vastus medialis. Its antagonistic muscle group, hamstrings, contributing to knee flexion consists of the biceps femoris, and semimembranosus, and semitendinosus. Both the rectus femoris producing knee extension and the biceps femoris producing knee flexion are selected for the observation of their EMG signals during knee isokinetic movement.

There are two ways to acquire EMG signal: needle and surface EMG techniques. The needle EMG technique uses fine wire electrodes by inserting the needle into the muscle tissue; however, the surface EMG technique uses the non-invasive skin surface electrode. The former is more suitable for diagnostic applications; the latter has major applications in biofeedback, prosthesis control, and movement analysis. Both are complementary and important tools for physiological research [4]. This study is focused on surface EMG. It needs surface electrodes, amplification, and acquisition to record the EMG signal. The NORAXON TeleMyo 2400T G2 is used to acquire data which includes surface EMG electrode leads with pre-amplifiers (common mode rejection ration > 100 dB, input range ±3.5 mV, gain 500), hardware filter (all surface EMG electrode leads have 1st order high pass filters set to 10 Hz, all channels have low pass anti-alias filters set to 1500 Hz), and transmitter data acquisition system (16-bit resolution, sampling frequency 1500 Hz). The measurement setup, reports generation, and the important signal check procedures including the proof of the EMG signal validity and inspection of the raw EMG-baseline quality are completed in the software environment NORAXON MyoResearch XP [9-11].

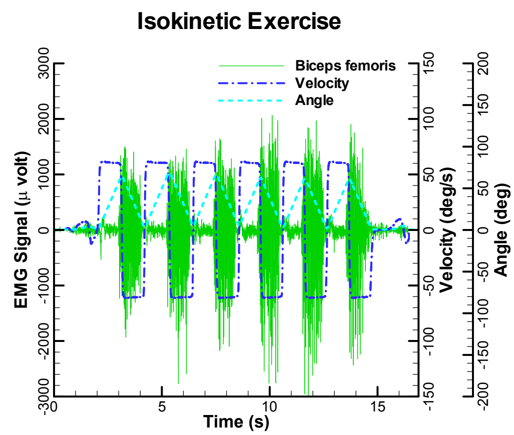
Finally the MathWorks, Inc., MATLAB is applied to signal processing such as full-wave rectification, mean, and moving average smoothing and the Amtec Engineering, Inc., Tecplot is applied to data visualization.

3. Results and Discussion

Fig. 1 presents a global view of the raw EMG of rectus femoris and biceps femoris associated with velocity and angle in isokinetic exercise. In every cycle of knee extension-flexion, the period of positive angular velocity represents extension at the knee and the period of negative angular velocity represents flexion at the knee. A muscle action potential produced by nervous contraction command results in a burst of EMG signal. As shown in Fig. 1 (a), the rectus femoris is activated during knee extension and relaxed during knee flexion. In contrast, as shown in Fig. 1 (b), the biceps femoris is activated during knee flexion and relaxed during knee extension. The EMG clearly indicates muscle activity. The full-wave rectification of EMG signal is shown in Fig. 2 and 3. Rectification is taking the absolute value of the raw EMG signal. The "on-off" characteristic can be derived by setting a threshold of rectified EMG. Let the threshold be 200 μ volt, a short but distinct delay between the onset of rectified EMG signal and the onset of velocity is observed from Fig. 2 and 3. This is referred to as the electromechanical delay (EMD) [1], indicating the transport delay between neural signal input to the muscle and kinematic signal output of the muscle. As shown in Fig. 2 and 3 the EMDs for rectus femoris and biceps femoris are within 100 ms.



(a) Rectus femoris EMG



(b) Biceps femoris EMG

Figure 1. The raw EMG data of rectus femoris muscle and biceps femoris muscle

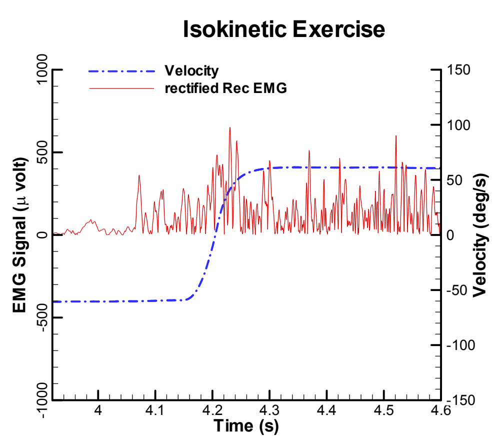


Figure 2. The electromechanical delay in rectus femoris EMG

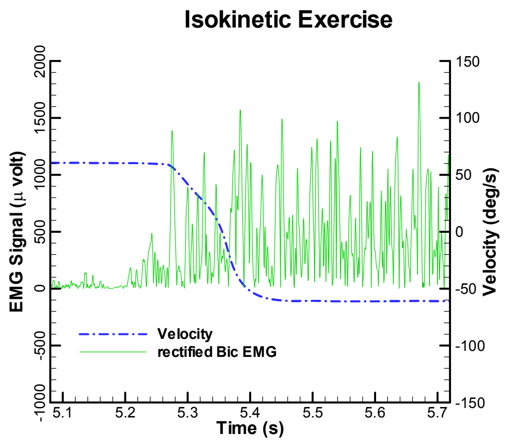


Figure 3. The electromechanical delay in biceps femoris EMG

Fig. 4 presents the mean of rectified EMG signal in isokinetic exercise. The results show that the rectus femoris and biceps femoris are activated by turns. There is no co-activation in knee isokinetic movement. It suggests that the rectus femoris and biceps femoris are sophisticated cooperated with each other to perform the knee extension and flexion smoothly. If a quantitative amplitude is targeted, the mean of rectified biceps femoris EMG signal is as much as 3 to 4 times larger than that of rectified rectus femoris EMG signal.

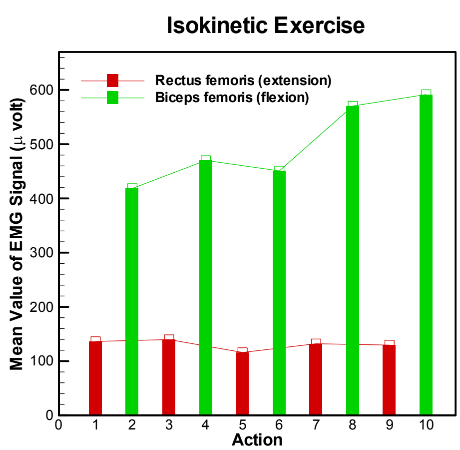


Figure 4. The mean of rectified EMG signal in isokinetic exercise

Fig. 5 and 6 presents the linear envelopes of rectified rectus femoris EMG signal and biceps femoris EMG signal by using moving average method at 100 ms in isokinetic exercise. As the pattern of EMG is of random nature, the EMG cannot be reproduced by a specific shape. In order to increase reliability and validity of findings from EMG signal, the smoothing method is applied to outline the mean trend of EMG signal. The resulting linear envelope provides clear curve characteristics that would be helpful to explore the relationship between kinetics and EMG. In Fig. 5 and 6 the the linear envelopes of EMG signals and torques curves appears a close relation to be revealed.

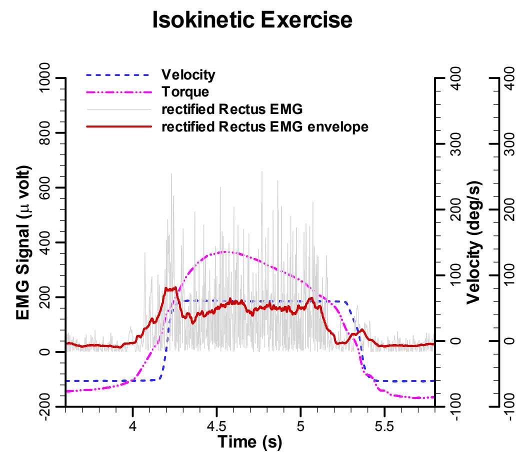


Figure 5. The linear envelope of rectified rectus EMG signal by moving average smoothing

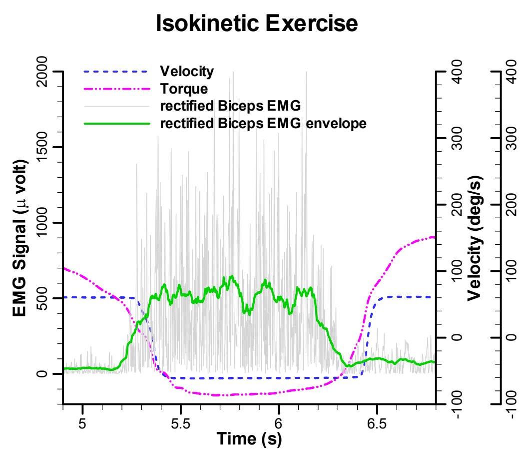


Figure 6. The linear envelope of rectified biceps EMG signal by moving average smoothing

4. Conclusion

This paper presents a preliminary study of knee isokinetic movement from EMG signal. The EMG indicates that the rectus femoris is active in knee extension and the biceps femoris is active in knee flexion. The mean of biceps femoris EMG is about 3 times than that of rectus femoris EMG. The electromechanical delay between rectified EMG signal and kinematic response is observed, ranging from 50 to 100 ms. Finally, The linear envelope by applying moving average method to the rectified EMG signal is obtained. It would be useful for the determination of the relationship between human body kinetics and EMG.

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