IN VIVO BEHAVIOR OF HUMAN MUSCLE DURING ISOMETRIC RAMP CONTRACTION: A SIMULTANEOUS EMG, MMG AND ULTRASONOGRAPHY INVESTIGATION

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ABSTRACT

The purpose of this study was to investigate the electromyography (EMG), mechanomyography (MMG), and the muscle architecture, i.e. cross-sectional area (CSA), amplitude versus torque relationships during voluntary isometric ramp contractions. The ultrasound images, EMG and MMG signals were simultaneously recorded from the rectus femoris (RF) muscle. A novel image processing algorithm was developed to automatically extract cross-sectional area (CSA) from ultrasound images. The root mean square (RMS) amplitudes of the EMG and MMG were computed on adjacent epochs in synchronization with the ultrasound images. Polynomial regression analyses indicated that both EMG and MMG amplitudes increased and CSA decreased curvilinearly with torque increment, and the change fashion of CSA was significantly different from those of EMG and MMG. The results demonstrated that the continuous change of CSA can provide useful information about muscle contractions. It may therefore complement EMG and MMG for studying muscle activation strategies.

Index Terms—ultrasonography, electromyography, mechanomyography, cross-sectional area, isometric contraction

1. INTRODUCTION

In vivo muscle behavior is an important but unsolved problem. Generally, the muscle behavior can be measured using various techniques such as electromyography (EMG), mechanomyography (MMG), and ultrasonography. EMG is composed of electrical contributions made by the active motor units (MUs) during muscle contraction [1]. Meanwhile, MMG is a recording of the low-frequency lateral oscillations of active MUs and is considered to be the mechanical counterpart of the MU electrical activity as measured by EMG [2]. Ultrasonography was traditionally utilized for clinical diagnosis; and recently it has been effectively employed to estimate the morphological changes of muscle during contraction [3, 4]. However, to our knowledge, little work has been conducted to explore the continuous muscle behavior during isometric contraction by simultaneously measuring EMG, MMG and ultrasonography which might provide unique and complementary information of the muscle control strategy from different aspects. The aim of the present study is to examine the dynamic behavior of rectus femoris (RF) muscle during isometric ramp contraction with simultaneous measurement of EMG, MMG and ultrasonography. A novel image processing algorithm was developed to automatically track the morphological parameters from the image sequences continuously. The relationships of EMG, EMG, and CSA versus torque were explored to investigate the muscle control strategy from the aspects of electrical, mechanical and morphological characteristics, respectively.

2. METHODOLOGY

2.1. Experimental procedure

Nine healthy adults volunteered to participate in this study. During measurement, a subject was seated on a test bench of an isokinetic dynamometer, and was secured by straps around the trunk. All isometric torque assessments were performed at a right leg flexion angle of 90◦ between the thigh and leg. The subject was instructed to perform ramp contractions which produced torques increasing linearly from 0 to 90% of his/her maximal voluntary contraction (MVC) at a constant speed. A real-time B-mode ultrasonic scanner was used to obtain transactional ultrasonic images of the RF muscle. The video output of the scanner was digitized by a video capture card with a frame rate of 30 Hz. Two surface bipolar Ag-AgCl EMG electrodes were placed on the RF muscle belly parallel with the long axis of the muscle on both sides of ultrasound probe. The MMG signal was detected by an accelerometer placed near the ultrasound

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probe and fixed to the skin using double adhesive tape. The surface EMG and MMG signals were amplified by a custom-designed amplifier with a gain of 2000, filtered separately by 10-400 Hz, 5-100Hz band-pass analog filters, and digitized by a 12-bit data acquisition card. The isometric torque output from the dynamometer was also sampled in synchronization with the ultrasound image capture. Ultrasound images, surface EMG, MMG and torque signals were simultaneously collected and stored by custom-developed software for further analysis.

2.2. Signal and image processing

The EMG and MMG signals were segmented as 256-ms epochs. The center of each epoch was aligned in time with the corresponding ultrasound image, so that the epochs were synchronized with the image sequence in time domain. The root mean square (RMS) values of EMG and MMG (EMG_{RMS} and MMG_{RMS}) were calculated for each epoch and normalized as a percentage of their maximal values at 90% MVC.

In this study, a novel image processing method, named constrained mutual information (MI)-based free-form deformation (C-MI-FFD) tracking was developed to automatically extract the continuous CSA changes in the ultrasound image sequence. In the proposed C-MI-FFD method, we aim to determine the transformation function which describes the deformation between two successive images by minimizing a MI-based objective function. For accurate matching, the transformation in the C-MI-FFD method is carried out in two steps: 1) the global transformation and 2) the local transformation. In global transformation, the transformation parameters are determined by matching the two images globally so as to model their relative scale, translation and rotation. In the local transformation, the local deformation is defined by a 2D spline function and the transformation parameters are refined as displacement values at a regular grid to interpolate the spline function. To further improve the tracking performance, we incorporate three image structure derived constraints, including smoothing constraint, feature point constraint, and edge constraint, into the MI objective function.

For each trial, the first image in the sequence was selected as reference and the boundary of the RF muscle was outlined with smooth lines by the investigator using ImageJ software. Then the C-MI-FFD method was applied to track the boundaries in the subsequent images.

3. RESULTS

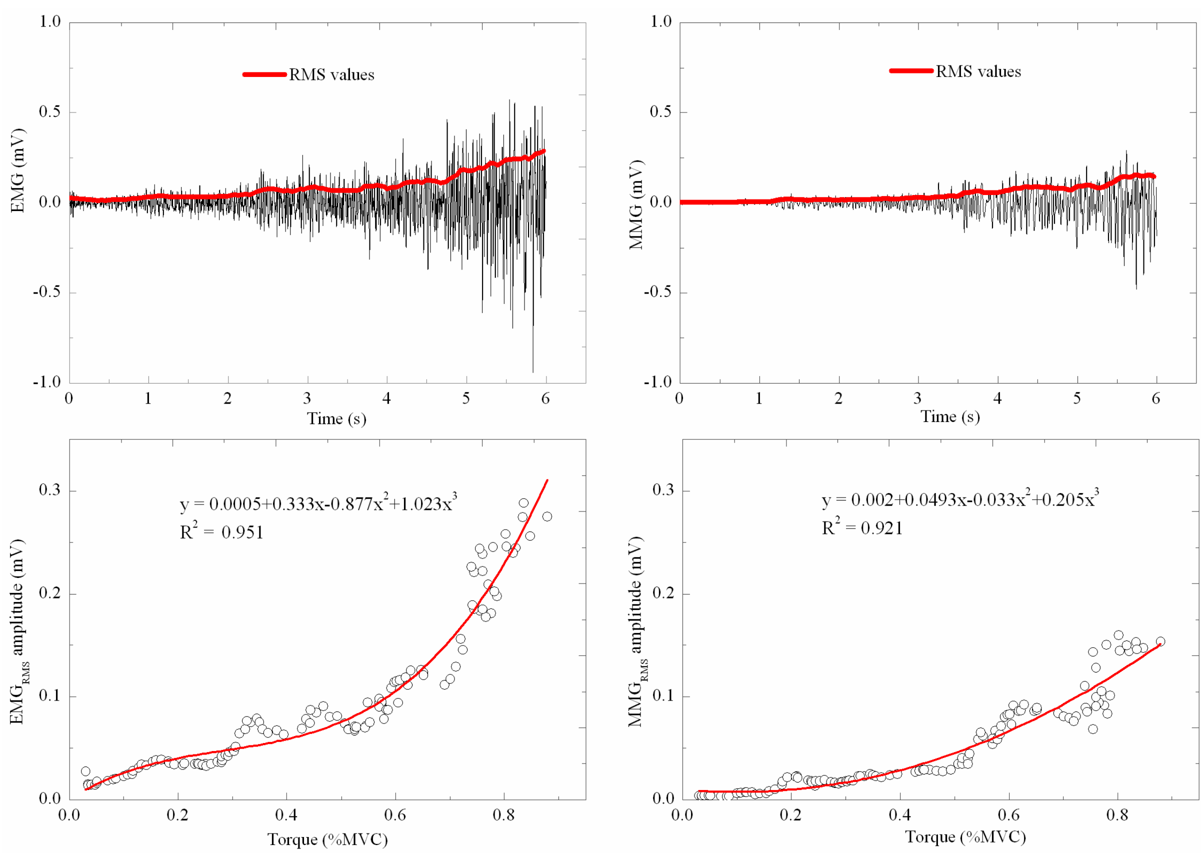


Fig. 1. The time courses of EMG and MMG signals during a representative trial. The relationship between RMS amplitude and torque was examined with polynomial regression analysis.

A typical example of the EMG and MMG signals during one representative ramp contraction is shown in Fig. 1. The relationship between RMS amplitude and torque was examined with polynomial regression analysis and the coefficient of determination R^2 was obtained.

Four images of a typical trial, including the first image, the first image with manually drawn boundary, the image at 50% MVC, and the image at 50% MVC with automatically tracked boundary, are shown in Fig. 2. The neighboring quadriceps muscles (vastus lateralis, vastus intermedius, and vastus medialis) are indicated. The relationship of normalized CSA versus torque in this trial is plotted in Fig. 3.

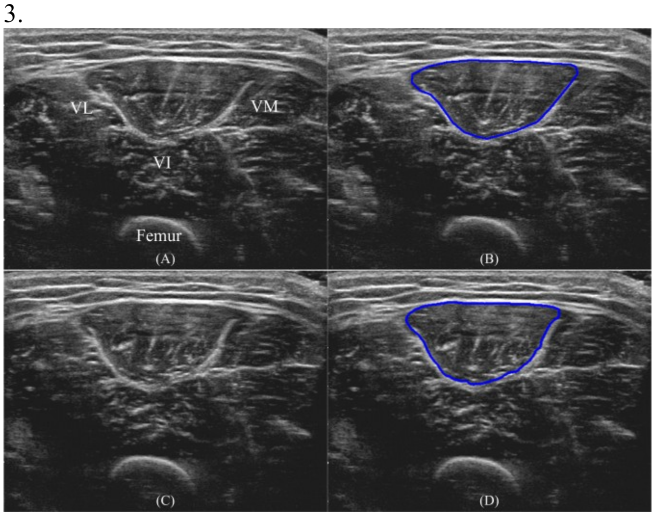


Fig. 2. Ultrasound images of the RF muscle in one trial. (A) The first image in the image sequence. (B) The first image in the image sequence, with manually outlined boundary as reference for further image processing. (C) The image at 50% MVC. (D) The image at 50% MVC, with automatically outlined boundary by the proposed C-MI-FFD algorithm.

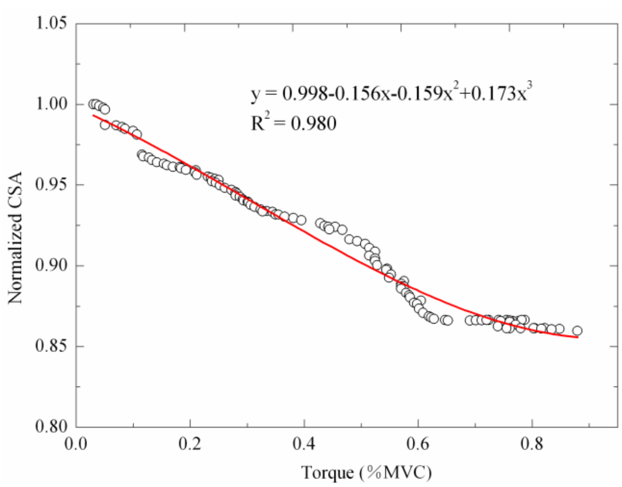


Fig. 3. The relationship of normalized CSA versus torque.

For all the subjects, the inter-individual means of the normalized EMG, MMG and CSA amplitudes are presented as a function of torque in Fig. 4. The circles are the mean values, and the gray area indicates the standard error. The composite relationships were investigated using polynomial regression. The solid lines are the regression curves.

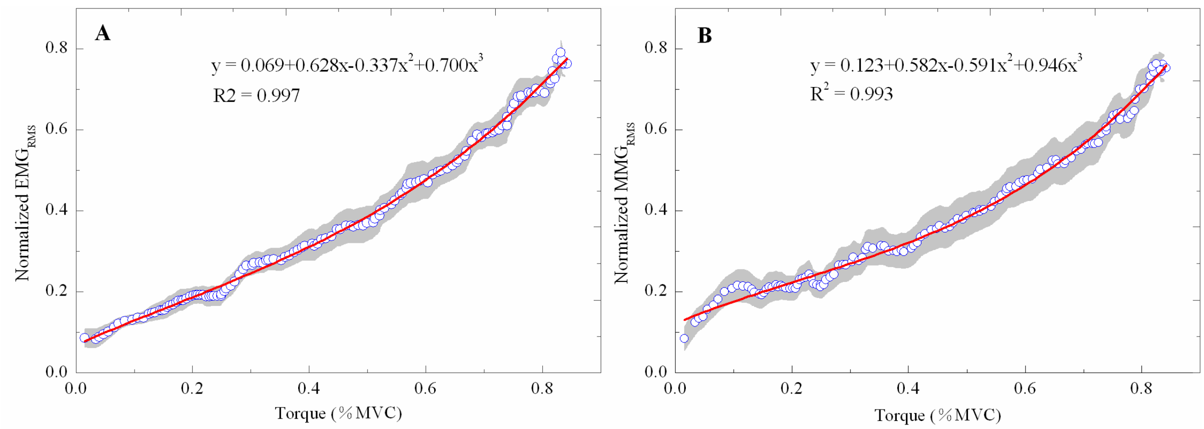
4. DISCUSSION

In this study, we collected ultrasound images, EMG, MMG and torque signals simultaneously for the RF muscle during isometric ramp contraction. The purpose is to characterize the nature of the relationships between morphological changes, EMG and MMG features of the RF muscle with increasing torque during contraction and hopefully to investigate the motor control strategy of ramp contraction with respect to morphological, mechanical and electrical characteristics.

EMG and MMG can provide indirect assessment of the electrical and mechanical activities of muscle. Previous studies have investigated the amplitude responses of EMG and MMG during isometric ramp and step muscle actions in the biceps brachii muscle [5], quadriceps femoris muscle group [6], and muscles of hand [7]. The findings indicated that the torque-related patterns of responses for EMG and MMG were different among subjects and were muscle and mode (ramp vs. step) specific.

On the other hand, studies have shown that muscle functions, such as the amplitude of force produced, are closely related to architectural characteristics of CSA [8]. Due to its ability of real-time imaging, ultrasonography is suitable to detect the dynamic muscle contraction. However, all the studies using ultrasonography approach measured the CSA values at separate contraction conditions by manually outlining the muscle boundary [9]. This manual operation can not handle the huge amount of images obtained in continuous condition. In this study, we developed an image processing algorithm to automatically extract the continuous CSA change of RF muscle during isometric ramp contraction. In the present study, the CSA of the RF muscle decreased with increasing torques, suggesting that the RF muscle was actively involved in isometric torque development.

The curvilinear fashion of CSA decrease is different from those of EMG and MMG (Fig. 4). This phenomenon might be explained by the mechanical aspect of muscle contraction which involves changes in muscle length and interaction between muscle and tendon. Compared with previous studies, the automatic tracking method in the present study has great advantages in the research on the dynamic muscle contraction because it may provide more information about the muscle contraction strategy from the morphological aspect of view.



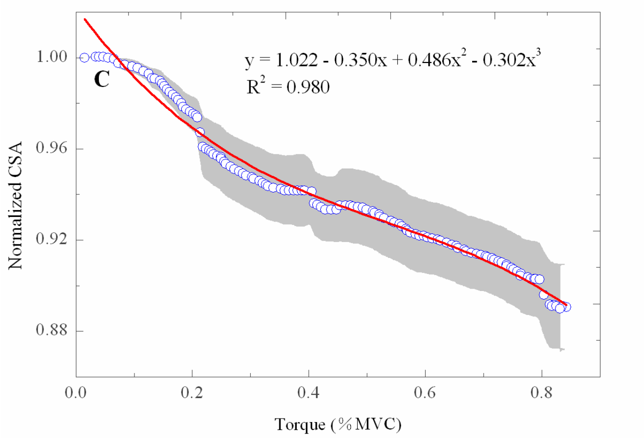


Fig. 4. The inter-individual means of the normalized EMG, MMG and CSA amplitudes are presented as a function of torque. The composite relationships were investigated using polynomial regression.

In conclusion, the ultrasonography, EMG and MMG recordings during isometric contraction revealed their respective nonlinear relationships with torque from different aspects. How to combine the three recordings should be further investigated for better understanding of the muscle control strategy.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Zhang ZG, Liu HT, Chan SC, Luk KDK, and Hu Y, "Time-dependent power spectral density estimation of surface electromyography during isometric muscle contraction: Methods and comparisons", *J Electromyogr Kinesiol* 20: 89-101, 2010.

[2] Orizio C, "Muscle sound: bases for the introduction of a mechanomyographic signal in muscle studies", *Crit Rev Biomed Eng* 21: 201-243, 1993.

[3] Fukunaga T, Kubo K, Kawakami Y, Fukashiro S, Kanehisa H, Maganaris CN, "In vivo behaviour of human muscle tendon during walking", *P Roy Soc Lond B Bio* 268: 229-233, 2001.

[4] Hodges PW, Pengel LHM, Herbert RD, Gandevia SC, "Measurement of muscle contraction with ultrasound imaging", *Muscle Nerve* 27: 682-692, 2003.

[5] Beck TW, Housh TJ, Johnson GO, Weir JP, Cramer JT, Coburn JW, Malek MH, "Mechanomyographic and electromyographic time and frequency domain responses during submaximal to maximal isokinetic muscle actions of the biceps brachii", *Eur J Appl Physiol* 92: 352-359, 2004.

[6] Ryan ED, Cramer JT, Egan AD, Hartman MJ, Herda TJ , "Time and frequency domain responses of the mechanomyogram and electromyogram during isometric ramp contractions: A comparison of the short-time Fourier and continuous wavelet transforms", *J Electromyogr Kinesiol* 18: 54-67, 2008.

[7] Esposito F, Limonta E, Ce E, Gobbo M, Veicsteinas A, Orizio C, "Electrical and mechanical response of finger flexor muscles during voluntary isometric contractions in elite rock-climbers", *Eur J Appl Physiol* 105: 81-92, 2009.

[8] Lieber RL, Friden J, "Functional and clinical significance of skeletal muscle architecture", *Muscle Nerve* 23: 1647-1666, 2000.

[9] Delaney S, Worsley P, Warner M, Taylor M, Stokes M, "Assessing Contractile Ability of the Quadriceps Muscle Using Ultrasound Imaging", *Muscle Nerve* 42: 530-538, 2010.