Detecting Displacement of Innervation Zone of Biceps Brachii Muscle due to Joint Angle Changes

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Introduction

EMG is a record of motor unit action potentials originating and spreading along muscle fiber bilaterally from an innervation zone (IZ) which is a cluster of end plates across muscle fibers. The EMG wave forms are symmetrical with respect to IZ; thus the position of IZ can be estimated from analysis of EMG wave forms (Masuda et al 1985). So far, estimated IZ position has only been utilized for correct detection of EMG signals. In the present study, we estimated IZ position in vivo, using multi-channel electrode arrays, and quantified its displacement due to joint angle changes. Because IZ is located in the middle of muscle fibers, we hypothesized that displacement of IZ reflects shortening of muscle fibers.

Methods

Healthy 8 male volunteers, aged 19-30, participated in this study. The subject was seated comfortably and performed elbow flexions at the maximal level (MVC) and 70% MVC, for 2-3 s, three times, at four different joint angles: 10, 30, 50, and at 70 deg (0=full extension). All data were analyzed for 1 s, when the torque was apparently stable.

Thirteen-channel electrode arrays, with an inter-electrode distance of 5 mm, were used to detect the surface EMG signals. The boundary between the short and long heads of biceps brachii muscle was palpated, and the electrodes were placed along the short head near the boundary. Surface EMG signals and joint torque were simultaneously digitized at 5000Hz. The frequency bandwidth was 10-3000 Hz.

The estimation of the displacements of IZ was done, using the method first described by Kaneko et al (1996) with multi-channel EMG. Following this method, we formulated the simultaneous equations related to the position of IZ, conduction velocity, the transition distance, and the time delay and, computed a series of time delay of all combination of EMG signals between electrodes to estimate the position of IZ. The equations were solved by using the generalized weighed least-squares method in each calculation window. Median value of the distribution was adopted as representative of each trial, since estimated series of IZ were distributed like in Fig. 1. To remove the effects of artifacts, the mean values of three trials were used for analysis.

For comparison between subjects, IZ values were normalized to the individual length of the upper arm and to the IZ values obtained for 50% MVC trials at 10 deg. Two way repeated ANOVA and Fisher’s multiple comparisons were used for statistical analysis.

Fig. 1 : Typical examples of time course of the displacement IZ and histogram for two elbow angles. This subject showed maximal change of IZ displacement ( Left: 70%MVC, 10deg. Right : 70%MVC, 70deg)
Results
The position of IZ from the reference displacement shifted significantly as a function of elbow angles and muscle contraction levels. Fig. 2 illustrates the mean values of all subjects. The IZ position at 50% MVC was located at distal 35.5 ± 5.1 % of the upper arm length. The relative IZ position shifted by 0.7% (10deg), 1.3% (30deg), 2.4% (50deg), and 5.2% (70deg) for 70%MVC, and 1.2% (10deg), 2.1% (30deg), 3.7% (50deg), and 6.3% (70deg) for MVC, respectively. The IZ positions changed proximally due to elbow flexion. Significant differences were observed in almost all angle joint combinations (except for 10deg v.s.30 deg). The displacements of IZ at 70%MVC were significantly different from those at MVC.

Discussion
So far estimation of IZ using this method has only been applied at weak contraction levels for detection of EMG signals. (Kaneko et al. 1996) It has been reported that distortion of EMG signals during high intensity contractions is not negligible. The present study used a series of simultaneous equations which resulted in extremely small coefficient of variations (0.62-1.51 %), suggesting repeatability of this method.

The IZ shifted proximally at higher muscle contraction levels, which is probably due to internal shortening of muscle fibers at the expense of tendon elongation.

We estimated the whole muscle length changes due to joint angle changes for comparison with the present results. The length change of biceps brachii muscle was calculated by following equation (An et al.1984).

\[ ma = \frac{\partial l}{\partial \phi} \]  

(1)

Where \( ma \) is moment arm of biceps brachii muscle, \( \frac{\partial l}{\partial \phi} \) is the partial derivation of the muscle-tendon length. Here we assumed the other variables than \( l \) and \( \phi \) are constant, therefore the equation (1) can be linearised as

\[ \Delta l = ma \times \Delta \phi \]  

(2)

Where \( \Delta l \) is the change of muscle-tendon length, \( \Delta \phi \) is the change of elbow joint angle. The \( ma \) were derived from a previous model (Murray et al. 1995).
Fig. 3 illustrates the result, with the change of IZ displacement from the 10deg trial at same contraction level. The change of the displacement of IZ position was approximately a half of the predicted length change of the whole biceps muscle, which might be attributed to the position of IZ (center of muscle fibers). However, a difference existed between different contraction levels, which would be due to different amount of tendon elongation, as stated above.

Unlike many other studies that have derived information on muscle activity from surface electromyography, the present study took a novel approach to derive anatomical information of muscle from EMG. Employment of additional techniques (e.g. electrical stimulation and scanning technique such as ultrasonography) would further add to the understanding of structure and function of human skeletal muscles in vivo.

**References**


