A Study for Conducting Waves by Using the Multi-channel Surface EMG

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Abstract. The surface electromyogram (EMG) is recorded as the interference electric potential generated by motor units in muscle. Therefore, it may be possible to analyze the muscle contraction mechanism in order to examine the composition of the interference signal of the surface EMG. We herein propose a new method by which to analyze the composition of the surface EMG. The proposed method involves searching conducting wave which mean similar waveforms considered same wave appearing during several channels by using multi-channel surface EMG, and we can analyze surface EMG as a set of conducting waves. The proposed method is referred to as the multi-channel method for conducting waves (m-ch method). We analyzed multi-channel EMG using the proposed method.

Keywords: EMG, surface EMG, MFCV, motor unit.

1 Introduction

Muscular activity is investigated by analyzing the action potential in muscle fiber, primarily in the field of clinical medicine [1] and [2]. The conduction velocity of potentials, i.e., the muscle fiber conduction velocity (MFCV), is measured by needle electrodes, and recent studies have measured the MFCV by surface electromyography rather than using needles because surface electromyography is a non-invasive technique [3]. The surface electromyogram (EMG) is mainly used to analyze the frequency and amplitude of EMG signals [4]. The conducting velocity is calculated based on the average response to a pair of EMGs and the delay time of these added signals [5] and [6].

Surface EMG is recorded as an interference wave of action potential that is generated by some of motor units in muscle. If composition of the interference wave can be analyzed, we may be able to examine the mechanism of muscular contraction, for example activity of motor units.

On the other hand, previous studies have analyzed multi-channel surface EMG, which is measured from multiple electrodes arranged in a line [7], [8], and [9]. These studies examined waves considered to be caused from motor units and examined the change of waves by conducting to search similar waveforms from surface EMG of

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several channels [7], [8], and [9]. However, to judge which waveform we should examine is subjective and time consuming. Therefore, we herein proposed a new method for analyzing multi-channel surface EMG in order to examine the mechanism of muscle activity. The proposed method involves dividing the surface EMG into zero-crossing sections comparing the waveforms quantitatively section by section. Conducting waves are similar waveforms that appear in several channels and are considered to be the same wave. We can examine various data, including the conducting velocity and the amplitude of each conducting wave, over multiple channels. We refer to the proposed method as the multi-channel method for conducting waves (m-ch method). We used the m-ch method to analyze conducting waves from multi-channel EMG.

2 Experiment

We performed a number of experiments in order to obtain data for the analysis (Fig. 1). We measured the multi-channel surface EMG by electrodes aligned along the surface of the biceps brachii muscle of each subject. The electrodes were made of silver and were 1 mm in diameter and 10 mm in length. The distance between electrodes was 5 mm. We placed the electrode on the belly of muscle so that the major axis of the electrode was aligned with the muscular fibers. We used 17 electrodes and measured 16-ch EMG from each electrode interval by using bipolar law. For 16-ch EMG, 1 ch is set to the shoulder side and 16ch is set to the elbow side.

We used amplifiers with a high cut of 1 kHz and a low cut of 5 Hz. The amplifiers had an amplification rate of 80 dB and a sampling frequency of 5 kHz. The EMGs were recorded on a PC. The number of subjects was five and the subjects were all males in their 20s. The subject kept his elbow joint at a 90-degree angle while seated, and his maximum muscular strength was measured (100% MVC). The subject then held four loads (10%, 20%, 30%, and 40% MVC) with the same posture for 15 s. The subject held the same load three times, for a total of 12 trials. The order of the trails was random, and the subjects took one-minute breaks between trials.

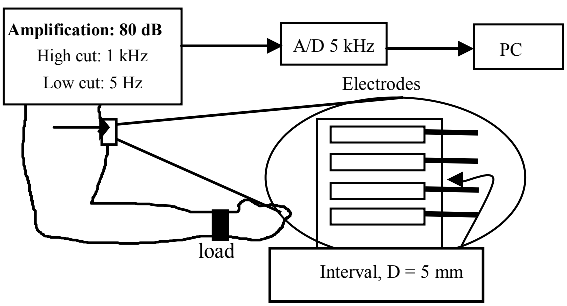

Fig. 1. Experimental system

3 Method

We developed the m-ch method in order to analyze multi-channel surface EMG by examining conducting waves. In order to obtain conducting waves, we first divided EMG signals in sections between points of electrical potential crossing zero from minus to plus (Fig. 2). For each section, we search other sections which appear nearby in time (within 10 ms) in the adjacent channel, and compare the waveforms to examine their similarity. Since these sections have different wavelengths, the coefficient of correlation cannot be calculated between sections. As such, sections are calculated a re-sampling to restore the analog signals, in pseudo-simulated Eq. (1).

$$x_a(t) = \sum_{k=-\infty}^{+\infty} x_a(k\Delta t) \cdot \frac{\sin\left[\frac{\pi}{\Delta t}(t-k\Delta t)\right]}{\frac{\pi}{\Delta t}(t-k\Delta t)} \tag{1}$$

where Δt is the sampling interval, xa(kΔt) are the sampling data, and xa(t) are pseudo-analog data restored from the sampling data.

In order to perform re-sampling, we analyze sections with any sampling frequency (Fig. 2). After re-sampling, the coefficient of correlation is calculated for the two sections in order to determine the similarity of the waveforms. In this study, we refer to the value of the coefficient of correlation of sections as the similarity ratio. The similarity ratio is used in a conducting condition to judge to be a conducting wave and is obtained as follows:

$$R_{xy} = \max[\gamma_{xy}(\tau)]$$
$$\gamma_{xy}(\tau) = \frac{\{\phi_{xy}(\tau) - m_x m_y\}}{\sqrt{\{\phi_x(0) - m_x{}^2\}\{\phi_y(0) - m_y{}^2\}}} \tag{2}$$

where Rxy is the similarity ratio, mx and my are the averages of potential of each zero-crossing section, φx and φy are the autocorrelation coefficients, andφxy is the cross-correlation coefficient.

The denominator of γxy in Eq. (2) is the amplitude of each section. However, the difference in amplitude cannot be examined through this calculation. Then, the amplitude ratio for one conducting condition is calculates as follows:

$$G_{xy} = \frac{\sqrt{\{\phi_x(0) - m_x{}^2\}}}{\sqrt{\{\phi_y(0) - m_y{}^2\}}} \tag{3}$$

The wavelength ratio is also needed for a conducting condition for judging wavelength similarity:

$$L_{xy} = \frac{L_x}{L_y} \tag{4}$$

where Lx and Ly are the wavelengths of each section.

In order to judge to be a conducting wave based on the similarity of waves, we set thresholds for the conducting conditions for the similarity ratio, the amplitude ratio, and the wavelength ratio. If a pair of sections satisfies the conducting conditions, these sections are considered to represent a conducting wave, i.e., the same wave is considered to appear in two channels.

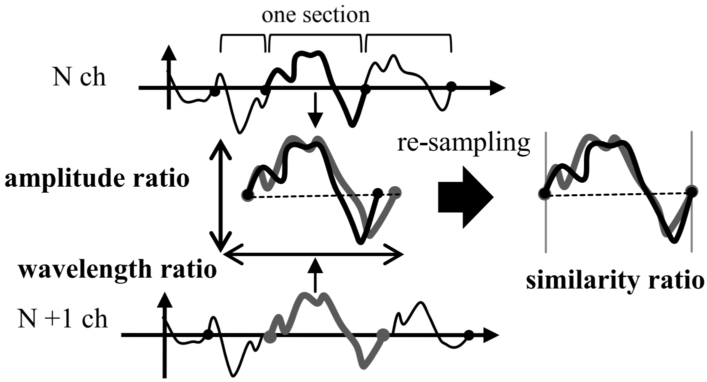

Fig. 2. Judging sections to be a conducting wave

The m-ch method involves the comparison of zero-crossing sections. So to apply this method to a section repeatedly in adjacent channel, we can get conducting wave appearing in multiple channels (Fig. 3). Moreover, we can analyze the change of a wave in conducting process to examine sections considered a same conducting wave in each channel.

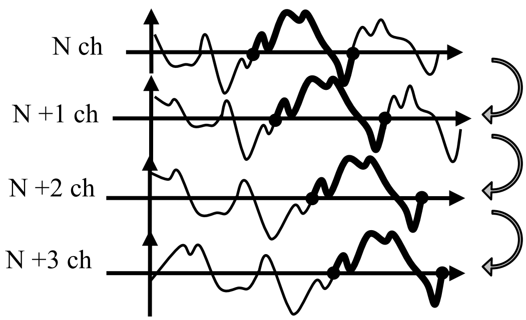

Fig. 3. Conducting wave in multiple channels

The conduction velocity is calculated by dividing the distance between the electrodes by the delay time of the conducting wave, as follows:

$$v_{xy} = \frac{D}{\frac{1}{2}(\Delta t_1 + \Delta t_2)} \quad (5)$$

where vxy is the conduction velocity, and D is the distance between the electrodes. In order to calculate the delay time of the waves, sections are divided at the midpoint.

In a section of next cannel, we set a dividing point. We calculate the coefficient of correlation between first half of each section, and the coefficient of correlation between each last half. We move the dividing point and calculate them to search the point where the average of two value of the coefficient of correlation is highest. When we find such dividing point, we calculate delay time of midpoint of each part of section (Δt1, Δt2). The average of these delay time is then considered to be the delay time of the waves (Fig. 4).

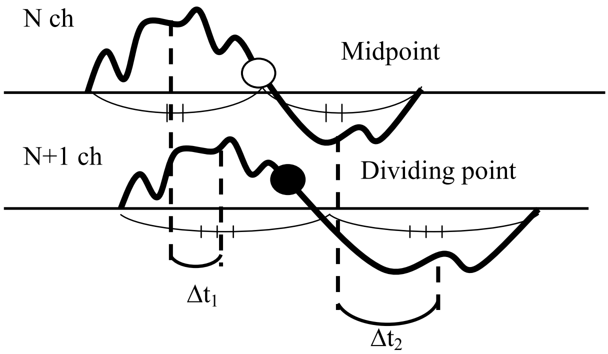

Fig. 4. Calculation of the conduction velocity

To use this method, we can get conducting waves appearing in multiple channels. Then, we add the number of conducting channels as a condition of wave to analyze.

When analyzing waves in more than three channels, there is the possibility that noise is included in sections which considered a conducting wave. Some of this noise will satisfy the conducting conditions but the delay time is too small. This noise appears to originate from a commercial power supply or electrical noise. Moreover, this noise has an abnormally fast conduction velocity. In order to counteract this noise, we calculate the variation index of the conduction velocity as calculated by each channel and add this index as a conducting condition.

4 Results and Discussion

4.1 Comparison of Methods

We compared the results obtained using the m-ch method and results obtained by the averaged response. In order to perform the m-ch method, we set thresholds of the conducting conditions: the similarity ratio, the amplitude ratio, and the wavelength ratio. We set the values of these three conditions to over 0.9. Moreover, we examined two-channel conducting waves in order to compare with the result using the averaged response. In order to calculate EMGs the averaged response, we set an electric potential threshold to search addition sections and set time width of the section.

The part of EMG from the point which electric potential exceed the threshold is considered to be an addition section. All addition sections are calculated the averaged response and we consider the result as an added wave. In the EMG of the next channel, the same time sections are calculated the averaged response as the added wave of this channel.

We compared two added waves in order to calculate the maximum value of the coefficient of correlation for each of the waves. The velocity was calculated based on the time lag of the starting points of the two waves when the coefficient of correlation was the highest. In the present study, we set the electric potential threshold to twice the RMS value of the EMG data and set the time period of the added section to 1 s.

The results obtained using the averaged response is shown as one value of velocity from two EMG data. In contrast, the result using the m-ch method is shown as many conducting waves. Each wave contains data such as conduction velocity, amplitude, wavelength, and number of conducting channels. Thus, we can analyze EMG in greater detail.

Figure 5 shows the distribution map for the amplitude and conduction velocity of the conducting waves appearing in a pair of channels, the velocity calculated using the synchronization addition is shown as a dotted line.

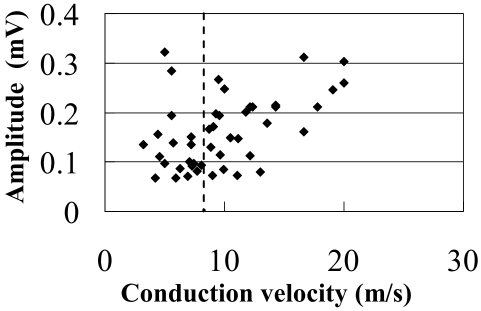

Fig. 5. Results of two methods (Sub1, ch 7-8, 20% MVC)

The velocity which calculated by using the averaged response is affected by the value of threshold and time width of the adding section, so the value of velocity is vague. The conducting waves obtained by the m-ch method have various velocities, which appears to indicate the existence of elements which caused by each muscular fiber.

We should examine these elements using conducting waves in order to clarify the mechanism of muscle activity.

4.2 Difference in Muscle Activity for Different Loads

We analyzed the difference in muscle activity for different loads in order to examine conducting waves using the m-ch method. In this analysis, in consideration of the conducting wave having a bigger change of the amplitude during channels than wavelength and waveform, we set the conducting conditions as follows: similarity ratio and wavelength ratio > 0.9, amplitude ratio > 0.7. We examined four-channel conducting waves in order to obtain more reliable results, as compared to two-channel conducting waves. We set the variation index of the conduction velocity to be less than 10%.

In order to examine the amplitude of the conducting waves for each load compared with 100% MVC, we calculated the relative amplitude as a ratio normalized with respect to the amplitude of the wave for 100% MVC.

We compared the conducting waves obtained by the EMG when the subject held each load. The relative amplitude versus the conduction velocity of the conducting wave is shown for two loads, 10% MVC and 40% MVC, in Figs. 6 and 7, which show the four-channel conducting waves from all channels for the two subjects.

In the case of 40% MVC load for both subjects, conducting waves having large relative amplitude increased from the case of 10% EMG load.

Examining the conduction velocity in the case of 40% EMG load, conducting waves having large velocity increased from the case of 10% EMG load in subject A. However,_Subject B did not should such as significant a difference.

We think the difference of the distribution map of conducting waves show the effects of working muscular fiber and recruitment of motor units.

The increase in relative amplitude is thought to be caused by the change in the interference with recruitment of motor units resulting from a change of working muscle. As more waves interfere with each other, the amplitude increases. As such, the change in amplitude appears to be caused by the working of motor units.

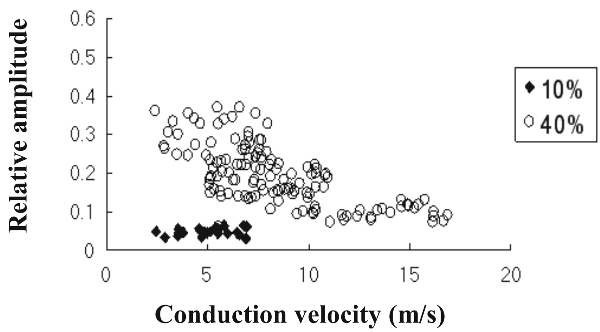

Fig. 6. Difference in conducting waves according to load (Sub A)

We believe the difference in the change of conduction velocity was caused by the effect of working muscle fiber. High-velocity waves are thought to be caused by fast muscles, and low-velocity wave are thought to be caused by slow muscles. Since the

10% MVC load did not require a great deal of power, slow muscles worked harder. In contrast, the 40% MVC load required fast muscles to work harder, generating high-velocity waves. The difference in velocity between subjects appears to indicate a difference in the composition of the muscular fiber. Specifically, compared to Subject B, Subject A appears to have more fast muscle or to need to use fast muscle more in the case of the 40% MVC load.

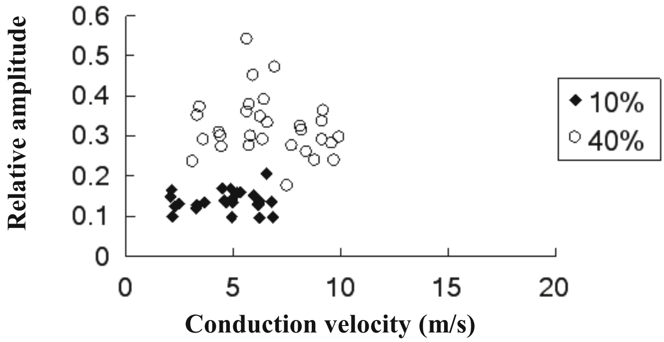

Fig. 7. Difference in conducting waves according to load (Sub B)

5 Conclusions

We proposed a new method of analyzing multi-channel surface EMG. Using the proposed method, we were able to find numerous conducting waves in EMGs and were able to examine these EMGs in detail. Analyzing the composition of conducting waves, we think that we can examine mechanism of the activity of muscle for example recruitment of working motor units and composition of muscular fiber. We analyzed differences in conducting waves generated by different loads. We believe that the proposed method can be used to analyze changes in EMGs caused by muscle fatigue or movement, for example. In the future, the results obtained by the proposed method should be compared with results obtained by another method of analyzing muscle activity.

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