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EMG-based Detection of Muscle Fatigue During Low-Level Isometric Contraction: Effects of Electrode Configuration and Blood Flow Restriction

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Abstract—**This study assessed muscle fatigue during low-level contraction, which is sometimes difficult to observe. Surface EMG signals were recorded with monopolar and bipolar configurations during low-level isometric muscle contraction under a blood flow restriction condition (BFR condition) and a non-blood flow restriction condition (CON condition). As indices of fatigue, center frequency (CF) of the power spectral density (PSD) of the surface EMG and rating of perceived exertion (RPE) with the Borg CR-10 Scale were used. Results suggested that the monopolar configuration, which has a wider detection area relative than the bipolar one, was well suited for obtaining wave slowing accompanied by muscle fatigue. In addition, the monopolar configuration could detect differences in muscle condition in the BFR and CON conditions.**

I. Introduction

MEASUREMENT of surface EMG signal is usually performed with the bipolar (single differential) configuration, which records the potential difference between the two electrodes arranged on the skin surface of the active muscle. However, since not only propagating potentials but also non-propagating potentials arise in the active muscle, it is difficult with the bipolar configuration to record non-propagating potentials. This means that the amount of information obtained from the surface EMG measured with the bipolar configuration may be insufficient. If the distance between the two electrodes is set relatively long, the entire activity of the target muscle can be obtained, although the wave shape of the surface EMG is planarized [1], [2].

It is our belief that the bipolar configuration is inadequate for measurement of wave slowing caused by muscle fatigue during low-level contraction. Since the monopolar configuration, the simplest configuration, has a wide detection area and flat frequency characteristics, the amount of information from the surface EMG is increased and wave slowing can be clearly observed, if noise can be minimized [3]–[5].

It has been reported that even during low-level contraction, on condition of special environments such as nosebleed territory environment where oxygen is thin, pain and/or fatigue is experienced within a small amount of time. This implies that artificially decreasing muscle blood flow is useful for detecting muscle fatigue during a low-level contraction, which is normally difficult to observe [6]–[8].

This study measured the surface EMG signal by means of monopolar and bipolar configurations during low-level isometric contraction in a blood flow restriction condition (BFR condition) and non-blood flow restriction condition (CON condition), and compared and evaluated their differences in detection of muscle fatigue.

II. Experimental Methods

Surface EMG signals were recorded with monopolar and bipolar configurations during a low-level isometric muscle contraction under BFR and CON conditions. Subjects did the exercise while watching their own surface EMG signals displayed on a monitor, that is, visual feedback was adopted. In addition, to evaluate subjective fatigue quantitatively during exercise, rating of perceived exertion (RPE) was confirmed using the Borg CR-10 Scale every 1 min [9].

The subjects were 4 healthy male adults in their twenties. They were informed of the content and risk of the experiment in advance and gave written consent to voluntarily participate in the experiments. Surface EMG was obtained from the long head of the biceps brachii muscle, which functions as a supinator muscle of a forearm. Each subject was seated comfortably with his dominant upper arm fixed perpendicular to the body trunk with his forearm supinated and his elbow extended. Preliminary experiments confirmed that the exercise intensity in the experiment corresponds to about 20 % of maximum voluntary contraction (MVC). Duration of the exercise was set at 8 min. During the exercise, each subject was instructed not to move the body trunk and spine. Each subject repeated the above exercise three times under each of the BFR and CON conditions, in order to ensure sufficient signals and obtain unbiased measurements.

In the BFR condition, forearm blood flow was restricted by placing a pneumatic cuff (aneroid sphygmomanometer, Q9917, YAMASU) on the upper arm at a pressure of 200 mmHg. The restriction was maintained for 5 min. Even after the restriction was discontinued, the exercise was continued for another 3 min.

Active electrodes (material: gold, shape: disc, diameter: 14 mm, AP-C300, DIGITEX LAB.) were used as recording, ground and reference electrodes. In the monopolar configuration, the recording, ground and reference electrodes were placed over the muscle belly mid-portion of the long

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head of the biceps brachii muscle, the wrist, and the elbow, respectively. In the bipolar configuration, the recording electrodes were placed over the same muscle parallel to the longitudinal axis of the muscle fiber. The recording electrodes were fixed so as not to sandwich the neuromuscular junction with them. The electrodes in bipolar configuration had a center-to-center spacing of 20 mm. The surface EMG signals recorded by the recording electrodes were sampled at 1000 Hz using a built-in A-D converter in a biological signal recording apparatus (PolymateII AP216, DIGITEX LAB.). To eliminate noise content in the surface EMG signal after A-D conversion, the signal was filtered between 10 Hz and 500 Hz (band-pass) and also between 49 Hz and 51 Hz (band-stop).

III. DATA ANALYSIS

In this analysis, the surface EMG data from each 8 min contraction was segmented nearly equally into noncontiguous 56 epochs. Each epoch was analyzed, and was comprised of 8192 points (8.192 sec). The power spectral density (PSD) was estimated from each epoch using a Hanning window and fast fourier transform (FFT), and the center frequency (CF) was computed. Next, for each 8 min contraction, the values of CF were normalized against the starting value, which was assumed to be 100 %. Finally, in each condition, geometrically averaged values of corresponding epochs were obtained. In addition, geometrically averaged values of RPE were computed every 1 min.

Statistical analysis was performed as follows. Values are presented as means±SE. Prior to the significance test, the normality of the data was checked with the two-sided Jarque-Bera test with a significance level of 0.05. The normality criteria were met. Therefore, the two-sided one-sample t-test (parametric method) with a significance level of 0.05 was employed. All statistical analyses were performed with dedicated software (Ekuseru-Toukei 2010, Social Survey Research Information). The targets of comparison of significance testing are shown below.

Comparisons of CF in each experimental condition

(a)BFR-monopolar condition vs. BFR-bipolar condition

(b)CON-monopolar condition vs. CON-bipolar condition

(c)BFR-monopolar condition vs. CON-monopolar condition

(d)BFR-bipolar condition vs. CON-bipolar condition

Comparison of RPE in each experimental condition

(e)BFR condition vs. CON condition

IV. RESULTS

Figure 1 shows CF values for the BFR-monopolar and BFR-bipolar conditions. Both CFs decreased during the BFR condition but did not change markedly during the CON condition. At the switching point between the BFR and CON conditions, both CFs appeared to increase in synchrony. The CF of the BFR-monopolar condition was below that of the BFR-bipolar condition from 40 sec, except at 7 min 30 sec ($P<0.05$ or $P<0.01$). Figure 2 shows CF values for the CON-monopolar and CON-bipolar conditions. Both CFs decreased nearly throughout the exercise. The CF of the CON-monopolar condition was below that of the CON-bipolar condition around 2 min and from 3 min 20 sec almost continuously ($P<0.05$ or $P<0.01$).

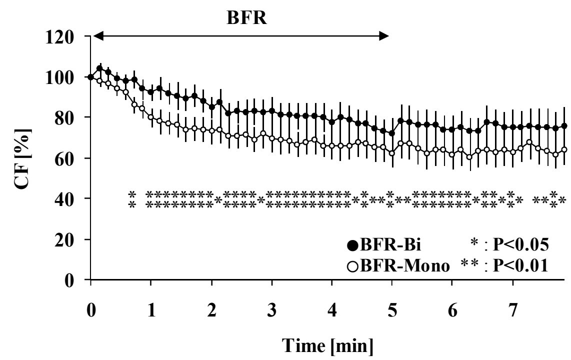

Fig. 1. Changes in center frequency (CF) in the BFR-monopolar and BFR-bipolar conditions. CF is normalized to its initial value. Values are means±SE (standard error) of 12 samples.

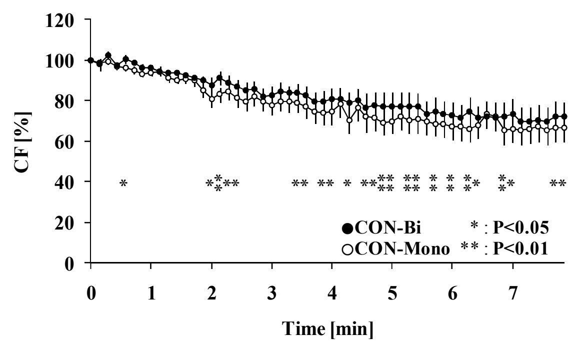

Fig. 2. Changes in CF in the CON-monopolar and CON-bipolar conditions. CF is normalized to its initial value. Values are means±SE of 12 samples.

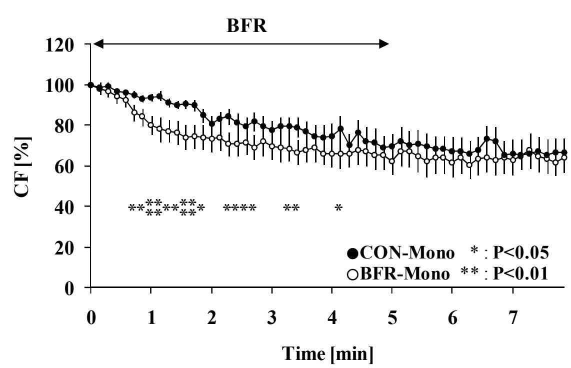

Fig. 3. Changes in CF in the BFR-monopolar and CON-monopolar conditions. CF is normalized to its initial value. Values are means±SE of 12 samples.

Figure 3 shows CF values for the BFR-monopolar and CON-monopolar conditions. The CF of the BFR-monopolar condition was below that of the CON-bipolar condition from 40 sec to 2 min 50 sec almost continuously ($P<0.05$ or $P<0.01$). Figure 4 shows CF values for the BFR-bipolar and CON-bipolar conditions. There was no significant difference between the CFs of these two conditions. Figure 5 shows RPE values for the BFR and CON conditions. Both RPEs increased throughout the exercise. RPE of the BFR condition was above that of the CON condition from 1 min, except at 7 min (P<0.05 or P<0.01).

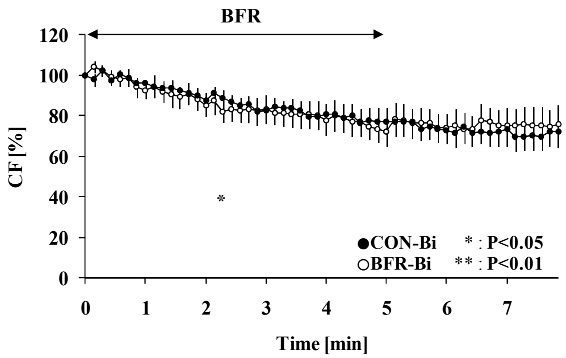

Fig. 4. Changes in CF in the BFR-bipolar and CON-bipolar conditions. CF is normalized to its initial value. Values are means±SE of 12 samples.

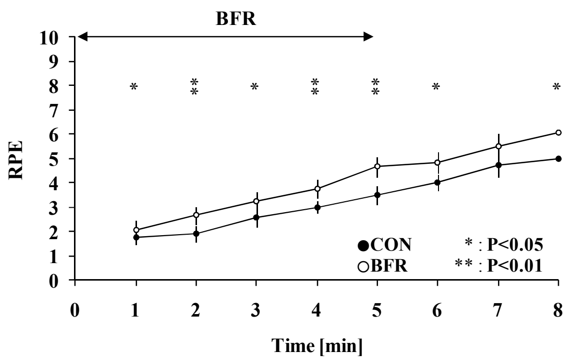

Fig. 5. Changes in rating of perceived exertion (RPE) on the BFR and CON conditions. Values are means±SE of 12 samples.

V. Discussion

As indicated in Figs. 1 and 2, CF values of the monopolar configuration were significant lower than those of the bipolar configuration in both BFR and CON conditions. The difference in the BFR condition was particularly pronounced. The monopolar configuration thus appears to be a more effective means of detecting muscle fatigue than the bipolar configuration [3]–[5].

As displayed in Figs. 3 and 4, under the monopolar configuration, there was a significant difference between the BFR and CON conditions, specifically in the relatively early stage, although there was not with the bipolar configuration. The subjects felt more fatigue from the beginning in the BFR condition, as shown in Fig. 5. This means that muscle fatigue progressed faster than in the CON condition. It is known that fast muscle fibers, which function only minimally during low-level contraction, are also recruited under the BFR condition, and fast muscle fibers are fatigable compared to slow ones. This recruitment is due to intracellular pH shift by metabolic products of energy metabolism [10], [11]. We therefore speculate that the results shown in Figs. 3 and 5 reflect such a condition of active muscle. It is possible that the monopolar configuration is capable of detecting the muscle condition variation induced by BFR [12].

VI. Conclusion

Our findings suggest that the monopolar configuration, which has a wider detection area than the bipolar configuration, is well suited to detection of wave slowing accompanied by muscle fatigue. In addition, the effect of BFR could also be detected with the monopolar configuration. To determine the effects of BFR on the surface EMG during fatiguing exercise from various perspectives, the authors intend to measure muscle oxidative metabolism using near-infrared spectroscopy (NIRS) during BFR and CON conditions.

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