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Electromyographic Evaluation of Muscle Recovery After Isometric Fatigue

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Abstract—**Despite growing interest in the behavior of electromyographic signals during muscle fatigue, few studies investigate fatigue recovery. In this work, we use surface electromyographic signals to determine the recovery time after isometric fatigue of the biceps brachii muscle in 90° flexion of the non-dominant elbow. Sixty volunteers were arranged into six experimental groups. Experiments were performed in three stages: reference phase (REF), fatigue resistance phase (RES), and recovery phase (REC). An isometric exercise was performed during the RES stage. The time interval between the RES and REC stages was different for each experimental group: 1, 2, 4, 8, 24 and 48 hours. Surface electromyographic signals were acquired during each phase, and the following electromyographic variables were calculated for each phase: median frequency (MDF), root mean squared (RMS) value, and maximum voluntary contraction (MVC). The REF data were compared with the REC data using a paired Wilcoxon test. The results show that the MVC is recovered 2 hours after the exercise. The MDF seems not to be fully recovered after 48 hours, but displays an apparent recovery trend.**

I. Introduction

Muscle fatigue may be studied in two stages: (a) resistance (RES), i.e. constant load sustentation; and (b) muscle recovery (REC), i.e. a return of the muscle state back to its initial stage of reference (REF) [1]. The complete process may be studied by analysis of the surface electromyographic (EMG) signal [2], [3], [4]. Knowledge regarding the duration of the REC phase is important in many areas of knowledge. In physiological studies, for example, the REC period is the minimum appropriated interval between two experiments that involve muscle fatigue [5]. EMG studies disagree with respect to the duration of the REC phase, suggesting periods in the range of minutes, hours, or even days [6] [7] [8]. This lack of consensus is enhanced when additional variables, such as metabolic parameters, are evaluated [9]. These discrepancies may be explained by the different experimental protocols adopted by different groups [9].

This work addresses the following questions. Is it possible to estimate the duration of the REC phase? Is there a relationship between mechanical and electrophysiological variables during the REC phase that would allow measuring the duration of the REC phase? Do mechanical and electrophysiological variables indicate the same REC phase duration? The aim of this work is to evaluate the values of electromyographic and mechanical variables from the REF and REC phases in order to estimate the duration of the muscle fatigue recovery period.

II. Materials and Methods

A. Subjects

The study involved 60 healthy men with age ranging from 19 to 33 years (26 ± 2 years), 79.53 ± 3.71 kg weight, 177.89 ± 6.57 cm height and 36.61 ± 2.75 cm non-dominant arm perimeter. All volunteers had been practicing weight training for at least six months (4.66 ± 1.33 years of training). Subjects did not present symptoms of neuromuscular disorders or ligament problems, and were not using anti-inflammatory medication or muscle relaxants. Written informed consent was obtained from all subjects prior to inclusion. Each subject answered an individual questionnaire, which was followed by an Edinburgh handedness inventory.

B. Experimental protocol

The study was conducted in accordance with the declaration of Helsinki and the experimental protocol was approved by the research ethics committee of the University of Brasília (School of Medicine, process no. 007/2006).

During signal acquisition, the volunteers stayed in orthostatic position, with the foot of the contralateral leg positioned in front of the equipment (Fig. 1). The biceps brachii (BB) muscle sustained a 90° isometric contraction of elbow flexion, with the forearm in supine position, and flexed fingers in a hand grip. The force was monitored by a SS25L strain gauge hand dynamometer (Biopac Systems Inc, USA). Three measurements of maximum voluntary contraction (MVC) were performed. The MVC duration was 4.5 seconds in average, and the interval between measurements was 3 minutes. Prior to each MVC, subjects were encouraged to exceed the previous force value. Visual

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force biofeedback was given by computer monitor (with a distance of 1.3 m from the subject). The force signal was acquired with an amplifier circuit with 1000-fold of gain and an A/D converter with a 500 Hz sampling frequency.

Experiments were performed in three stages: reference phase (REF), fatigue resistance phase (RES), and recovery phase (REC). During the REF and REC phases, the EMG signal was measured without any load and also during a 20% MVC contraction, with 1 min duration each. During the RES phase, muscle fatigue was achieved with a 60% MVC isometric exercise until the subject failed to maintain the prescribed load (i.e., exhaustion). All measurements were performed during isometric contraction of the non-dominant BB, and were prepared by the same researcher.

Subjects were randomly allocated into six 10-subject groups. For each group, the time interval between the RES and REC phases was different: 1, 2, 4, 8, 24 and 48 hours.

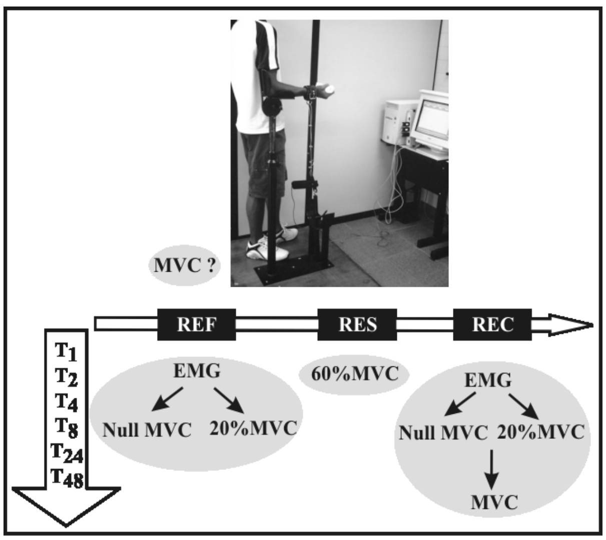

Fig. 1. Experimental Protocol. (Adapted by Peixoto[10]).

C. Electromyographic signal acquisition

EMG signals were measured on the long head BB muscle. Signals were acquired using passive bipolar Ag/AgCl circular electrodes with gel and hydrogel adhesives (Kendall, MedTrace, New York, USA), with 36 mm of total diameter and a 10 mm diameter for the signal pickup area.

The interelectrode distance was 20 mm. Surface electrodes were applied following appropriate skin preparation to reduce interelectrode impedance to less than 30 kΩ. Impedance was monitored using a digital meter. Electrodes were placed on the BB according to SENIAM recommendations [9]. Subjects in groups T_1, T_2 and T_4 did not have their electrodes removed until after the REC phase. Subjects in groups T_8, T_{24} and T_{48} had their electrodes removed and discarded after the RES phase. The electrode locations were marked with dermatographic pen, and new electrodes were applied for the REC phase experiment. Cables were taped down in order to avoid motion artifacts.

EMG signals were acquired using an MP30 data acquisition system (Biopac Systems Inc, Santa Barbara, CA, USA) and BSL Pro software version 3.6.5 (Biopac Systems Inc, Santa Barbara, CA, USA). The sampling frequency was 2500 Hz, the passband was 30–500 Hz, and the amplification gain was 2500. The signal-to-noise ratio was measured without load to verify the quality of the measured signal. The recorded signals were saved on a computer and transferred to dedicated software packages for off-line processing and analysis.

D. EMG signal processing

Segmentation of the raw signals was performed in the BSL Pro software. The segmented signals were processed in Matlab 6.5 (Mathworks Inc., South Natick, MA, USA), in which the root mean squared (RMS) value of the signal and the median frequency (MDF) of the signal's power spectrum were calculated [11]. The power spectrum was calculated using 1-second Hamming sliding windows with 0.5-second overlap, according to Welch's sub-windowing method [12]. The mean MDF and RMS values calculated from the first 34 seconds of each signal. This was the minimum contraction duration achieved by the volunteers. The MDF and RMS values were normalized based on the corresponding MVC percentages sustained during the experimental protocol.

E. Data Analysis

The electrophysiological variables (MDF and RMS) measured for each group during the REC phase were compared to the REF phase measurements. The goal is to identify which groups achieved full recovery of these variables after the fatiguing exercise, i.e. a return to the reference conditions. Since different time intervals were used between the RES and REC phases of each group, this analysis should provide an indication of the duration of the muscle recovery period.

F. Statistical analysis

The Statistica 7.0 software (Statistica 7.0, Statsoft, Tulsa, U.S.A.) was used for the statistical analyses. Data dispersion was analyzed using the Shapiro-Wilk W test. The paired Wilcoxon test was used to evaluate the difference between the REF and REC variables from each group. The group was assumed to have recovered from the exercise if no significant difference was observed between the two phases.

III. RESULTS AND DISCUSSION

A total of 83 volunteers were considered for this study. However, only 60 volunteers concluded all the phases of the experiment. The other 13 volunteers were dismissed because they did not satisfactorily meet the research criteria: 7 volunteers were dismissed after the RES phase because the expected increase in RMS value and decrease in MDF (indicating fatigue) was not observed during the 60% MVC exercise; and 3 volunteers abandoned the study before the REC phase.

Fig. 2 shows the mean and standard deviation values for MDF, RMS and MVC, measured for each group during the REF and REC phases. Table I shows the results of the paired Wilcoxon tests.

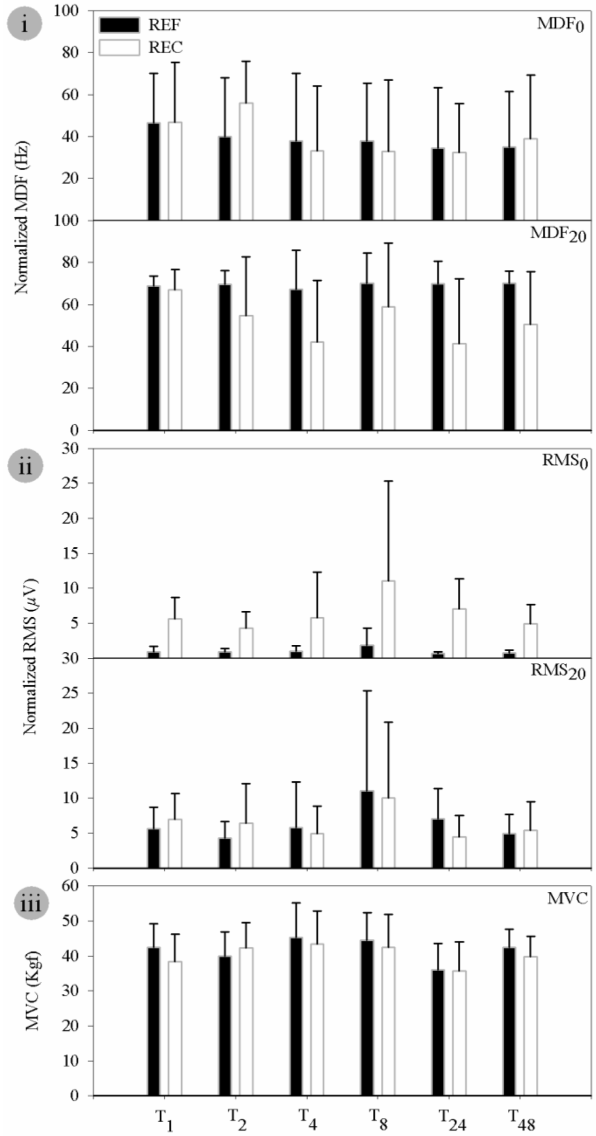

Fig.2. Comparison between mean reference (black bars) and recovery (white bars) values of (i) MDF (at 0 and 20% MVC), (ii) RMS (at 0 and 20% MVC), and (iii) MVC, for each group (10 subjects per group). Ti denotes a group with i hours between the fatiguing exercise and the estimation of recovery values. Error bars indicate standard deviation (95% confidence).

A. MDF

We expected the REF values to be similar for all groups. However, this was not observed with 0% MVC (Fig. 2i, top row). One possible explanation for this unexpected behavior is the influence of the low load used in this protocol. The MDF value is influenced by the number of recruited muscle fibers and by the firing rate and synchronism. Thus, MDF variability is higher in low load protocols.

Table I

Paired Wilcoxon test confidence level: REF vs. REC

Group	REF *vs.* REC				
	MDF_0	MDF_{20}	RMS_0	RMS_{20}	MVC
T_1	0.445	0.575	0.005**	0.139	0.047*
T_2	0.139	0.214	0.005**	0.314	0.445
T_4	0.767	0.037*	0.005**	0.333	0.074
T_8	0.508	0.575	0.013*	0.386	0.332
T_{24}	0.878	0.013*	0.005**	0.007**	0.721
T_{48}	0.508	0.017*	0.005**	0.952	0.059

T*i* denotes a group with *i* hours between the fatiguing exercise and the estimation of the recovery values. n=10; *p<0.05; ** p<0.01.

With 20% MVC, the REF values were similar for all groups, as expected (Fig. 2i, bottom row). The results of the paired Wilcoxon test (Table I) show that the REC values were significantly different from the REF values for groups T4 (p=0.037), T24 (p=0.013) and T48 (p=0.017), suggesting that the muscle fibers were not fully recovered from fatigue after 48 hours.

B. RMS

With 0% MVC, the REF values were similar for all groups, as expected (Fig. 2ii, top row). The data from the T_8 group showed higher mean and standard deviation. The REC data were consistently higher than the REF values, with statistically significant difference (p<0.05). REF and REC data show similar trends. The same conclusions may be drawn from the results with 20% MVC, except that no significant differences were observed between REF and REC results. These results suggest that the RMS value is not a good indicator of muscle fatigue recovery, which is in agreement with the literature [13], [14].

C. MVC

The REF results for the MVC variable were as expected: the differences between the groups and each group's standard deviation were high, which is associated to the differences between the individuals. This is because the experiment is characterized by a situation of extreme effort. Statistically significant differences between the REF and REC results were observed only for group T_1 (p = 0.047), i.e., one hour after the exercise, the mean MVC was lower than before the exercise. With more than 1 hour of recovery, the individuals were able to produce the same MVC that was produced in the REF stage. This suggests that the MVC could be an indicator of muscle fatigue recovery.

D. Fatigue recovery indicators

While the MDF20 results suggested that full recovery was not achieved after 48 hours of rest, the MVC results suggested that recovery was achieved after only 1 hour. This inconsistence may be one of the causes for the divergences found in the literature [13], [6], [15].

The results also show that electromyographic variables measured at 0% MVC were not good indicators of fatigue recovery. This is in agreement with the current literature [4], [16], [17]. At 20% MVC, the MDF variable seems to provide a good estimate of fatigue recovery. For more conclusive results, the experiment should be repeated with rest intervals longer than 48 hours, in order to determine the total fatigue recovery period. As future work, these variables could also be investigated at loads higher than 20%.

IV. CONCLUSION

The results based solely on mechanical values (MVC) suggest that fatigue recovery was achieved after 2 hours of rest. However, an electromyographic analysis based on the MDF variable suggests that fatigue recovery was not achieved after 48 hours of rest. The RMS value of the electromyographic signal does not seem to provide reliable indication of fatigue recovery.

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