Changes in Force Development and Electromyographic Activity in the Muscle Fatigue Induced by Sustained Maximal Plantar Flexion

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Abstract

In an attempt to evaluate central and peripheral contributions to muscle fatigue, changes in force development and electromyographic (EMG) signal after sustained isometric plantar flexion (IPF) were examined. Sustained IPF of maximal effort was continued until the contraction force was reduced to values of 50% of maximum voluntary contraction (MVC). Maximal IPFs of 3 s durations were done before (pre-IPF) and after (post-IPF) the sustained IPF. Post IPF was done by immediately finished sustained IPF. The contraction force and the EMG signals of the gastrocnemius in pre- and post-IPFs were measured, and the rate of force development (RFD) and the rate of EMG signal development (RED) were calculated. The evoked torque was electrically stimulated by posterior tibial nerve. The peak force, average force, RFDs in post-IPF were significantly smaller than those in pre-IPF. The root mean square and median power frequency (MdPF) of the EMG were not changed in post-IPF. The electrically evoked torque was increased after sustained IPF. These results suggested that the early phase of post-IPF fatigue was the almost pure muscular origin, while the late phase of IPF fatigue contained the influence of central nervous system, possibly due to the difficulty of large motor neurons recruitment after the sustained IPF.

Introduction

Muscle fatigue is an essential phenomenon in a variety of sports activities and rehabilitation. The previous study defined muscle fatigue as the state in which the ability to output strength and power decreased [1]. The fatigue is known to be caused by changes in various components including cardiorespiratory functions, energy consumption and change in state of muscle fibers themselves [2, 3].

The repetition of maximal contraction reduced discharge frequency of spinal motoneurons, which reduced muscle force without muscle contraction speed, and some motor units, might stop firing altogether [4]. The previous study showed that the decrease of continuous force or evoked force on submaximal contractions was affected by spinal and supraspinal factors [5].

Possible involvement of functional changes in the central nervous system (CNS) in muscle fatigue has been considered. It was suggested that a decrease in the activity of the motor cortex pathway to muscle might contribute to fatigue so that the neural activity cannot maintain to drive the muscle to generate its full force [6]. In the previous study, it was called this decrease in voluntary activation of muscle by the decline of motor command supraspinal fatigue [7]. Evidence supporting the presence of central factors in fatigue has been accumulating in recent studies [6,8-11]. For example, it was showed that increases in various components including cardiorespiratory functions, energy consumption and change in state of muscle fibers themselves [2, 3].

To evaluate the extent of neural contributions in muscle fatigue, we compared variables of muscle force and electromyographic (EMG) activity before and after the muscle fatigue induced by sustained isometric plantar flexion (IPF).

Methods

Eight male and two female subjects participated in this study (age 22.1 ± 0.5 years, mean ± standard deviation). The subjects were healthy and without a history of serious injury in the lower extremity, especially, in the ankle joint. They were fully informed about the risk of experiment and signed an informed consent document before the experiment. Ethics Committee for the Human Subject Researches in Health Science University approved this study.

The experiments were done on the right ankle, which was in the dominant leg for all of the subjects. The Biodex system 3 (Biodex Medical Systems, Inc. USA) was used for measurements of IPF force. The right foot was fixed to the plate connected to the Biodex system (Figure 1). The subject was seated on an adjustable seat, and the trunk was positioned at 80 degrees flexion with the knee and the ankle at 0 degrees in the sagittal plane. The upper limbs were crossed in front of the trunk. The force output signal during IPF was digitized at 2 kHz and stored in a computer system.


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Bipolar surface electrodes (diameter 10 mm, center-to-center distance 20 mm) for recording EMG signal were placed over the muscle of gastrocnemius of the right leg. Before the electrode placement, the skin surface was lightly abraded and cleansed with alcohol to reduce impedance at the skin-electrode interface below 10 kΩ. The EMG signal was amplified and digitized at 2 kHz, and stored in the computer system.

IPFs of maximal effort for 3 s (pre-IPFs) were done three times at 5 min intervals, and the most substantial value of the evoked force was adopted as maximal voluntary contraction (MVC). After 5 min rest, an IPF maintained with maximal effort (sustained IPF) was continued until the IPF force was reduced to 50% of MVC. Then the sustained IPF was stopped and immediately a trial of 3 s maximal voluntary IPF (post-IPF) was done.

The electrodes for nerve stimulation was placed on the popliteus to the posterior tibial nerve stimulation was done with rectangular pulses of 1 ms duration with strength two times larger than the minimum strength evoking the maximal M-wave (Figure 1). The electrical stimulation was done at three different time points during the sustained IPF: at 50% of MVC on the rising phase of torque development (50% MVC); at the peak of torque (100% MVC); and at the end of the sustained IPF whose torque was decreased to 50% of MVC (Fatigue) (Figure 2). The torque evoked by electrical stimulation was determined as the height of the first peak of torque after stimulation.

The force signal of each of the pre- and post-IPFs was numerically differentiated to estimate the rate of the force development (RFD), and maximal RFD (RFDmax) was obtained as the first peak amplitude of the RFD of the MVC trial. The absolute values of the gastrocnemius EMG signals were numerically filtered with a Gaussian filter of the cutoff frequency of 4 Hz [13]. The smoothed signal of each of the pre- and post-IPFs was then numerically differentiated to obtain the rate of rise of the EMG signal development (RED), and the maximal RED (REDmax) of the MVC trial was obtained as the first peak amplitude of the RED [14]. The median power frequency (MdPF) of the power spectral density and the root mean square (RMS) amplitude were calculated from the EMG data for 1 s period starting at 1 s from the onset of contraction in pre- and post-IPFs. RFD and RED of the initial phase of contraction were calculated at 30, 50, 100, and 200 ms from the onset of contraction in pre- and post-IPFs. The onset of contraction was defined as the time point at which the force curve exceeded baseline moment by 2.5% of the difference between baseline moments [15].

Data analysis was done using KyPlot 5.0 (Kyens LabInc, Japan). Values are given as means ± standard error of the mean (SEM). The corresponding values of various measurements of pre- and post- the IPFs were compared using the paired t-test. The evoked torques by electrical stimulation were tested using repeated-measures analysis of variance (ANOVA). Post hoc multiple comparisons were conducted using the least significant difference method (Fisher’s LSD). Statistical significance was set at the 5% level.
Results

The values of the duration time of Sustained IPF were 288.4±7.91 seconds (mean±SEM).

Table 1 gives the values of force and EMG measurements in pre and post-IPFs. The values of the peak and average forces in post-IPF were about 20% lower than those in pre-IPF. The values of RFDmax and REDmax were also decreased by about 30% in post-IPF, whereas no significant changes were observed in RMS and MdPF (Figure 3).

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<th>Pre</th>
<th>Vs</th>
<th>Post</th>
<th>Post/pre</th>
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<tbody>
<tr>
<td>Peak force (N.m)</td>
<td>137.19±10.01 ***</td>
<td>107.63±7.9</td>
<td>0.78±0.03</td>
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<tr>
<td>Ave. force (N.m)</td>
<td>133.11±10.22 ***</td>
<td>104.43±7.51</td>
<td>0.78±0.03</td>
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<tr>
<td>RFDmax (N.m/s)</td>
<td>356.39±39.69 ***</td>
<td>242.98±27.54</td>
<td>0.68±0.05</td>
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<tr>
<td>REDmax (mV/s)</td>
<td>17.79±2.35 **</td>
<td>12.50±2.51</td>
<td>0.70±0.07</td>
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<tr>
<td>RMS (mV)</td>
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<td>0.26±0.06</td>
<td>0.87±0.16</td>
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<td>MdPF (Hz)</td>
<td>65.24±9.66</td>
<td>52.93±5.6</td>
<td>0.81±0.12</td>
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Table 1: Comparison of the values of force and EMG measurements of pre- and post-IPFs. Values are mean ± SEM. ** p<0.01, *** p<0.001.

Discussion

In this study, the values of the contractile force, EMG amplitude, and their rates of rise of plantar flexor muscles in pre- and post-IPFs were compared. The peak and average forces in post-IPF were about 20% lower than those in pre-IPF, indicating the development of muscle fatigue by the sustained IPF.
by sustained IPF. Moreover, decrease of torque by sustained IPF, the rise of evoked torque due to electrical stimulation, was the decline of activation of CNS.

Competing Interests

The authors declare that they have no competing interests.

References
