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Effects of low-frequency electrical stimulation on cumulative fatigue and muscle tone of the erector spinae

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Abstract. [Purpose] The aim of this study was to determine the effect of low-frequency electrical stimulation on fatigue recovery of the erector spinae with cumulative fatigue induced by repeated lifting and lowering work. [Subjects] Thirty-two healthy men volunteered to participate in this study and they were randomly divided into three groups: a MC group of 12 persons who underwent microcurrent, a TENS group of 10 persons who underwent Transcutaneous electrical nerve stimulation, and a control group of 10 persons who only rested. [Methods] Cumulative fatigue was induced and then, EMG, muscle tone, CK and LDH serum levels of the erector spinae were measured. Each group then underwent the assigned intervention and was re-measured. To analyze the differences in fatigue between before and after the intervention, the paired t-test was conducted, while groups were compared using analysis of covariance with a control group. [Results] The MC groups showed a significant reduction in muscle fatigue and decreased muscle tone when compared to the control group. However, no significant differences were found between the TENS and control groups. [Conclusion] These results suggest that microcurrent stimulation was effective for recovery from cumulative muscle fatigue while TENS had no effect.

Key words: Fatigue, Microcurrent, Transcutaneous electrical nerve stimulation

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INTRODUCTION

Repetitive lifting and unloading as well as moving with excessive weights have been known to be major causes of various musculoskeletal disorders and low back pain¹⁾. Such carrying or actions may increase the load on the spine while decreasing the pressure that protects the spine, thereby increasing the risk of low back pain and injury to the spine²⁾. Therefore, to ensure workers' safety and prevent injury, cumulative fatigue induced in repetitive work environment needs to be in studies using various interventions for recovery from fatigue.

In this study, muscle fatigue, tone of the erector spinae, and blood levels of CK (creatine kinase) and LDH (lactate dehydrogenase), two blood serum enzymes, were measured before and after the intervention and their results were compared to analyze the cumulative fatigue.

TENS causes muscle contraction by stimulating α -motor neurons. It has been widely used to improve reduced muscle function, muscle strength, and joint range of motion, as well

as the muscle activities of neurological patients. However, if long-term TENS is applied to the human body, it can cause muscle fatigue and the accumulation of waste matter, and serious muscle damage. It has also been reported that TENS does not have a significant effect on fatigue after high-intensity exercise^{3–5)}. Therefore, although therapies using TENS may have a variety of advantages, more study is required to conclusively determine the effect TENS has on muscles with cumulative fatigue.

Microcurrent stimulation plays a role in restoring cells or facilitating healing by increasing the creation of adenosine triphosphate (ATP) and proteins, and curing wounds through the supply of electric energy at the cell level, which restores the potential of the cell membrane to normal potential⁶⁾. In recent years, a number of studies of microcurrent stimulation have been performed for in a wide range of conditions such as fracture and fatigue recovery, and various diseases involving cancers and diabetic nerve damage^{7–10)}. In particular, microcurrent stimulation is known to be effective for cumulative fatigue recovery as it reduces CK in the blood of patients with delayed onset muscle soreness¹¹⁾. However, a study by Cheng et al. reported that microcurrent stimulation had no positive effect on the recovery of an arm with delayed onset muscle soreness¹²⁾.

In this study, microcurrent stimulation and TENS were administered to subjects with cumulative fatigue to analyze their effects on fatigue recovery.

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SUBJECTS AND METHODS

Thirty-two male persons in their 20s participated in this study and they were randomly divided into three groups: an MC group of 12 persons who underwent microcurrent stimulation, a TENS group of 10 persons who underwent transcutaneous electrical nerve stimulation, and a CON group of 10 persons who only rested. The subjects had no musculoskeletal disorders or related disease histories and were restricted to right-hand dominant males. Prior to participation in this study, subjects were given a detailed description of the experimental and safety procedures, and each subject signed an informed-consent form. This study was approved by Sehan University's Research and Ethics Committee. The following Tables show the general characteristics of the subjects and the homogeneity test results for the two groups (Tables 1 and 2).

Before the test, subjects wore comfortable dresses and were informed about the correct motions. To maintain the same work condition, a 75-cm-high small table was prepared and a 30-cm-wide, 30-cm-deep, and 25-cm-high box was filled with a 10-kg dumbbell¹³⁾. As soon as subjects had completed repeated lifting and lowering of the box 100 times during 15 minutes with a symmetrical posture in the sagittal plane¹⁴⁾, the pre-test measurements were conducted. Immediately after the pre-test, the TENS group was administered transcutaneous electrical nerve stimulation (ES-420, Ito, Japan) after connecting two rectangular radiofrequency catheters (50×90 mm). The longissimus and iliocostalis were treated for 20 minutes (monophasic pulsed direct current of 80 Hz with phase duration of 10 s, pulse width of 300 μ s and on/off time 10 s/50 s). The MC group received microcurrent from a microcurrent stimulator (ES-420, Ito, Japan) at 100 mA and 0.3 Hz on the same spot for 20 minutes. The CON group took a rest for 20 minutes while lying prone on the floor. Immediately after the intervention, EMG, muscle tone, CK, and LDH were measured. The temperature and humidity in the laboratory were maintained at 23 °C and 60%.

Muscle activating signal was checked by using surface EMG machine (MP100, biopac, USA). The sampling rate of the signal was 100 Hz and bandpass filtering was performed between 20–500 Hz. The digitized signal was processed with FFT (Fast Fourier transformation) using Acqknowledge 3.91 software on a personal computer to obtain the median frequency (MF). Maximum voluntary contraction (MVC) was measured using a dynamometer (T.K. K. SI02, Takei, Japan). The closest two of the recorded values were averaged and used as the MVC value of the subjects. After the MVC measurement, 60% MVC was calculated for the quantification of the collected measurement values from the experiments so that measurements before and after the treatment were performed with the above method. The electrode was attached to the right and left erector spinae of the right- and left-side back and the longissimus and the iliocostalis around the hip. To measure the EMG of these muscles, a pair of surface electrodes was attached horizontally in the right and left directions to the muscle belly 5 cm away from the neurocentral joints of thoracic vertebrae T10 and lumbar

Table 1. General characteristics of the subjects

	MC (n=12)	TENS (n=10)	CON (n=10)
Age (yr)	21.8±1.8	22.4±1.5	21.5±1.8
Height (cm)	173.6±4.9	176.2±5.9	174.8±5.3
Weight (kg)	70.1±9.8	69.7±3.1	65.4±6.4

Mean±SD, MC: Microcurrent Group, TENS: TENS Group, CON: Control Group

Table 2. Pre-intervention values of the three groups

	MC (n=12)	TENS (n=10)	CON (n=10)
RMF (Hz)	72.6±10.6	073.3±4.6	073.3±4.7
LMF (Hz)	74.3±7.6	071.2±6.1	070.5±5.7
RMT (kg/mm)	12.2±0.9	012.4±0.8	012.3±1.4
LMT (kg/mm)	12.5±1.8	014.1±6.0	012.2±1.2
CK (U/l)	119.0±17.4	126.5±61.1	115.3±32.8
LDH (U/l)	417.1±40.6	421.2±41.2	429.3±53.7

There were no significant differences: ANOVA, $p>0.05$, MC: Microcurrent Group, TENS: TENS Group, CON: Control Group, RMF: right median frequency, LMF: left median frequency, RMT: right myotonometry, LMT: left myotonometry, CK: creatine kinase lactate, LDH: lactate dehydrogenase

vertebrae L2¹⁴⁾.

In order to measure muscle tone of the erector spinae, a myotonometer (Missoula, MT, Neurogenic Technologies Inc., USA) was used. While subjects rested on a bed, the longissimus and the iliocostalis at the waist were measured. The measurement probe consists of inner and outer cylinders. According to the resistance of the tissue, the distance between two cylinders changes and the resistance of the tissue is converted into force. The force applied to the cylinder was divided into eight stages (0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00 kg) so that measurement at each position of the level of displacement could be made. Force-displacement curves were created using computational software and the areas under the curve (AUC) were calculated from the obtained data. The area under the curve (AUC) is indicating of level of muscle tone^{15–17)}.

SPSS/win 18.0 was used for all statistical processing. Means and standard deviations of all measurements were calculated and analysis of variance (ANOVA) was conducted to test the homogeneity of the experimental groups. In order to analyze the effect of the treatment on muscle fatigue, muscle tone, and CK and LDH serum levels, the paired t-test was used to examine within group pre- and post-test differences, while analysis of covariance (ANCOVA) was used to compare the MC and TENS groups with the CON group. The significance level was chosen as $\alpha=0.05$ for all analyses.

RESULTS

Microcurrent stimulation, TENS, and rests were given to subjects who had fatigues and then EMG, muscle tones, CK and LDH were measured and analyzed. The results are shown in Tables 3, 4, and 5.

Table 3. The effects of intervention on the muscle fatigue index

	Group	Pre-intervention	Post-intervention
RMF* (Hz)	CON	70.7±10.6	67.4±7.9
	MC †	72.6±10.6	63.8±8.5
	TENS	73.3±4.70	65.9±3.8
LMF* (Hz)	CON	70.8±11.4	63.7±9.7
	MC †	75.4±7.6	59.1±10.4
	TENS	70.5±5.7	68.5±5.3

*paired t-test ($p<0.05$), †ANOVA, MC group \neq CON group ($p<0.05$), MC: Microcurrent Group, CON: Control Group, TENS: TENS Group

Table 4. The effects of intervention on the myotonometry index

	Group	Pre-intervention	Post-intervention
RMT* (kg/mm)	CON	12.3±1.4	16.5±1.8
	MC †	12.2±0.9	18.8±1.2
	TENS	12.4±0.8	16.2±1.3
LMT* (kg/mm)	CON	12.2±1.2	15.2±2.4
	MC †	12.5±1.8	19.3±1.3
	TENS	14.1±6.0	16.7±1.1

*paired t-test ($p<0.05$), †ANOVA, MC group \neq CON group ($p<0.05$), MC: Microcurrent Group, CON: Control Group, TS: TENS Group Group, TENS: TENS Group

Table 5. The effects of intervention on fatigue markers in the blood

	Group	Pre-intervention	Post-intervention
CK* (U/l)	CON	119.0±40.6	91.6±36.4
	MC	126.5±61.1	85.7±29.8
	TENS	139.3±42.0	95.5±21.8
LDH* (U/l)	CON	421.2±41.2	374.7±41.1
	MC	417.1±40.6	355.0±31.1
	TENS	433.3±55.8	395.0±44.6

*paired t-test ($p<0.05$), MC: Microcurrent Group, CON: Control Group, TENS: TENS Group

All the three groups showed significant changes in muscle fatigue, muscle tone, and blood levels of CK and LDH, between before and after the intervention ($p<0.05$). The comparison result of the MC and CON groups found a significant difference in muscle fatigue and muscle tone in the right and left erector spinae ($p<0.05$). However, no significant difference was found in the blood levels of CK and LDH. In addition, no significant difference was found between the TENS and CON groups.

DISCUSSION

A study by Dolan et al. reported that 100 times of lifting and lowering a 10-kg weight for 12.1 minutes resulted in increase of muscle fatigue¹⁴. Furthermore, Lee et al. revealed that after repetitive work of more than six times per minute with a sub-maximal weight of 15%, it took more

than five minutes for the workers' backs to recover from cumulative fatigue to the initial condition. When cumulative fatigue occurs, loads on the vertebrae continue to increase during the repetitive work whereas pressure that protects the vertebrae starts to reduce thereby increasing the risk of low back pain².

Clarkson et al. reported that when subjects aged between 18 and 40 years performed repeated of lifting and lowering, 50 times, with maximum eccentric contraction, muscle damage to the biceps brachii was induced along with increases in both CK and LDH level in the blood¹⁸. The accumulation of markers of fatigue in the blood and muscle fatigue due to repetitive lifting and lowering work is known as one of the main reasons for injury during work¹⁹.

An increase in muscle tone indicates an abnormal state in the musculoskeletal system and it is used as an indicator of muscle fatigue²⁰. Roja et al. reported that with additional lifting and lowering of heavy goods, muscle tone of workers increased further, whereas workers without such repetitive work showed relatively less muscle tone²¹. In addition, muscle tone was shown to correlate with EMG frequency and a decrease in muscle fatigue increases muscle tone as well²². In this study, cumulative muscle fatigue and muscle tone showed significant changes after the intervention. In particular, subjects administered microcurrent stimulation showed significant changes in muscle fatigue and muscle tone.

Weber et al. administered microcurrent stimulation to subjects with delayed onset muscle soreness and reported no significant difference in muscle fatigue was shown by the subjects²³. However, a study by Cho et al. reported that patients with plantar fasciitis who wore shoes that produced microcurrent stimulation for six weeks showed a significant reduction in, muscle fatigue in the tibialis anterior as assessed by the median frequency⁶. Their result is similar to that of our present study in which muscle fatigue in the right and left erector spinae was reduced significantly. Microcurrent stimulation can induce cell responses in damaged tissues through bioelectricity thereby assisting with the healing of tissues. It can also facilitate endogenous bioelectric current which would reduce resistance in the damaged portion, and promote conduction of bioelectric current assisting with the recovery of homeostasis of the human body. That is, microcurrent enhances electrical and chemical processes, which assist the healing process, returning damaged muscle tissues to a normal state²³. Reduction of the median frequency value indicates a reduction in muscle fatigue^{22, 24}, and muscle tone and microcurrent stimulation is more effective for the recovery of muscle fatigue and muscle tone than only taking a rest. The microcurrent therapy increased collagen formation speed in the recovery of damaged cells more than in the TENS therapy, which is why the microcurrent stimulation had a more positive effect on muscle fatigue and muscle tone.

No significant differences were found after the intervention between the TENS and CON groups. This result is in agreement with Park's study in which an administration of 100 PPS to finger muscles for 30 minutes had no effect on muscle fatigue and muscle strength²⁵. Although appropri-

ate stimulation through TENS can help to prevent fatigue accumulation by increasing the local blood flow, the temporary increase in local circulation was not sufficient enough to have a significant effect on muscle fatigue recovery.

A study by Lim reported that after heavy exercise, CK and LDH decreased slightly or increased for up to 30 minutes, together with aggravation of the pain in patients with delayed onset muscle soreness^{26, 27}. Thus, future should investigate intervention effects on cumulative fatigue over 24 hours. Furthermore, a study that can provide a generalized conclusion through a large number of subjects and various measurement tools shall be conducted in the future.

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