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The Effect of Electrical Stimulation on Blood Lactate after Anaerobic Muscle Fatigue Induced in Taekwondo Athletes

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Abstract. [Purpose] The aim of this study was to determine the effect of electrical stimulation on blood lactate after anaerobic muscle fatigue was induced in Taekwondo athletes. [Subjects] Twenty-four male collegiate Taekwondo athletes voluntarily participated in this study (from June 7, 2010 to June 18, 2010, a total of 2 weeks). Subjects were randomly divided into three groups of 8: a) Electrical stimulation group (ES) which received electrical muscle stimulation; b) the massage group which received massage; and the control group which took a rest after induction of anaerobic muscle fatigue. [Methods] This study was a double-blind randomized controlled trial. It was conducted at the sports science research laboratory of Kyungwoon University, Gumi, Korea. Muscle fatigue was induced via anaerobic exercise. Blood samples were collected when the athletes were in a relaxed state, immediately after anaerobic exercise, 15 minutes after anaerobic exercise, and 25 minutes after anaerobic exercise. [Results] Repeated measures ANOVA showed statistically significant differences in lactic acid concentration in the blood with time in the three groups, as well as among the three groups. The lactic acid concentrations in the blood was highest immediately after exercise, decreased significantly 15 min after exercise, and further decreased 25 min after exercise. Scheffe's post-hoc test revealed statistically significant differences between the massage group and the control group, and between the ES group and the control group, whereas no statistically significant difference was found between the massage group and the ES group. [Conclusion] Electrical stimulation was shown to enhance muscle fatigue recovery caused by anaerobic exercise by Taekwondo athletes.

Key words: Anaerobic muscle fatigue, Electrical stimulation, Muscle fatigue recovery

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INTRODUCTION

Taekwondo, a Korean martial art sport, was adopted by the IOC as an official sport for the 2000 Sydney Olympic Games. It is widespread in over 191 (As of April. 5, 2010) countries in the world (Table 1)[1)]. A Taekwondo match consists of three rounds, each of which lasts for three minutes, with a one-minute break between rounds. In a tournament, several matches are conducted in a day[1,2)]. This Korean combat art requires intensive power of 10 METs (Metabolic Equivalent)[3)] as Taekwondo athletes perform quick steps, attack, and defense. Such movements are conducted via anaerobic metabolism[4–6)]. In anaerobic metabolism, accumulates in the muscle via lactate metabolism of glucose. The lactic acid accumulated in the muscle is then released into the blood by a circulatory process, and lactic acid concentration in the blood is commonly used as an index of the activation of lactate metabolism and an also as index of fatigue after exercise[7)]. The hypothesis that skeletal muscles produce lactic acid during high-intensity exercise has been widely accepted. That is, there is common agreement that the dissociation of lactic acid into lactate and a proton (H) is responsible for muscular acidosis during high-intensity exercise, which causes muscular fatigue and performance level decline[8)]. Muscular fatigue can change muscle recruitment during a Taekwondo front kick and cause injury during a match[9)], and it is one of the many factors affecting lower limb dynamic joint stability during athletic tasks[10)]. Therefore, the ability to rapidly remove accumulated lactic acid during the one-minute break of a Taekwondo match is considered an important factor in muscle recovery from fatigue, that can enhance performance, and reduce the risk of injury.

Various ways for reducing lactic acid concentration in the blood of Taekwondo athletes have recently been proposed. Massage is commonly used by athletes, as well as by Taekwondo players. A few studies have reported that massage significantly reduced lactic acid concentration in

Table 1. Member Nations (WTF)

Asian Taekwondo Union [ATU]	43
European Taekwondo Union [ETU]	49
Pan American Taekwondo Union [PATU]	42
African Taekwondo Union [AFTU]	44
Oceanian Taekwondo Union [OTU]	13
Total	191

the blood and boosted muscle fatigue recovery[11,12]. Hinds et al.[13] reported, however, that the application of massage after exercise is inadequate from a scientific point of view. These contradictory results are likely to be attributable to the effect on muscle fatigue recovery of the massage type and methods, and the masseuse's experience. Therefore, there has been increasing interest in methods that can reduce lactic acid concentration in the blood using an apparatus that can apply constant work continuously. One representative of such method is electrical stimulation.

Electrical stimulation is a commonly used modality for both athletic training and physical therapy. Some studies have reported a significant effect of electrical stimulation on muscle fatigue recovery[14–18]. There are limited objective data, however, on quantitative analysis of changes in the blood lactate[14–15,18]. Interferential current stimulation (ICS), one of the electrical muscle stimulation methods, is commonly used in pain control, as is Transcutaneous Electrical Nerve Stimulation (TENS). It produces biphasic pulses within the tissue and has an advantage in that it does not cause skin irritation, unlike some other electrical stimulation techniques[19] ICS, which uses medium-frequency alternating currents, induces vasodilatation and increases peripheral blood flow[20,21]; and the suction system with an electrode has a massage effect. These biological and mechanical effects of ICS may favorably change the blood lactate level in Taekwondo athletes. The aim of this study was to determine the effect of ES on blood lactate after anaerobic muscle fatigue was induced in Taekwondo athletes.

SUBJECTS AND METHODS

Twenty-four male collegiate Taekwondo athletes voluntarily participated in this study (from June 7, 2010 to June 18, 2010, a total of two weeks). They had had no orthopedic, neuromuscular, or cardiovascular problem within the previous six months. They were asked not to take part in vigorous physical activities for two days before their test date. They were randomly divided into three groups with eight persons in each. The groups were as follows: (a) the electrical stimulation group (ES group) which received electrical muscle stimulation; (b) the massage group which received a massage; and (c) the control group which rested after anaerobic muscle fatigue had been induced. All the subjects gave their written informed consent to participate in this study prior to the conduct of the study. The general characteristics of the subjects are shown in Table 2. There were no significant differences among the three groups ($p>0.05$) indicating the homogeneity of the groups.

This study was a double-blind randomized controlled trial. It was conducted at the sports science research laboratory of Kyungwoon University. During the conduct of the study, a temperature of 22° and a humidity of 60% were maintained to minimize changes in the subjects' physiological responses due to environmental factors. The subjects were asked to wear short-sleeved shirts and pants. Muscle fatigue was induced by asking them to perform anaerobic exercise. Blood samples were collected from the subjects when they were in a relaxed state, immediately after anaerobic exercise, 15 minutes after anaerobic exercise, and 25 minutes after anaerobic exercise (four times).

A Wingate ergometer (Excalibur Sport, Lode BV Groningen, The Netherlands) was used to induce anaerobic muscle fatigue in the subjects. In previous studies, the Wingate anaerobic test (coefficient 0.89) has been used extensively, and sports practitioners use it often to examine maximal power output and as a standard exercise task to analyze athletes' responses to supramaximal exercise[22,23].

The subjects were asked to sit on the ergometer and to put their feet on the pedals, to which their feet were fixed. In the initial posture for measurement, each participant was asked to maintain their body angle at a 75-degree inclination, and a 10-degree angle between the handle of the bicycle ergometer and elbow. The torque applied to each participant was set at 0.8 × body weight (in Nm). The subjects sat on the ergometer and warmed up for 3 minutes at under 60 rpm and 100 W to raise the heart rate to 120–125. A 5-second countdown was made to signal to the participating athletes to pedal with all their strength for 30 seconds immediately after the command "Start". After 30 seconds, the participants were allowed to have active rest for 10 seconds under 60 rpm and 100 W. This was performed three times to make sure the athletes experience fatigue[24]. Verbal feedback was given to obtain the maximum velocity from the subjects. As for the induction of muscle fatigue, those subjects who had fatigue indices of more than 35 W/sec, which were recorded on a worksheet provided during the Wingate anaerobic exercise, a mean power/weight of 10 W/

Table 2. Comparison of general characteristics of subject

	Control group (n=8)	Massage group (n=8)	ES[1] group (n=8)
Age (yr)	19.7 ± 0.5	19.9 ± 0.4	19.8 ± 0.5
Height (cm)	176.2 ± 1.5	178.0 ± 2.3	177.4 ± 2.7
Weight (kg)	64.5 ± 2.3	69.3 ± 7.3	66.3 ± 3.4
Career (yr)	4.62 ± 1.18	4.37 ± 1.30	5.50 ± 1.51

Value are the mean ± SD. [1]Electrical Stimulation.

Table 3. omparison of Wingate variable characteristics measured after anaerobic exercise (n=24)

	Control group (n=8)	Massage group (n=8)	ES[1] group (n=8)
Fatigue index (W/Sec)	44.20 ± 8.53	45.86 ± 7.94	48.98 ± 8.77
Mean power/weight (W/Kg)	10.85 ± 0.69	9.72 ± 3.51	11.18 ± 0.79
Total work (Joule)	10,751.25 ± 1.430.13	10,703 ± 1,444.66	11,169 ± 1.438.66

Value are the mean ± SD. [1]Electrical Stimulation.

Table 4. Changes in the lactic acid concentration in the blood with time. (n=24)

	At Rest	After Exercise	15 Minutes after Exercise***	25 Minutes after Exercise***
Control group (n=8)	2.71 ± 0.31	17.43 ± 2.83	12.368 ± 2.27	7.86 ± 0.75
Massage group (n=8)	2.67 ± 0.79	18.86 ± 2.03	9.71 ± 1.60	4.73 ± 1.24
ES[1] group (n=8)	2.60 ± 0.53	17.41 ± 2.23	9.94 ± 0.87	5.01 ± 1.06

Value are the mean ± SD, ***: $p<0.001$, [1]Electrical Stimulation. The results of the Scheffe post-hoc test are as follows (one-way ANOVA). Significant changes in the blood lactate were found between the massage group and the control group, and between the ES group and the control group, 15 min and 25 min after exercise, respectively ($p<0.05$), whereas no significant change in the blood lactate was found between the massage group and the ES group.

kg, and a total work output of 10,000 Joules were selected. The characteristics of the Wingate variables for the subjects are presented in Table 3, and they confirm the same muscle fatigue, as no statistical significance was found among the three groups ($p >0.05$).

The ES group underwent electrical muscle stimulation using ICS. Noble et al.[20] reported that interferential current therapy applied at 10 ± 20 Hz via suction electrodes produced an increase in the cutaneous blood, followed by a concomitant increase in the skin temperature. This suggests that the underlying physiological effect is vasodilation, i.e., inhibition of the sympathetic nervous system by the applied interferential current. Therefore, an electrical variable proposed by Noble et al.[20] was used in this study. An interferential current unit (EU-940, ITO CO., LTD, Tokyo, Japan) was used to stimulate the muscle. The interferential current was applied through four vacuum electrodes attached to a vacuum unit (SU-520, ITO CO., LTD, Tokyo, Japan). The four vacuum electrodes were assigned to the vastus medialis and the vastus lateralis, two vacuum electrodes each. The vacuum pressure was expressed in pulses per minute (60 ppm). The carrier frequency was set at 4 kHz. The pulse duration was fixed at 125 μs. The current intensity was set within the range of the minimum visible contraction of the quadriceps femoris muscle.

The massage group was given a massage according to the same protocol provided in a previous study[12], which reported a significant effect of sports massage on muscle fatigue recovery after anaerobic exercise ($p<0.05$); and the control group rested by raising both legs on a chair in a supine position for 15 min.

Blood samples were collected before and after the anaerobic exercise, and at 15 min and 25 min (four times). Blood (3 cc) was collected using a syringe with a 10-gauge needle from the antecubital vein of each subject. The blood sample was centrifuged (5 min at 2,500 rpm) after it was put into a vacutainer tube, to separate it into serum and hemocyte layer. Only the upper layer of the serum was collected, and it was preserved via refrigeration (below 10°C), until used for the analysis of blood lactate at the Department of Analysis of Nuclear Medicine of Kyungpook National University Hospital, Deagu, Korea.

One-way ANOVA was conducted to confirm the significance of the general characteristics of the subjects in all the groups, the identity of their muscle fatigue variables, and lactic acid concentration in the blood at each sampling time.

Repeated measured ANOVA was conducted to confirm the significance of the changes in the lactic acid concentration in the blood in all the groups immediately after exercise and 15 min and 25 min after exercise. The Scheffe post-hoc test was also used. All the statistical analyses were performed using the SPSS program (SPSS 12.0KO for Windows, SPSS, Inc., Chicago, USA), and results were considered statistically significant at values of $p<0.05$.

RESULTS

One-way ANOVA found no statistically significant differences in the lactic acid concentrations in the blood among the three groups before or immediately after exercise ($p>0.05$), whereas statistically significant differences in the lactic acid concentrations in the blood among the three groups were found at 15 min and 25 min after exercise. There were significant differences between the massage group and the control group, and between the ES group and the control group (post-hoc Scheffe test, $p<0.05$) (Table 4).

The repeated measures ANOVA showed statistically significant differences in the lactic acid concentration in the blood with time in the three groups, as well as among the three groups. The lactic acid concentrations in the blood was highest immediately after exercise, it had decreased significantly 15 min after exercise, and had further decreased 25 min after exercise. The post-hoc test found statistically significant differences between the massage group and the control group, and between the ES group and the control group (post-hoc Scheffe test, $p<0.05$), but no statistically significant difference was found between the massage group and the ES group (post-hoc Scheffe test, $p>0.05$).

DISCUSSION

It has been reported that the lactic acid concentration in the blood significantly increase during Taekwondo matches. Lee[4] reported that the lactic acid concentration in the blood was 1.57 ± 0.58 mmol/*l* at rest, and significantly increased to 5.29 ± 1.6 mmol/*l* after the first round of a match to 6.11 ± 1.79 mmol/*l* after the second round and to 8.37 ± 1.86 mmol/*l* after the third round, showing significant differences when at rest and after exercise ($p<0.01$) as well as among the rounds ($p<0.01$). Kim[5] also reported that the lactic acid concentration in the blood significantly increased by 314% after the first round of a match to 386% after the second round and to 496% after the third round, from the concentration when at rest. These results indicate that lactate metabolism takes place during Taekwondo matches. It is speculated that the change in the lactic acid concentration in the blood increases the muscle fatigue of Taekwondo athletes affecting their performance and heightening the risk of injury during matches.

Many studies have reported that active exercise recovery lowers lactate faster than passive rest recovery, but the former may not always be practical[25]. An alternative treatment, ES, may have benefits similar to those of active recovery in lowering the blood lactate, but it has not yet been studied[14–15,18]. The lactic acid concentration in the blood was more significantly decreased in the ES group than in the static resting group in this study. This result is inconsistent with that of So et al.1[8] who reported that the TEAS treatment was significantly more effective than the pseudo-TEAS treatment in enhancing the rate of muscle force recovery (knee extension peak torque recovery after 15 min, from 155 to 195 Nm in the TEAS group and from 155 to 182 Nm in the pseudo-TEAS group), but had no effect on lactate removal. In contrast, Park[15] and Jang[17] reported significant changes in the blood lactate level. Park[15] reported reduced lactate after application of TENS during recovery after anaerobic exercise and remarkable differences between immediately after the exercise and 15 and 20 min during the recovery ($p<0.001$ and $p<0.01$, respectively). Jang[17] reported that the lactate changed more significantly in the TENS group than in the resting group after anaerobic exercise. Neric et al.[14] reported that after swimming-induced muscle fatigue, EMS (TENS) led to a lower mean blood lactate level (3.12 +/– 1.41 mmol.L-1) after 20 min of recovery than with passive rest (4.11 +/– 1.35 mmol.L-1). Blood lactate levels in submaximal swimming recovery were significantly poorer, however, at 10 min (3.506 +/– 1.57 mmol.L-1) and 20 min (1.6060 +/– 57 mmolL-1) after recovery without EMS. Neric et al.[14] reached the conclusion that EMS shows promise as an alternate recovery treatment for lowering blood lactate. It is likely that the electrical stimulation that was applied to acupoint in the study of So et al.[18] had at least a heat effect rather than causing visible contraction of the muscle. In addition, the results of the study of So et al.[18] are likely to differ from the results of other studies, as the significance of the acupoints was investigated in their study rather than the stimulation or contraction of the muscle. In contrast, the gastrocnemius was stimulated at a low frequency (5 Hz) and a high intensity (at a range that can cause minimal visible contraction) for 15 min in the study of Park[4] In addition, in the study of Neric et al.[18] a low frequency (2 Hz) was used in an attempt to elicit a peripheral muscle pump action by electrically inducing low-tension, non-fatiguing muscle contractions at approximately 10% of the maximum voluntary contraction. Despite the difference in the frequency type, these studies were similar to the present study in that an alternating current was used for TENS and an intensity that can cause minimal visible contraction was applied. These results are likely to have been caused by a significant increase in the temperature in the quadriceps femoris muscle due to muscle shaking induced by electrical stimulation. A significant change in the body temperature was shown when an alternating current was applied to the body using ICS[19] and the increased body temperature was reported to have increased the volume and rate of the blood flow[20]. In addition, ICS suppresses the sympathetic nervous system activity, which causes vasodilation of the blood vessels, and allowing the removal of noxious substances[21]. It is likely that these physiological changes rapidly change the lactic acid concentration in the blood. Therefore, it is more appropriate to use ICS, which has the same effect as other electrical muscle stimulation methods and has a significant effect when applied to the body, if a significant change in the lactic acid concentration in the blood is shown with the use of an alternating current.

A quantitative study on the effect of electrical stimulation on muscle fatigue has yet to be conducted, and the variables electrical stimulation have not yet been established. Another limitation of this study is that the variables of electrical stimulation were not precisely controlled. Although the significance of electrical stimulation in muscle fatigue recovery was confirmed in this study, a further study on the effect of electrical stimulation on muscle fatigue recovery is required.

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