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Original Article

Effect of Capacitive and Resistive electric transfer on changes in muscle flexibility and lumbopelvic alignment after fatiguing exercise

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Abstract. [Purpose] This study aimed to clarify the effects of Capacitive and Resistive electric transfer (CRet) on changes in muscle flexibility and lumbopelvic alignment after fatiguing exercise. [Subjects and Methods] Twenty-two healthy males were assigned into either the CRet (n=11) or control (n=11) group. Fatiguing exercise and CRet intervention were applied at the quadriceps muscle of the participants' dominant legs. The Ely test, pelvic tilt, lumbar lordosis, and superficial temperature were measured before and after exercise and for 30 minutes after intervention. Statistical analysis was performed using one-way analysis of variance, with Tukey's post-hoc multiple comparison test to clarify within-group changes and Student's t-test to clarify between-group differences. [Results] The Ely test and pelvic tilt were significantly different in both groups after exercise, but there was no difference in the CRet group after intervention. Superficial temperature significantly increased in the CRet group for 30 minutes after intervention, in contrast to after the exercise and intervention in the control group. There was no significant between-group difference at any timepoint, except in superficial temperature. [Conclusion] CRet could effectively improve muscle flexibility and lumbopelvic alignment after fatiguing exercise.

Key words: Thermotherapy, Lumbopelvic alignment, Muscle fatigue

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INTRODUCTION

Inappropriate lumbopelvic alignment is widely accepted as a risk factor for injuries. In particular, excessive anterior pelvic tilt and lumbar lordosis are reported to be associated with injuries such as low back pain (LBP) and anterior cruciate ligament (ACL) injury. Heather et al. reported that patients with LBP exhibited an increased lumbar lordosis compared with those without LBP[1)]. Roncarati and McMullen[2)] found an association between increased lumbar lordosis and anterior pelvic tilt and LBP. Regarding ACL injury, Hertel et al.[3)] and Loudon et al.[4)] indicated that increased anterior pelvic tilt was related to a history of ACL injury. These injuries are common in athletes and may prevent athletes from participating in sports for a long time[5, 6)]. Therefore, it is important to maintain the appropriate lumbopelvic alignment to prevent injuries.

Factors to define lumbopelvic alignment include a balance between the anterior and posterior pelvic muscles. If a person stands with an exaggerated anterior pelvic tilt and lumbar lordosis, his hip flexor and lumbar extensor muscles are short-

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ened or tightened, whereas the abdominal muscles are weakened[7]. Tashiro et al.[8] revealed that anterior pelvic tilt was significantly greater in Japanese Keirin cyclists than in the controls and concluded that poor flexibility of the quadriceps muscle, which includes the rectus femoris muscle acting as a hip flexor, contributed to an increase in anterior pelvic tilt. Thus, a decrease in hip flexor muscle flexibility can lead to excessive anterior pelvic tilt and lumbar lordosis.

Muscle fatigue is one of the factors associated with decrease in muscle flexibility. Various studies have reported that muscle fatigue induced by intense exercise causes an increase in muscle hardness, resulting in a decrease in muscle flexibility[9–13]. Therefore, muscle fatigue of the hip flexor is considered to change lumbopelvic alignment by decreasing muscle flexibility. Since poor muscle flexibility itself is also related to the occurrence of injuries[14–17], it is important to enhance muscle recovery after fatigue, and maintain appropriate muscle flexibility and lumbopelvic alignment.

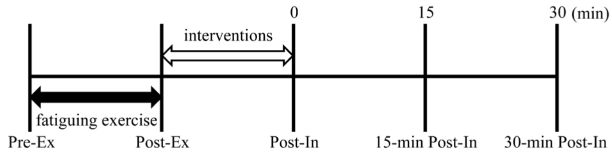

Fig. 1. The Ely test, pelvic tilt, lumbar lordosis, and superficial temperature were measured before (Pre-Ex) and after (Post-Ex) the fatiguing exercise. Then, the interventions for CRet and control groups were performed for 15 minutes. Each measurement was performed immediately (Post-In), 15 minutes (15-min Post-In), and 30 minutes (30-min Post-In) after the interventions.

Various modalities are utilized to facilitate muscle recovery from fatigue, including stretching[18, 19], massage[20, 21], active recovery[18, 22], contrast water therapy[23, 24] cryotherapy[25, 26], and thermotherapy[27, 28]. However, the effectiveness of these modalities is controversial. Recently, Capacitive and Resistive electric transfer (CRet), which is a type of diathermy, has been developed as a form of deep thermotherapy and applied in sports medicine[29]. This device delivers radiofrequency energy, which passes between an active and inactive electrode, and generates heat within the body[30, 31]. Previous studies indicated that CRet was more effective in improving blood circulation than a hot pack, which is a conventional thermotherapy modality used frequently in clinical practice[32, 33]. Improving blood circulation would play an important role in the enhancement of muscle recovery after fatigue[34, 35]. Thus, CRet can be an effective modality to enhance muscle recovery after fatigue, leading to maintain and improve the appropriate muscle flexibility and lumbopelvic alignment. However, there was no study indicating the effects of CRet on fatigued muscle and the changes in muscle flexibility and lumbopelvic alignment after fatiguing exercise are unknown. Therefore, the purpose of the present study was to clarify the effects of CRet on changes in muscle flexibility and lumbopelvic alignment after fatiguing exercise.

SUBJECTS AND METHODS

Twenty-two healthy males participated in the study. All participants were not active in spots and were not currently on a regimented strenuous excessive exercise. The quadriceps muscles of their dominant legs received fatiguing exercise and intervention. Individuals with a history of orthopedic or nervous system disease in their lower limbs or low back or who corresponds with contraindication of the CRet intervention were excluded. Written informed consent was obtained from each participant in accordance with the guidelines approved by Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1975. The study was approved by the ethical committee of Kyoto University Graduate School of Medicine (R1284).

The experimental design and time course of the measurements were summarized in Fig 1. Participants were randomly assigned into one of two groups the CRet group or control group. The CRet group (n=11) received 15 minutes of CRet intervention after fatiguing exercise, while the control group (n=11) was instructed to rest for 15 minutes. Measurements were performed pre- and post- exercise (Pre-Ex and Post-Ex, respectively) and immediately, 15 minutes, and 30 minutes after intervention (Post-In, 15 min Post-In, and 30 min Post-In, respectively).

Quadriceps muscle fatigue was induced in the participants' dominant leg by concentric and eccentric knee extension exercise. Participants sat on the bed with their hip joint angle at approximately 100° and their feet off the floor. From this position, the participants were instructed to extend their knee fully over 3 seconds (concentric phase), keep their knee extended for 1 second (isometric phase), and slowly lower the leg over 3 seconds (eccentric phase). They performed 10 sets of 10 repetitions with a 30-second interval between sets. The resistance was set at approximately 30% of the participants' maximum voluntary isometric contraction (MVC) force measured using a μ Tas F-1 hand-held dynamometer (Anima Corp., Tokyo, Japan).

Indiba® activ Pro Recovery HCR902 (Indiba S.A., Barcelona, Spain) was used for the CRet intervention. This device operates at a frequency of 448 kHz. A rigid circular metallic electrode with a 65-mm diameter was used as the active electrode and a large flexible rectangular metallic plate (measuring 200 × 260 mm) was used as the inactive electrode. A radiofrequency (RF) energy was delivered using in two modes: capacitive (CAP) and resistive (RES) at the active electrode. The CAP electrode has a polyamide coating that acts as a dielectric medium, insulating its metallic body from the skin surface, and thus it generates heat externally near the skin. The RES electrode is uncoated and the RF energy travels directly through the body into the inactive electrode, therefore, it generates heat in deeper regions of the body. There are several contraindications

Table 1. Physical characteristics of the participants

	CRet group (n=11)	Control group (n=11)
Age (years)	23.0 ± 1.3	23.2 ± 2.3
Height (cm)	171.7 ± 5.3	168.5 ± 6.5
Weight (kg)	61.7 ± 7.8	60.0 ± 8.1
Body mass index (kg/m^2)	20.9 ± 2.4	21.1 ± 1.8
MVC (N)	331.5 ± 69.7	307.8 ± 57.9

Values are represented as mean ± standard deviation.
CRet: Capacitive and Resistive electric transfer; MVC: maximum voluntary isometric contraction.

to receiving CRet including pregnancy, deep vein thrombosis, hypoesthesia, damaged skin, or the presence of an implanted pacemaker. The CRet group underwent a 15-minute intervention (5 minutes in CAP mode, and 10 minutes in RES mode). The active electrode was continually moved in the circular motion on the skin of posterior thigh and the inactive electrode was placed under the thigh. A manufacturer- supplied conductive cream was used as coupling medium between the active electrode and skin surface during the intervention. The intensity was determined subjectively by a score of 6 or 7 on a subjective analog scale, which is an 11-point scale for the participant self-reporting of thermal sensing (0, no thermal sensing; 10, worst possible thermal sensing). The intensity and duration of CRet intervention were based on the manufacturer's recommending method, which were considered to be the most effective without feeling discomfort or pain[31)].

The Ely test was used to determine changes in quadriceps muscle flexibility[36)]. The participants laid prone on the bed with their dominant leg passively bent. The knee flexion angle, at which the hip rise was felt by the examiner, was measured using a universal goniometer.

Pelvic tilt was measured using a palpation meter (PALM, Performance Attainment Associates, St Pail, MN, USA)[37)]. During the measurements, the participants stood with their feet aligned with their shoulders and were instructed to keep their arms crossed over the chest and look at a fixed point ahead to control for postural sway. The landmarks for measurement were the ipsilateral anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS). Anterior pelvic tilt was measured by placement of the PALM caliper tips in contact with the ipsilateral ASIS and PSIS. The degree of deviation from the horizontal was read from an inclinometer. A positive degree was used to describe anterior pelvic tilt and a negative degree was used to describe posterior tilt in the sagittal plane. The measurements were performed two times on the participants' dominant leg and the average value was used for analysis.

Lumbar lordosis was measured using the Spinal Mouse (Index Ltd., Tokyo, Japan)[38)]. The Spinal Mouse is a computer-aided electric measuring device that measures intersegmental angles in a non-invasive manner. As with PALM measurement, the participants stood with their feet aligned with their shoulders and their arms beside the body; they were instructed to look at a fixed point ahead to control postual sway. The Spinal Mouse was guided along the midline of the spine beginning at the spinous process of C7 and finishing at the top of the anal crease (approximately the level of S3). The lumbar lordosis angle was calculated from the sum of six segmental angles from Th12/L1 to L5/S1. The measurements were performed three times and the average value was used for analysis.

Superficial temperature was measured using an infrared thermometer (IT2-80, KEYENCE Co., Ltd., Japan) to estimate the thermal effects of the CRet intervention. The measurement site was the center of the quadriceps muscle of the participants' dominant legs.

For each measure index, the amount of change (Δ) from the first value was calculated. The one-way analysis of variance was used to analyze the changes at each time point within the group. The Tukey post hoc multiple comparison (Tukey-HSD) test was performed to clarify differences within each group. The student t-test was used to compere changes at each time point between two groups. Statistical analyses were performed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA), with a statistical threshold of 0.05.

RESULTS

The physical characteristics of the participants in each group are shown in Table 1. There was no significant difference in the participants' physical characteristics between groups. The mean resistance used in the knee extension exercise performed by the CRet and control groups were 9.6 ± 1.4 kg and 9.2 ± 1.6 kg, respectively.

A significant decrease in Ely test angle was observed at Post-Ex in the CRet group ($p<0.05$), and from Post-Ex to 30-min Post-In in the control group (Post-Ex, Post-In, 15-min Post-In, $p<0.01$; 30-min Post-In, $p<0.05$). The pelvic tilt significantly increased at Post-Ex in the CRet group ($p<0.01$), and at Post-Ex and Post-In in the control group ($p<0.01$). There was no significant difference in lumbar lordosis in each group. Superficial temperature significantly increased at Post-In, 15-min Post-In, and 30-min Post-In in the CRet group ($p<0.01$), and at Post-Ex and Post-In in the control group ($p<0.05$) (Table 2).

Superficial temperature showed a significant difference between groups from Post-Ex to 30-min Post-In (Post-Ex, 30-min

Table 2. Changes in the measurement value

		CRet group	Control group
Ely test (°)	Pre-Ex	0	0
	Post-Ex	−6.0 ± 3.0*	−6.5 ± 2.8**
	Post-In	−2.6 ± 5.8	−5.8 ± 2.7**
	15-min Post-In	−3.2 ± 5.7	−3.9 ± 2.0**
	30-min Post-In	−3.4 ± 6.0	−3.1 ± 2.6*
Pelvic tilt (°)	Pre-Ex	0	0
	Post-Ex	1.9 ± 1.2**	1.4 ± 0.9**
	Post-In	0.5 ± 0.8	1.1 ± 0.8**
	15-min Post-In	−0.9 ± 0.8	0.5 ± 0.7
	30-min Post-In	0.0 ± 0.9	0.4 ± 0.7
Lumbar lordosis (°)	Pre-Ex	0	0
	Post-Ex	−1.1 ± 2.2	−1.1 ± 4.8
	Post-In	−1.7 ± 2.6	−0.8 ± 4.0
	15-min Post-In	−0.8 ± 2.5	0.2 ± 3.7
	30-min Post-In	−0.3 ± 2.3	−1.4 ± 3.4
Superficial temperature (°C)	Pre-Ex	0	0
	Post-Ex	0.3 ± 0.7†	0.9 ± 0.6*†
	Post-In	5.1 ± 1.3**‡	0.9 ± 0.7*‡
	15-min Post-In	2.9 ± 1.0**‡	0.6 ± 0.8‡
	30-min Post-In	1.7 ± 1.3**‡	0.6 ± 0.8†

Values are represented as mean ± standard deviation.
*Significant difference from Pre-Ex value (p<0.05, Tukey-HSD).
**Significant difference from Pre-Ex value (p<0.01, Tukey-HSD)
†Significant difference between groups (p<0.05, Student t-test)
‡Significant difference between groups (p<0.01, Student t-test)
CRet: Capacitive and Resistive electric transfer.

Post-In, $p<0.05$; Post-In, 15-min Post-In, $p<0.01$). There was no significant difference in Ely test angle, pelvic tilt, and lumbar lordosis between groups (Table 2).

DISCUSSION

In the present study, we investigated the effect of CRet intervention on changes in muscle flexibility and lumbopelvic alignment after fatiguing exercise. The results showed a significant decrease in the angle of the Ely test and thus quadriceps flexibility, as well as a significant increase in the angle of anterior pelvic tilt immediately after exercise in both groups. In the control group, significant differences in Ely test results and pelvic tilt were observed until 30 minutes after and immediately after the intervention, respectively; while; in the CRet group, significant differences in the Ely test and pelvic tilt were no longer observed after CRet intervention.

Intense exercise, particularly which contains eccentric contraction, is known to induce an increase in muscle hardness[9–11]. Repetitive muscle contractions frequently increase the intramuscular water content level[39, 40]. This exercise-induced fluid accumulation increases the intramuscular pressure, resulting in an increase in muscle hardness. Therefore, Ely test angle significantly decreased immediately after the knee extension exercise in both groups. This result suggests that the quadriceps muscle flexibility decreased immediately after knee extension exercise in both groups since the Ely test is an indicator of quadriceps muscle flexibility.

The results of the present study suggested that quadriceps muscle flexibility returned to baseline sooner in the CRet group than in the control group. This difference seems to be due to the thermal effects of the CRet intervention. In the present study, the change in superficial temperature was 5.1°C immediately after CRet intervention. Our previous study showed that the change in superficial temperature was 2.4°C immediately after CRet intervention applied at the hamstring muscles[33]. Although we measured superficial temperature using a different instrument, the intervention in the present study was carried out at the same intensity and duration using the same instrument as in this previous study. Therefore, we assumed that the thermal effects in the present study may be equal to or higher than in the previous study.

There are three possible factors contributing to the change in quadriceps muscle flexibility. The first factor is improvement in blood circulation to the muscle. Many studies have revealed that thermotherapy improves blood circulation[34, 35, 41, 42].

Moreover, previous studies showed that CRet intervention was more effective on the improvement in blood circulation than hot pack application[32, 33]. An increase in muscle hardness is caused by an increase in intramuscular pressure resulting from fluid accumulation[9]. We infer that muscle hardness may decrease since the accumulated fluid would be removed by the improvement in blood circulation from CRet intervention. Muscle hardness affects muscle flexibility, thus, muscle flexibility of the quadriceps could be improved by CRet intervention. The second factor is the increase in soft tissue extensibility, including that in connective tissue composed primarily of collagen fibers[43–45]. As temperature increases, collagen extensibility increases, and connective tissue viscosity and the viscoelasticity of muscle fibers are reduced[46–48]. Subsequently, the extensibility of soft tissues increases, and muscle flexibility improves. The third factor is muscle relaxation. Thermal stimulation decreases the activity of α motor neurons by changing the activity of group II fibers, γ motor neurons and Ib fibers[49]. These changes in neuronal activity cause muscle relaxation. In the present study, thermal stimulation by CRet intervention may alter nerve activity and cause muscle relaxation, resulting in improvement in quadriceps flexibility based on the Ely test.

The result of the present study showed that the pelvic tilt angle significantly increased immediately after exercise in both groups and returned to its original value sooner in the CRet group than in the control group. These changes are considered to be associated with the change in quadriceps muscle flexibility. The position of the pelvis is determined by a balance between the anterior and posterior pelvic muscles. Kendall et al.[50] described that tightness of the hip flexors led to an anterior pelvic tilt in the standing position. The quadriceps muscle group is composed of four muscle, vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris; the rectus femoris also acts as a hip flexor. Thus, it is considered that the angle of pelvic tilt increased immediately after knee extension exercise and decreased after CRet intervention, along with a change in quadriceps muscle flexibility.

There was no significant difference in lumbar lordosis in both groups at any time point. It is widely believed that lumbar lordosis is associated with pelvic tilt. Levine et al.[51] found that altering pelvic tilt significantly changed the angle of lumbar lordosis in the standing position. According to Youdas et al.[52], the correlation between pelvic tilt and lumbar lordosis in the standing position is significant, albeit weak. We assume that the change in pelvic tilt was insufficient to affect lumbar lordosis because the exercise and intervention were performed on participants' dominant legs only.

Poor muscle flexibility is a risk factor of various injuries[14–17], thus it is important to maintain and improve muscle flexibility to prevent injuries. Furthermore, inappropriate lumbopelvic alignment could cause injuries such as low back pain[1, 2] and ACL injury[3, 4]. The results of the present study indicated that fatiguing exercise decreased muscle flexibility, resulting in a change in pelvic alignment. Those who perform fatiguing exercise on a daily basis, for example athletes, require a faster recovery from fatigue and enhance injury prevention through the appropriate conditioning in order for them to optimally practice and to compete. Moreover, it is important to recover muscles after strenuous exercise in a short time because, in many sports, situations in which athletes are not given enough time to recover their muscle fatigue are abundant; for example, the situation in which they have to participate in a lot of games in a day. Our study results suggest that CRet could play an important role in athletes' conditioning.

This study had several limitations. First, we did not include female and various aged participants, and the population was restricted to young healthy males belonging to the same university. The effects of CRet in other populations is uncertain; therefore, further research is required in this regard. Second, we assessed the quadriceps muscle only by the Ely test. The detailed changes caused by exercise and CRet intervention remain unclear. Third, the measurement time was limited. We investigate the effects of CRet on changes in muscle flexibility and lumbopelvic alignment before and after exercise and for 30 minutes after intervention. The lasting effects of these are unknown. Thus, studies with long-term follow up are needed. Despite these limitations, the results of the present study provide valuable information on the effects of CRet.

The effects of CRet on changes in muscle flexibility and lumbopelvic alignment after fatiguing exercise was investigated. The results showed that the changes in quadriceps muscle flexibility and anterior pelvic tilt was significant immediately after knee extension exercise in both groups; however, that these indexes returned to the pre-exercise value sooner in the CRet group than after intervention. These findings suggest that the CRet intervention is effective on improvement of muscle flexibility and pelvic tilt after fatiguing exercise. CRet could be a useful means to recover muscle fatigue and maintain the appropriate muscle flexibility and lumbopelvic alignment.

Conflict of interest

None.

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