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Possibility of a Novel Warm-Up Strategy Using Capacitive and Resistive Electric Transfer: A Pilot Study

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Abstract

[Purpose] Capacitive and resistive electric transfer (CRET) is becoming prevalent in sports settings. CRET is effective for improving pain and healing injured tissue; however, its influence on muscle function and morphology is still unclear. This study confirmed the immediate effects of CRET on the duration of muscular stiffness and range of motion (ROM). [Method] This study describes the protocol for a single-arm trial with the non-blinding of participants and researchers. Twenty-four healthy men participated in the study. They received CRET therapy for their low back areas. The muscular stiffness of the multifidus muscle (superficial and deep) and the ROM using the active straight leg raise (ASLR) test were measured pre-intervention, post-intervention (immediately), and 15 and 30 min post-intervention. We compared these parameters using a one-way analysis of variance and Dunnett's test (multiple comparison tests for subtests). [Results] The muscular stiffness of the superficial and deep multifidus muscles was significantly decreased, and the ASLR test showed a significant increase compared with the test performed pre-intervention. In addition, these effects persisted for 30 min. [Conclusion] Warm-up is vital for improving muscular stiffness and increasing the ROM. CRET is a useful device for achieving these aims, particularly as a passive warm-up method in sports settings.

Keywords

Capacitive and Resistive Electric Transfer, Muscular Stiffness, Range of Motion, Active Straight Leg Raise, Multifidus Muscle

1. Introduction

Thermal stimulation of the human body results in vasodilation and improves blood circulation [1] [2] [3] [4]. Thermotherapy is one of the physiotherapy methods used in clinical settings; its effectiveness in treating musculoskeletal pain and tissue injury (muscles, tendons, and ligaments) is well known [1] [2] [3] [4]. Therefore, thermotherapy is recognized as a major modality for therapy. Thermotherapy is classified as superficial or deep thermotherapy. Generally, superficial thermotherapy includes the use of heating pads, hot packs, paraffin baths, and infrared heat lamps, and is useful for increasing the skin and surface tissue temperature along with vasodilation. However, deep thermotherapy techniques, such as the use of shortwave diathermy, microwave diathermy, and ultrasound, also cause vasodilation, but these can increase the deep tissue temperature [5]. Deep thermotherapy devices, such as ultrasound and shortwave diathermy, can improve hemoglobin saturation, boost treatment, and improve fatigue [6] [7].

Blood (hemoglobin) delivers oxygen to all body parts and carries carbon dioxide back to the lungs. The oxygenated hemoglobin and muscle blood volume are reportedly decreased in fatigued lumbar muscles [8]. There have been reports that recovered tissue oxygenation facilitates the improvement of fatigued muscles [9] [10] [11]. Vasodilation due to heat is caused by the direct activation of the skin thermoreceptors in vascular smooth muscles and the suppression of the sympathetic nervous system via the indirect activation of local spinal reflexes and increased levels of inflammatory chemical mediators [12] [13] [14].

Traditional deep thermotherapy techniques have several disadvantages. For instance, ultrasound has a risk of periostitis because of the energy concentration on the bone tissue [15]. Diathermy devices with a frequency of 8 - 14 MHz may cause excessive heat during the treatment, resulting in skin burns [16]. Recently, capacitive and resistive electric transfer (CRET) with a frequency of 400 - 500 kHz has been developed [17]. It uses high-frequency electromagnetic energy to generate heat within the body tissues. CRET with a lower frequency does not produce excessive heat between the skin and electrode; therefore, it is safer than traditional diathermy. Furthermore, previous studies have revealed that CRET is effective in improving low back or shoulder pain by increasing the hemoglobin saturation and muscle temperature [18] [19] [20] [21]. CRET is effective for improving pain and disability in patients with musculoskeletal disorders; however, its influence on muscle function and morphology in healthy people is still unclear.

Increased muscle temperature affects the maximum muscle power and maximum contraction speed. McGowan *et al.* stated that the raised muscle temperature (passive or active) leads to an increase in adenosine triphosphate turnover, cross-bridge cycling rate, and muscle fiber conduction velocity [22]. Athletes need splinting after sustaining high-intensity injuries and could benefit from using this mechanism; hence, therapeutic modalities, including CRET, are frequently used. In the Rio 2016 Olympic games, 28% of athletes received electrotherapy to recover from injuries and maintain their body at the Olympic Polyclinic [23]. This percentage was the most frequent among all the treatment modalities. Compared with the 2012 London Olympic games, the Rio 2016 Olympic games increased the type and utilization of modality treatment [24]; hence, these therapies are more popular in sports settings. If CRET enables an immediate rise in the temperature of deep tissues and contributes to improved physical function, then this device is useful for warm-up before sports. In this study, we examined the immediate effects, such as the range of motion (ROM) and the duration of multifidus muscle stiffness, after irradiating the low back area using CRET.

2. Participants and Methods

2.1. Participants

Healthy participants were recruited from four hospitals and a university. The inclusion criteria were men aged 20 - 50 years. The rehabilitation staff confirmed the participant's health condition using a questionnaire, and the participant attended as a volunteer. The exclusion criteria were as follows: the presence of tumors, obvious lumbar herniation, lumbar spinal canal stenosis, infections, musculoskeletal disorder, sciatic nerve compression and pain, sensory impairment, and decreased muscle strength and reflexes. In addition, participants did not have a habit of performing strenuous exercise. Each participant signed an informed consent form, based on the requirements of the Helsinki Declaration. This study was approved by the Ethics Committee of the Kanazawa Orthopedic Sports Medicine Clinic (kanazawa-OSMC-2021-004) and registered in the University Hospital Medical Information Clinical Trials Registry (UMIN000046304).

This interventional study was a single-arm trial with the non-blinding of participants and researchers. We calculated the sample size needed for one-way analysis of variance (ANOVA) (effect size 0.80, significance level [α] error = 0.05, power [$1 - \beta$] = 0.80) using G Power software (version 3.1; Heinrich Heine University of Düsseldorf, Düsseldorf, Germany), and obtained a result of 24.

2.2. Experimental Procedure

Participants' body mass index (BMI) was calculated after measuring their height and weight. They also received CRET therapy once for their low back. The stiffness of the superficial and deep multifidus muscles on the right side was measured. Subsequently, the ROM was measured using the active straight leg raise (ASLR) test. These measurements were conducted at baseline (T0), immediately after intervention (T1), 15 min after intervention (T2), and 30 min after intervention (T3) (**Figure 1**).

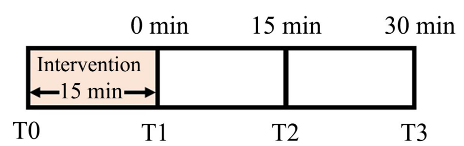

Figure 1. The experiment setting with the intervention and measurement.

2.3. Intervention

The CRET device was Physio Radio Stim Pro (SAKAI Medical Co. Ltd., Japan). This device works at a frequency of 500 kHz. A highly rigid circular electrode was used as the active electrode, and a large, flexible rectangular electrode was used as the inactive electrode. This device supplies high-frequency electromagnetic energy with two modes for the active electrode: capacitive electrode transfer (CET) and resistive electrode transfer (RET). The CET electrode is coated with polyamide, which can insulate from the skin surface as a dielectric medium and heat the external skin. The uncoated RET electrode supplies heat to the deep tissues of the body owing to the direct conduction of energy to the inactive electrode.

Participants received CRET therapy in the prone position on the plinth. An inactive electrode was placed on the abdominal area. To maintain conductivity between the electrode and skin surface during the intervention, a manufacturer-supplied cream was used. The irradiation time of CRET was 5 min using CET and 10 min using RET for the multifidus and erector spinae muscles. This intervention time was based on previous studies [7] [21]. The intensity of CRET was defined as 6 or 7 using the 11-level analog scale (0 = no heat sensing, 10 = worst heat sensing) to demonstrate the participants' subjective feeling of heat. During the intervention, the Duty was set at 50% in CET and 100% in RET and there were seven levels of power. After 15 min of intervention, the conductive cream was completely removed. No other therapies that might affect the judgment of the therapeutic efficacy were conducted.

2.4. Measurements

2.4.1. Ultrasound

We used a B-mode ultrasonographic apparatus (SSD-3500SV; FUJIFILM Healthcare Corporation, Tokyo, Japan) with a linear transducer (scanning frequency, 7.5 MHz). An attachment dedicated to an acoustic coupler (EZU-TECPL1, FUJIFILM Healthcare Corporation, Tokyo, Japan) with an elastic modulus of 22.6 ± 2.2 kPa was set on the probe and placed between the measurement area and probe. The elastography images were recorded while pressing the transducer attached to the acoustic coupler on the multifidus muscle. Each participant in the prone position placed a rolled towel under the abdomen to adjust the neutral alignment of the lumbar spine. The stiffness of the superficial and deep multifidus muscles was measured at 2 cm on the right side of the third lumbar spine vertebra, the space between the third and fourth lumbar spine vertebra transverse processes. Owing to the anisotropy of muscles, the parallel direction of the muscle fiber was confirmed [25]. Subsequently, the outline of the probe was marked on the skin to assess the accuracy of each measurement. All measurements were performed by an experienced rater.

In previous studies, muscular stiffness was measured as the strain ratio, calculated using an acoustic coupler, which acts as the reference [26] [27]. The measurement area of the acoustic coupler was defined as follows: the vertical axis was the vertical diameter of the acoustic coupler, and the horizontal axis was the central 3/4 area of the image. For the measurement area of the multifidus muscle, the vertical axis was the muscle thickness, and the horizontal axis was the central 3/4 area of the image. Regarding muscular stiffness, the (A) measurement area of each muscle was divided by the (B) measurement area of the acoustic coupler; thus, the value was calculated as A/B. If the strain ratio is larger than 1.0, the muscle is stiffer than the coupler (>22.6 kPa) (**Figure 2**).

2.4.2. ASRL Test

The participants were positioned supine on the plinth. Both arms were rested on the abdomen, and the cervical spine was maintained in a neutral position using a towel under the head. The examiner asked the participant to raise their right leg slowly with the hip joint in a neutral position, knee joint in extension, and ankle in maximum dorsiflexion [28] [29]. The participant was asked to stop raising their leg at "submaximal pain" and the ROM was measured at this point. We explained submaximal pain to the patients as a substantial discomfort that can be tolerated, and participants stopped ASLR when they wanted to because the pain increased. To measure the ROM, we placed the sensor of a magnetic 3D position measuring device (LIBERTY, Polhemus, USA) 15 cm above the cranial of the patella. The participants repeated the ASLR test three times to perform the statistical analysis, and the mean value was calculated.

2.5. Statistics

To compare the measurement value of muscular stiffness and the ROM using the ASLR test in each intervention (before, immediately after, 15 min after, and 30 min after), one-way ANOVA was used. For the subtests, Dunnett's test was used for multiple comparisons. The level of significance was set at $p < 0.05$. The statistical software used was SPSS for Windows (version 24.0; IBM Corp., Armonk, New York, USA).

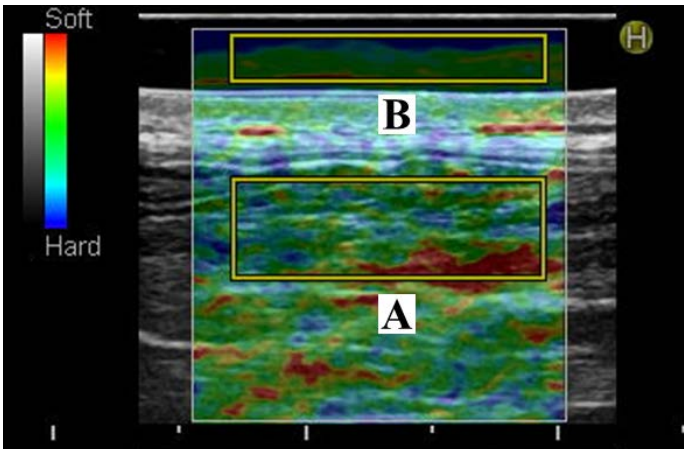

Figure 2. Representative elastography images of the (A) superficial multifidus muscles and the (B) acoustic coupler.

3. Results

Twenty-four healthy men (age, 33.0 ± 8.4 years; height, 174.4 ± 7.5 cm; weight, 66.6 ± 7.9 kg; BMI, 21.8 ± 1.8) participated in this study.

The results for muscular stiffness and the ASLR tests are shown in **Table 1**. The muscular stiffness of the superficial and deep multifidus muscles was significantly lower at T1 than at T0; however, the ROM was significantly greater at T1 than at T0. Both measurement components showed significant differences between T0, T2, and T3.

4. Discussion

This study examined the immediate effects and the duration of multifidus muscular stiffness and ROM using the ASLR test after CRET therapy to the low back. The muscular stiffness of the superficial and deep multifidus muscles after the intervention was significantly decreased and the ROM significantly increased compared with those before the intervention. The effects lasted for 30 min. These results showed that CRET causes pain reduction and improves the stiffness and flexibility of the muscles. Muscular stiffness and decreased flexibility are causes of impairment [30] [31]. Therefore, CRET may contribute to the prevention of muscle strain or low back pain and improve sports performance.

CRET reportedly improves pain and blood circulation after an injury. Thermal stimulation reduces pain directly or indirectly by inhibiting ischemia and muscle spasms and facilitating tissue healing [32] [33]. Stimulation of the thermal receptors causes vasodilation, and ischemic pain is reduced. This mechanism is considered to reduce vasospasm. Vasodilation by thermotherapy facilitates tissue healing and an increase in the local pain threshold. CRET is an effective treatment for injured participants and is used in clinical settings; however, our study revealed improvement in muscular stiffness and the ROM in healthy participants. It seems that the flexibility of the muscle and collagen tissue of the fascia was improved. The soft collagen tissue can undergo elastic deformation by thermal energy, and it increases and maintains its extensibility [34] [35]. Knight *et al.* reported that deep heating by ultrasound on the plantaris muscles significantly increased dorsiflexion [36]. CRET also increased the ROM in the present study. Because ultrasound has a small probe and there is a risk of inflammation

Table 1. Sequential changes in muscle stiffness and ASLR.

	T0	T1	T2	T3
Stiffness				
Superficial multifidus	5.42 ± 9.87	0.71 ± 0.44*	0.71 ± 0.47*	0.67 ± 0.38*
Deep multifidus	12.88 ± 18.13	1.38 ± 1.83*	0.99 ± 0.60*	1.09 ± 0.75*
ASLR (˚)	64.1 ± 14.7	69.7 ± 16.5*	68.9 ± 18.5*	65.9 ± 16.7*

Values are represented as mean ± standard deviation. *Significant difference from T0 value ($p < 0.05$). ASLR, active straight leg raise.

in the periosteum [37], CRET may be a safer option than ultrasound. A previous study reported that 26% of hip joint flexion results from posterior pelvic tilt [38]. The multifidus muscle and thoracolumbar fascia have muscle connections with the hamstrings via the sacral ligament or ischial tuberosity [39]. Therefore, the increased flexibility of the multifidus muscle and thoracolumbar fascia due to CRET improved the ROM. Improving the ROM is a vital in addition to raising the muscle temperature during warm-ups for sports events [22]. In particular, increased ROM can prevent injury and improve the splinting and kicking performance [40] [41].

Regarding decreased muscular stiffness, the stagnant body fluid might be removed by improving blood circulation. Muscular stiffness occurs through increased intramuscular pressure caused by stagnant body fluid [26]. In addition, muscular stiffness causes reduced ROM; therefore, CRET may contribute to increasing the ROM. Another factor for decreased muscular stiffness is an increase in the extensibility of the soft tissue including connective tissue with collagen fiber [42] [43]. As the temperature increases, the extensibility of collagen fibers increases; leading to a decrease in the viscoelasticity of muscle fibers and viscosity of the connective tissue [44]. Muscle flexibility was gained because of increased extensibility of soft tissue.

The effect on muscular stiffness and ASLR persisted for 30 min. Warm-ups before sport events are widely endorsed by athletes and coaches, and it is necessary to ensure optimal performance. However, excess active warm-ups may cause muscle fatigue, which result in poor performance. Neiva *et al.* reported that warm-ups are recommended for 15 - 25 min to prevent fatigue [45]. Utilization of CRET differs from active warm-ups; it does not deplete energy and enables superficial and deep muscular stiffness and the ROM to be improved. Therefore, in this study, CRET could prevent injury and contribute to improved sports performance.

This study had several limitations. First, we only included healthy young men; however, it is necessary to confirm the effect on other groups with different compositions, such as varying age groups, athletes of various sports, or women. Women have greater pain sensitivity, enhanced pain facilitation, and lower pain inhibition than men do [46]; therefore, women may be less affected by CRET therapy than men. In addition, in men, a negative correlation between muscle stiffness and the ROM exists; in women, one does not [47]. Thus, women would be differently affected by CRET. Second, the multifidus sarcomeres are positioned on the ascending portion of the length-tension curve [48]. This biomechanical property is also reported in the rectus lateralis and brachialis [49] [50]. Therefore, increasing the ROM of hip flexion and posterior pelvic tilt through CRET would allow the muscle to become intrinsically stronger. In the future, we should examine the pelvic tilt and muscle activities during ASLR. Finally, whether the same effect of CRET would be found in the other areas of the muscles is unknown. Navarro-Ledesma *et al.* described that CRET intervention could change the elasticity of the supraspinatus tendon in healthy badminton athletes [51]. The insertion site of the supraspinatus tendon has an insufficient blood supply and tissue degeneration or rupture may likely occur [52]; therefore, CRET therapy may be effective. In contrast, the Achilles tendon or plantaris muscle needs to maintain stiffness to generate running economy and speed [53] [54]; therefore, improving flexibility may cause poor performance.

5. Conclusion

Using the ASLR test, the present study showed that CRET intervention improved multifidus muscle stiffness and ROM, and that the effect lasted for 30 min in healthy young men. The aim of the warm-up is to improve muscular stiffness, increase the ROM, raise the muscle temperature, and prevent injuries. CRET might be a useful therapy for passive warm-up to improve muscle stiffness of the low back among young men in sports and clinical settings. Furthermore, CRET's effects on actual sports performance, such as running or jumping, need to be studied. Active warm-up is also required after passive warm-up. Therefore, future studies should compare actual sports movement or combined usage with other warm-up exercises.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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