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Original Article

Deep heating using microwave diathermy decreases muscle hardness: A randomized, placebo-controlled trial

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Backgroud: Microwave diathermy treatment is one of the deep heating modalities used in rehabilitation. However, no study has reported on the change in the range of motion (ROM) and muscle hardness after microwave diathermy treatment.

Objective: We aimed to determine the effect of microwave diathermy on muscle hardness and passive ROM.

Methods: Twenty healthy adults (12 men and 8 women) participated in this study. The subjects were randomly assigned to receive microwave diathermy treatment (n = 10; six men, four women) or placebo (n = 10; six men, four women). Microwave diathermy (100 W) and placebo treatments were administered to each subject's right calf for 15 minutes in the microwave and placebo groups, respectively. The hardness of the soleus muscle and passive ROM of ankle dorsiflexion were measured before and after the intervention.

Results: Soleus muscle hardness and passive ROM of ankle dorsiflexion did not change before and after the placebo intervention. However, in the microwave group, there was a decrease in the soleus muscle hardness and an increase in ankle dorsiflexion ROM following the intervention.

Conclusion: Our findings indicate that microwave diathermy treatment can decrease muscle hardness and increase passive ROM.

Key words : deep heating; muscle condition; joint range of motion

1 Introduction

Muscle hardness is defined as the resistance of the muscle against perpendicular pressure, while muscle stiffness is defined as the resistance that is built when the muscle is extended longitudinally.[1-3] Thus, muscle hardness and muscle stiffness are different, but they are related.[1] Muscle hardness can be used to objectively determine a muscle's condition[1, 2] because it can increase under several conditions, such as spasms and damage.[1, 4] It is important to decrease muscle hardness to improve or maintain muscle condition.[5, 6] In addition, muscle pain is associated with muscle hardness.[7] These findings suggest that decreasing muscle hardness may be useful for athletes to enhance their performance by improving or maintaining muscle condition and reducing muscle pain.

Heat is effective for enhancing joint range of motion (ROM).[8] Deep heating, including with microwave diathermy, ultrasound, and shortwave diathermy, is often used before or during stretching to heat the muscle layer and increase ROM. It has been reported that using ultrasound together with stretching can increase ankle dorsiflexion ROM.[9-11] Furthermore, shortwave diathermy with stretching has been reported to increase ankle dorsiflexion ROM[12] and knee extension ROM.[13] Deep heating increases muscle temperature, resulting in improved ROM. It is obvious that ROM is related to muscle stiffness because muscle stiffness represents the resistance that appears when the muscle is extended longitudinally. Therefore, because muscle stiffness and muscle hardness are related, we hypothesized that deep heating could decrease muscle hardness.

Microwave diathermy treatment can be applied to a

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larger area than therapeutic ultrasound can, and physical therapists do not have to remain near the person being treated. Therefore, we determined to use microwave diathermy as the deep heating modality in this study. The purpose of this study was to evaluate the changes in the soleus muscle's hardness after a single deep-heating session using microwave diathermy. We hypothesized that deep heating with microwave diathermy would decrease muscle hardness and that its effects on athletes' muscles would be positive.

2 Methods

2.1 Trial Design

We performed a randomized, placebo-controlled pilot trial in the present study, which was approved by the ethics committee of the Osaka Prefecture University (2012-PT05).

2.2 Subjects

This was a randomized, placebo-controlled trial. Twenty healthy adults (12 men and 8 women) participated in this study. Their mean age, height, and weight were 20.9 ± 0.9 years, 164.0 ± 8.7 cm, and 57.7 ± 8.4 kg, respectively. The exclusion criteria were previous ankle fractures within the last 12 months and passive right ankle dorsiflexion of $<0^{\circ}$ with the right knee extended at 0°. After screening, the subjects were randomly allocated to either the deep heating group or the placebo group. All subjects were informed of the study's purpose, and they provided informed consent.

2.3 Intervention

Subjects in the microwave group received a single microwave diathermy treatment using a microwave therapy apparatus (2,450 Hz, ME-7200, OG Giken Co. Ltd, Okayama, Japan). The probe of the apparatus was placed 10 cm above each subject's right calf in the prone position, and the treatment was administered for 15 minutes at 100 W. The placebo treatment was administered to subjects in the placebo group by using the unplugged microwave device for 15 minutes on each subject's right calf in the prone position. The room temperature was maintained at 23－25℃ during the experiment.

2.4 Outcome Measures

Deep temperature, muscle hardness, and passive ROM were measured before the interventions.

Deep temperature was measured while the participant was in the prone position using a deep temperature monitor (Core Temp CTM-205, Terumo Corp., Tokyo, Japan), and the probe was placed 5 cm distal from the right gastrocnemius muscle-tendon junction.

Soleus muscle hardness was measured using a muscle hardness meter (NEUTONE TDM-N1, TRY-ALL Corp., Chiba, Japan) in the prone position. The device has high repeatability and efficacy of the measurement of muscle hardness.[14] Muscle hardness was measured 5 cm distal from the gastrocnemius muscle-tendon junction, while the right knee joint was extended at 0° and the right ankle joint was dorsiflexed at 0° (Fig. 1). Muscle hardness was measured three times, and the mean value was used for analysis.

Fig. 1 Measurement of muscle hardness

Passive ROM of ankle dorsiflexion was measured by an analog goniometer. Passive ROM of ankle dorsiflexion was measured while the participant was in the prone position, with the right knee flexed at 90°. To ensure the consistency of the passive ROM measuring conditions, the right ankle joint was dorsiflexed at 5 kgf using a handheld dynamometer (μTas F-1, Anima Corp., Tokyo, Japan). The ankle joint was held in a dorsiflexed position, and the ROM was measured. Ankle joint positioning and the measurement of ROM were performed by the same assessors to avoid measurement errors.

2.5 Blinding

Outcome assessors were blinded to the treatment or placebo to eliminate bias. However, subjects could not be blinded, because they could feel their calf heat up or remain unchanged during the intervention.

2.6 Sample size

The sample size was calculated based on the effect on the muscle hardness (partial $\eta^2 = 0.211$) that was obtained from our preliminary study. It was calculated using G*Power, version 3.1.7 (Statistical Power Analyses for Windows and Mac, http://www.gpower.hhu.de), when α was set at 0.05 and power was set at 0.95. A necessary sample size of 16 (8/group) was calculated. We also assumed a reduction of 20 % because of the exclusion criteria.

2.7 Data Analysis

All continuous data were expressed as the mean ± standard deviation. Statistical analyses were performed using SPSS for Windows, version 14.0 (SPSS Inc., Chicago, USA). The characteristics and baseline data, which were the pre-intervention data, between the deep heating and placebo groups were compared using the unpaired *t*-test for quantitative data and the chi-squared test for qualitative data. A two-way repeated measures analysis of variance (ANOVA), one between groups (two levels: intervention and control) and one within groups (two levels: pre-intervention and post-intervention), was used to determine the interaction effect. When interactions were found, a simple main effect test was performed as a lower-level ANOVA to interpret how the values from each group changed, or did not change, from pre-intervention to post-intervention. Statistical significance was set at $p < 0.05$. The 95 % confidence interval (CI) was calculated for all the results.

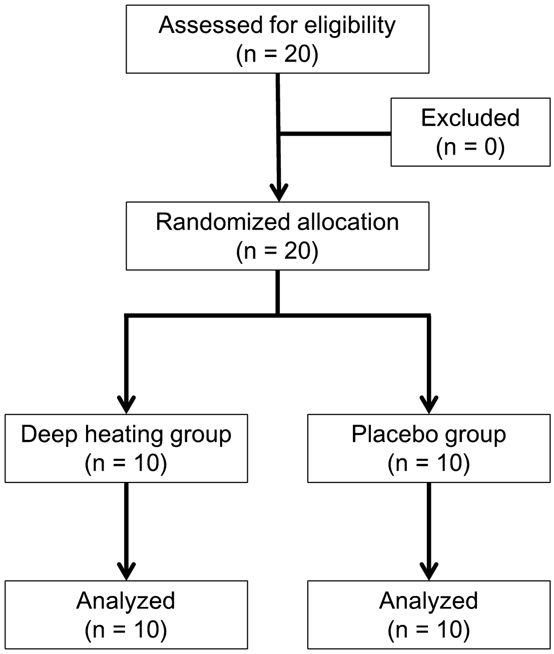

Fig. 2 Flowchart of participation in the present study

3 Results

Twenty healthy subjects were randomly allocated to the deep heating group (n = 10; six men, four women) or placebo group (n = 10; six men, four women) (Fig. 2). No significant differences in characteristics and baseline levels were detected between the groups (Table 1).

The mean change in the deep temperature of the calf after the intervention was 4.4 ℃ ± 1.7 ℃ (95% CI, 3.4 ℃ to 5.3 ℃) in the deep heating group and −0.3 ℃ ± 1.1 ℃ (95 % CI, −1.2 ℃ to 0.7 ℃) in the placebo group. For the measurement of deep temperature of the calf, an interaction effect between time and group was observed ($p < 0.001$), suggesting a difference between the deep heating group and the placebo group (Table 2).

Table 1 Characteristics and baseline demographics of subjects

	Deep heating	Placebo	P
Age (years)	21.2 ± 0.9	20.5 ± 0.8	0.094
Height (cm)	163.9 ± 7.6	164.2 ± 10.1	0.941
Weight (kg)	56.3 ± 6.7	59.1 ± 10.0	0.471
Soleus muscle hardness (mN)	1104 ± 123	1164 ± 96	0.236
Ankle dorsiflexion (degrees)	23.9 ± 8.8	24.9 ± 7.8	0.790
Deep temperature (°C)	33.0 ± 1.5	32.9 ± 1.5	0.837
Sex (men/women)	6/4	6/4	1.000

Values are presented as mean ± standard deviation. Differences in continuous data and categorical data between the groups were examined by using the unpaired *t*-test and chi-square test, respectively.

Table 2 Deep temperature, soleus muscle hardness, and ankle dorsiflexion

		Pre-intervention	Post-intervention	Changes (Post- to Pre-)	95% confidence interval	Interaction effect testing	
						F	p
Deep temperature (°C)	Deep heating	33.0 ± 1.5	37.4 ± 1.2*	4.4 ± 1.7	3.4, 5.3		
	Placebo	32.9 ± 1.5	32.6 ± 1.0	-0.3 ± 1.1	-1.2, 0.7	51.884	< 0.001
Soleus muscle hardness (mN)	Deep heating	1104 ± 123	1048 ± 97*	-56 ± 40	-84, -28		
	Placebo	1164 ± 96	1167 ± 77	3 ± 44	-25, 31	9.797	0.006
Passive ROM of dorsiflexion (degrees)	Deep heating	23.9 ± 8.8	26.5 ± 9.0*	2.6 ± 1.8	1.3, 3.9		
	Placebo	24.9 ± 7.8	25.2 ± 7.8	0.3 ± 2.1	-1.0, 1.6	7.159	0.015

Values are presented as mean ± standard deviation. Interaction effect testing was a result of two-factor repeated-measures analysis of variance. ROM means range of motion. *Significant change from the pre- to post-intervention measurement within the groups was based on tests of simple main effect ($p < 0.05$).

The mean change in passive ROM of ankle dorsiflexion after the intervention was 2.6° ± 1.8° (95 % CI, 1.3° to 3.9°) in the deep heating group and 0.3° ± 2.1° (95% CI, − 1.0° to 1.6°) in the placebo group. For the measurement of passive ROM of ankle dorsiflexion, an interaction effect between time and group was observed ($p = 0.015$), suggesting a difference between the deep heating group and the placebo group. When examining the results by using a simple main effect test, it was observed that there was an increase in passive ROM for the deep heating group. In contrast, no change in passive ROM of ankle dorsiflexion was observed in the placebo group (Table 2).

The mean change in soleus muscle hardness after the intervention was − 56 mN ± 40 mN (95 % CI, − 84 mN to − 28 mN) in the deep heating group and 3 mN ± 44 mN (95 % CI, − 25 mN to 31 mN) in the placebo group. For the measurement of soleus muscle hardness, an interaction effect between time and group was observed ($p = 0.006$), suggesting a difference between the deep heating group and the placebo group. When analyzing the results by using a simple main effect test, it was observed that there was a decrease in muscle hardness for the deep heating group. In contrast, no change in soleus muscle hardness was observed for the placebo group (Table 2).

4 Discussion

The present study reports a novel result, namely that muscle hardness decreases after deep heating using microwave diathermy. The results supported our hypothesis. The findings suggest that deep heating may improve or maintain muscle condition by reducing muscle hardness.

Muscle hardness decreased after microwave diathermy irradiation. Static stretching over a single weeks and over 5 weeks increased passive ankle dorsiflexion ROM while reducing gastrocnemius muscle hardness.[5, 6] These results were similar to our findings. The changes in ROM and muscle hardness after stretching may be induced by an increase in intramuscular connective tissue extensibility, resulting in reduced muscle stiffness. On the other hand, we considered that the mechanisms underlying the changes in ROM and muscle hardness caused by deep heating using microwave diathermy are different from those obtained when using stretching. Similar to our findings, passive dorsiflexion ROM increased after heating using short-wave diathermy.[15] The mechanisms underlying this phenomenon are not that the increased ROM was induced by changes in extensibility of the connective tissue but by changes in the mechanical stiffness of the muscle tissue, by changes in the afferent nerve activity, or by a combination of both. Although an increase in the extensibility of the connective tissue is needed to increase the tissue's temperature from 40 ℃ to 45 ℃,[16] our results showed that the muscle's temperature after microwave diathermy reached about 37 ℃. Therefore, it is thought that our findings might not be induced by the increase in the extensibility of the connective tissue but by the changes in the mechanical stiffness of the muscle tissue, by the changes of the afferent nerve activity or by a combination of both as reported previously.[15] Accordingly, deep heating using microwave diathermy would decrease muscle stiffness, resulting in increased passive ROM and decreased muscle hardness due to the aforementioned mechanisms. Consequently, microwave diathermy may be a useful method for improving or maintaining muscle condition and reducing muscle pain.

There are certain limitations of the present study. The individuals assessing muscle hardness and ROM could not be blinded to treatment, because the skin turned red after heating when using microwave diathermy. In addition, the subjects could not be blinded to the treatment, because they could feel their calf heat up or remain unchanged during the intervention. Therefore, bias could not be completely excluded.

Decreased muscle hardness is expected to prevent muscle injury and improve or maintain muscle condition.[5] Muscle pain is associated with muscle hardness,[7] which decreases when muscle pain is reduced.[17] Therefore, physical therapists could use deep heating treatment for athletes to prevent muscle injury, improve or maintain muscle condition, and reduce muscle pain in clinical settings. However, future studies are needed to determine whether deep heating would have these effects for athletes.

5 Conclusion

The purpose of this study was to evaluate changes in soleus muscle hardness after deep heating. Deep heating using microwave diathermy for 15 min decreased soleus muscle hardness. Our results suggest that deep heating using microwave diathermy is effective for improving or maintaining muscle condition and reducing muscle pain.

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