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Research article

Time-Course Changes in Dorsiflexion Range of Motion, Stretch Tolerance, and Shear Elastic Modulus for 20 Minutes of Hot Pack Application

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Abstract

The application of thermal agents via hot packs is a commonly utilized method. However, the time-course changes in the range of motion (ROM), stretch sensation, shear elastic modulus, and muscle temperature during hot pack application are not well understood. This study aimed to investigate the time-course changes in these variables during a 20-minute hot pack application. Eighteen healthy young men (21.1 ± 0.2 years) participated in this study. We measured the dorsiflexion (DF) ROM, passive torque at DF ROM (an indicator of stretch tolerance), and shear elastic modulus (an indicator of muscle stiffness) of the medial gastrocnemius before and every 5 minutes during a 20-minute hot pack application. The results showed that hot pack application for ≥5 minutes significantly ($p < 0.01$) increased DF ROM (5 minutes: $d = 0.48$, 10 minutes: $d = 0.59$, 15 minutes: $d = 0.73$, 20 minutes: $d = 0.88$), passive torque at DF ROM (5 minutes: $d = 0.71$, 10 minutes: $d = 0.71$, 15 minutes: $d = 0.82$, 20 minutes: $d = 0.91$), and muscle temperature (5 minutes: $d = 1.03$, 10 minutes: $d = 1.71$, 15 minutes: $d = 1.74$, 20 minutes: $d = 1.66$). Additionally, the results showed that hot pack application for ≥5 minutes significantly ($p < 0.05$) decreased shear elastic modulus (5 minutes: $d = 0.29$, 10 minutes: $d = 0.31$, 15 minutes: $d = 0.30$, 20 minutes: $d = 0.31$). These results suggest that hot pack application for a minimum 5 minutes can increase ROM and subsequently decrease muscle stiffness.

Key words: Thermal agents, stretch sensation, muscle stiffness, passive torque, muscle temperature.

Introduction

It is generally accepted in sports and rehabilitation settings that elevating soft tissue temperature prior to exercise is beneficial (Bleakley and Costello, 2013). The augmentation of tissue temperature is thought to alter the viscoelastic properties of muscle and other collagenous tissue, thereby preparing them for sports or rehabilitation activities (Woods et al., 2007). This can involve active or passive warm-up utilizing thermal agents, such as hot packs (HP), continuous therapeutic ultra-sound, shortwave diathermy, and microwave applications. Amongst these, HP application is the most prevalent method of thermal therapy as it is the simplest and least expensive to administer. Previous research has demonstrated that heat application can augment a range of motion (ROM) (Bleakley and Costello, 2013; Kain et al., 2011), and heat applied with stretching provides larger gains in ROM compared to stretching alone (Fujita et al., 2018; Knight et al., 2001; Nakano et al., 2012).

An in vitro study demonstrated that muscles heated to 40°C exhibit greater elongation at a given load than unheated muscles (Noonan et al., 1993). Additionally, previous research has demonstrated a reduction in passive stiffness and increased viscous mechanical behaviors at higher temperatures (Bleakley and Costello, 2013; Huang et al., 2009; Wang et al., 2005). However, the effect of heat application on the mechanical properties of muscles in vivo studies is not consistent with findings from in vitro studies (Kubo et al., 2005; Takeuchi et al., 2021). As a result, an increase in ROM after heat application could be attributed to changes in participants' sensory perception, specifically stretch tolerance (Takeuchi et al., 2021).

Recent in vivo studies have enabled the measurement of muscle stiffness using shear wave elastography (SWE). However, to the best of our knowledge, the effect of hyperthermia through HP application on muscle stiffness remains unknown. Utilizing SWE allows for the clarification of the effect of HP application on muscle stiffness in vivo. Furthermore, in view of clinical applications, it is essential to understand the time-course changes during HP application. Therefore, this study aimed to investigate the time-course changes in dorsiflexion (DF) ROM, stretch tolerance, the shear elastic modulus of of the medial gastrocnemius (MG), and muscle temperature during a 20-minute HP application.

Methods

Participants

We investigated the time-course changes in the DF ROM, passive torque at DF ROM, muscle temperature, and shear elastic modulus of the MG during 20 min HP application. Eighteen healthy young male volunteers participated in the study (age, 21.1 ± 0.2 years; height, 172.6 ± 6.6 cm; body mass, 62.6 ± 7.4 kg). Participants with a history of neuromuscular disease or musculoskeletal injury on the lower extremity were excluded. All participants were fully informed of the procedures and purpose of the study, and all provided written informed consent.

The study adhered to the guidelines outlined in the Declaration of Helsinki and received approval from the

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Ethics Committee of the Niigata University of Health and Welfare, Niigata, Japan. A sample size of 18 participants was determined to be sufficient for a one-way repeated analysis of variance (ANOVA) (effect size = 0.40 [large], alpha error = 0.05, and power = 0.80) using G*Power 3.1 software (Heinrich Heine University, Düsseldorf, Germany).

Experimental design

We measured all variables, i.e., DF ROM, passive torque at DF ROM, muscle temperature, and shear elastic modulus of the MG both prior to (PRE) and at 5 min intervals (5, 10, 15, and 20 min) during the HP application. Prior to the experiment, all participants were familiarized with the procedures and instructed to remain relaxed throughout the measurement period.

Assessment of DF ROM and passive torque at DF ROM

The participants were instructed to lie in the prone position on a Biodex System 3.0 (Biodex Medical Systems Inc., USA) with their hips securely held in place by an adjustable lap belt. The knee of the dominant leg was maintained in full extension, and the foot of the same leg was firmly attached to the footplate of the dynamometer using adjustable lap belts. An examiner manually moved the footplate of the dynamometer at a slow pace to avoid eliciting a stretch reflex. The passive movement started from an ankle angle at 30° plantarflexion to the DF angle just before the participants began to feel discomfort or pain. We instructed the participants to verbally inform the examiner when they started to feel discomfort or pain (Kiyono et al., 2021; Nakamura et al., 2018). We fixed the footplate at that angle, measured the ankle angle and passive torque, and defined the angle as DF ROM and the passive torque as passive torque at DF ROM. Also, we defined the passive torque at DF ROM as the index of sensory perception. An increase in passive torque at DF ROM was defined as a change in stretch tolerance (sensory perception) (Mizuno et al., 2013; Nakamura et al., 2021b).

Assessment of the shear elastic modulus via SWE

In this study, we adopted the shear elastic modulus measured by ultrasonic SWE as an indicator of muscle stiffness. The shear elastic modulus of the MG was measured using an ultrasonic SWE machine (Aplio 500, Toshiba Medical Systems, Tochigi, Japan) with a 5 - 14 MHz linear probe at 10° DF, similar to the procedures during the measurements of the DF ROM and passive torque (Kiyono et al., 2021; Nakamura et al., 2018). Similar to the previous studies, we measured the shear elastic modulus of the MG at 30% proximal from the popliteal crease to the lateral malleolus (Akagi and Takahashi, 2013; Akagi and Takahashi, 2014). An ultrasound transducer was positioned parallel to the direction of the muscle fibers on the measurement points, as confirmed by tracing several fascicles without interruption across the B-mode image.

This study's quadrangular region of interest was set to cover the whole muscle. The obtained elastographic images were analyzed using image analysis software (MSI Analyzer version 5.0; Institute of Rehabilitation Science, Tokuyukai Medical Corporation, Japan). The elastographic image of the MG was measured twice, and the average value of the shear elastic modulus was used for further analysis (Akagi and Takahashi, 2013; Akagi and Takahashi, 2014).

Muscle temperature assessment

The deep tissue temperature, as an index of the temperature of the MG, was measured using an infrared thermometer (Terumo Corporation Coretemp CM-210) by the zero-heat flow method. A previous study reported that the temperature of deep body tissues measured by this method highly correlated with the muscle temperature at a depth of 18 mm. The measurement position was affixed to the proximal 30% of the peroneal malleolus from the popliteal fossa in an area that did not interfere with the shear elastic modulus measurement.

Hot Pack (HP) applications

The HP was applied to cover the muscle belly of the gastrocnemius of the dominant side for 20 min (Figure 1). The participants lay in the prone position, similar to the outcome measurement. Precisely, the participants were placed in the prone position with the ankle joint fixed to a footplate, the ankle in the neutral position, and the knee joint in full extension. The HP was heated to 75°C in a hydro collator and wrapped in a towel.

Figure 1. **Hot pack application for the gastrocnemius muscle.**

Test-retest reliability of the measurements

Test–retest reliability was assessed by the coefficient of variation (CV) and intraclass correlation coefficient (ICC) in 11 healthy men (21.3 ± 0.7 years, 175.5 ± 7.8 cm, 66.8 ± 9.7 kg) with a 5-min interval between two measurements without any intervention. The CV and ICC were 1.9 ± 1.9 and 0.938 in the DF ROM, 2.7% ± 2.2% and 0.979 in passive torque at DF ROM, and 5.8% ± 3.2% and 0.991 in the shear elastic modulus.

Statistical analysis

We employed SPSS version 24.0 (SPSS Japan Inc., Tokyo, Japan) for statistical analysis in this study. The distribution of the data was evaluated using the Shapiro-Wilk test, and it was confirmed that the data adhering to a normal distribution. A one-way repeated-measures ANOVA with the Bonferroni post-hoc test was utilized to determine the differences between the measurements obtained at PRE, 5 min, 10 min, 15 min, and 20 min. Classification of effect size was set where $\eta_p^2 < 0.01$ was considered small, 0.02 – 0.1 was considered medium, and more than 0.1 was considered to be a large effect size (Cohen, 1988). Additionally, we calculated the Cohen's d effect sizes as differences in the mean value divided by the pooled standard deviation between PRE and 5 min, 10 min, 15 min, and 20 min. Cohen d of 0.00 - 0.19 was considered trivial, 0.20 - 0.49 was small, 0.50 - 0.79 was moderate, and ≥0.80 was large (Cohen, 1988). The difference was considered statistically significant at an alpha level of $p < 0.05$. Data are presented as mean ± standard deviation.

Results

Figure 2 presents the time-course changes in all variables during 20 min of HP application. One-way repeated-measures ANOVA showed the main effects of DF ROM ($p < 0.01$; $F = 23.7$; $\eta_p^2 = 0.583$), passive torque at DF ROM ($p < 0.01$; $F = 11.6$; $\eta_p^2 = 0.406$), shear elastic modulus ($p < 0.01$; $F = 6.11$; $\eta_p^2 = 0.264$), and muscle temperature ($p < 0.01$; $F = 100.9$; $\eta_p^2 = 0.856$). The post hoc test revealed that the DF ROM after 5 - 20 min (5 min: $d = 0.48$, 10 min: $d = 0.59$, 15 min: $d = 0.73$, 20 min: $d = 0.88$, respectively) was significantly ($p < 0.01$) larger than the PRE value, and the DF ROM after 20 min was significantly ($p = 0.015$) larger than the 5-min value (Figure 2A). Moreover, passive torque at DF ROM after 5 - 20 min (5 min: $d = 0.71$, 10 min: $d = 0.71$, 15 min: $d = 0.82$, 20 min: $d = 0.91$, respectively) was significantly ($p < 0.01$) larger than the PRE value, and the DF ROM after 20 min was significantly ($p = 0.049$) larger than the 5-min value (Figure 2B). Conversely, the shear elastic modulus after 5 - 20 min (5 min: $d = 0.29$, 10 min: $d = 0.31$, 15 min: $d = 0.30$, 20 min: $d = 0.31$, respectively) was significantly ($p < 0.05$) lower than the PRE value (Figure 2C). The muscle temperature after 5 - 20 min (5 min: $d = 1.03$, 10 min: $d = 1.71$, 15 min: $d = 1.74$, 20 min: $d = 1.66$, respectively) was significantly ($p < 0.01$) larger than the PRE value, and the DF ROM after 10 min was significantly ($p < 0.05$) larger than that after 5 min (Figure 2D).

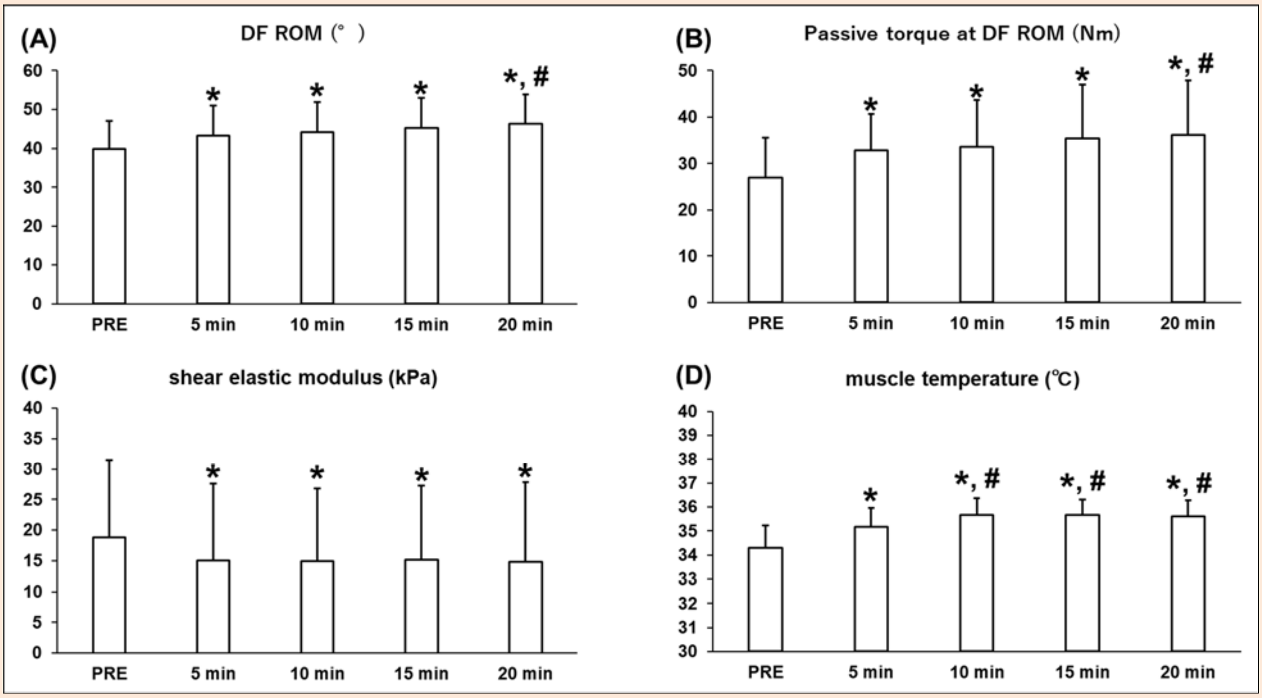

Figure 2. Time-course changes in dorsiflexion range of motion (DF ROM, a), passive torque at DF ROM (b), the shear elastic modulus of the medial gastrocnemius muscle (c), and muscle temperature (d) during 20 min of hot pack application.
* Significantly different from before hot pack application (PRE)
# Significantly different from 5 min

Discussion

This study investigated the time-course changes in ROM, stretch tolerance, muscle stiffness, and muscle temperature during 20 minutes of HP application. The results showed that 5 min of HP application could increase DF ROM, passive torque at DF ROM, and muscle temperature and decrease the shear elastic modulus. Moreover, the DF ROM after 20 min was significantly larger than after 5 min. To the best of our knowledge, time-course changes are observed within 20 min of HP application. Our results showed that already 5 min of HP application is enough to observe changes in ROM, stretch tolerance, muscle stiffness, and muscle temperature.

Our results showed that 5 min of HP application could increase the DF ROM, which is consistent with the results of previous studies. Moreover, significant changes were found in the passive torque at DF ROM, as an index of stretch tolerance and shear elastic modulus of the MG, as an index of muscle stiffness. Thus, if HP application increases the DF ROM and decreases muscle stiffness, 5 min of HP application could be a sufficient and effective approach. Interestingly, 20 min of HP application showed significant increases in the DF ROM and passive torque at DF ROM than values at 5 min, but no significant change was found in the shear elastic modulus. Previous studies have reported that an increase in the ROM could be associated with changes in stretch tolerance rather than with changes in muscle stiffness after static stretching (Nakamura et al., 2021b), foam rolling (Nakamura et al., 2021a), and icing application (Kiyono et al., 2021). Although the mechanism of the changes in stretch tolerance is unknown in this study, Bleakley and Costello (2013) pointed out that heat stimulation increases patients' stretch tolerance based on sensory stimulation and analgesia. Thus, the increase in the DF ROM following HP application may be related to the changes in stretch tolerance rather than to the changes in muscle stiffness.

As described above, our results showed a significant decrease in the shear elastic modulus of the MG after 5 min of HP application. Traditionally, heat application is thought to change the viscoelastic property of collagenous tissues, i.e., decrease in muscle stiffness. In in vitro studies, heat application could decrease muscle stiffness and greater viscous mechanical behaviors at higher temperatures (Bleakley and Costello, 2013; Huang et al., 2009; Wang et al., 2005). However, in in vivo studies, heat application could not induce the large temperature changes induced within in vitro models (Bleakley and Costello, 2013). No significant changes were found in the mechanical properties of human muscles and tendons after hot water immersion (Kubo et al., 2005; Takeuchi et al., 2021). Similarly, no significant changes were noted in the passive stiffness of the hamstring muscle-tendon unit after HP application (Fujita et al., 2018). These results were inconsistent with our findings, showing decreased muscle stiffness after HP application. To the best of our knowledge, this is the first study to investigate the effects of HP application on muscle stiffness. While these previous studies have used hot water immersion (Kubo et al., 2005; Takeuchi et al., 2021), the present study applied HP. This discrepancy between our results and those of previous studies (Kubo et al., 2005; Takeuchi et al., 2021) could be related to the difference in the type of thermal agent. Other thermal agents include therapeutic ultrasound, shortwave diathermy, and microwave. The effects of these types of thermal agents on muscle stiffness warrant further investigation.

HP application is a modality that can be easily used in sports and rehabilitation settings. The results of this study suggest that a 5-min HP application can increase ROM and decrease muscle stiffness due to changes in pain threshold; thus, its application is expected in sports and rehabilitation settings in the future.

There were some limitations in this study. First, we investigated the effect of HP application on passive property in young male participants. Also, we investigated the time-course changes during the 20-min HP application, and the sustained effect of HP applications remained unclear. Thus, future studies are needed to investigate the effects of HP applications, including the sustained effect, on the passive properties of the muscle-tendon unit in both males and females.

Conclusion

Our results suggested that HP application for ≥5 min effectively increases DF ROM and decreases the shear elastic modulus of MG. In addition, if a further increase in the DF ROM is desired, a 20-min HP application is even more effective compared to only 5min HP application.

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Key points

- We investigated the time-course changes in the passive properties of the medial gastrocnemius muscle-tendon unit during a 20-minute hot pack application.
- We measured the dorsiflexion range of motion (ROM), stretch tolerance, and muscle stiffness before and every 5 minutes during a 20-minute hot pack application.
- The results showed that hot pack application for ≥5 minutes significantly changed DF ROM, stretch tolerance, and shear elastic modulus.
- These results suggest that hot pack application for only 5 minutes is necessary to increase ROM and subsequently decrease muscle stiffness.

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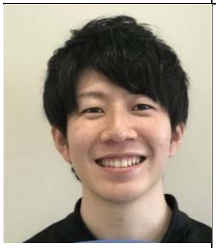

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