



Comparing heat and cold therapy for muscle recovery: insights into delayed onset muscle soreness

Sebastian Szajkowski ^{1ABCD}, Jarosław Pasek ^{2BD}, Witold Woch ^{3B},
Grzegorz Cieślar ^{4BD}

¹ Faculty of Medical Sciences, Warsaw Medical Academy of Applied Sciences, Warszawa, Poland

² Collegium Medicum, Jan Długosz University in Częstochowa, Poland

³ University of Applied Sciences, Faculty of Medicine and Health Sciences in Nowy Sącz, Poland

⁴ Department of Internal Medicine, Angiology and Physical Medicine, Medical University of Silesia in Katowice, Bytom, Poland

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Abstract: Background. The manifestation of Delayed Onset Muscle Soreness (DOMS) is the consequence of intense work performed by skeletal muscles. An increase in muscle tone and stiffness, concomitant with DOMS, is reflected in the altered values of biomechanical and viscoelastic parameters of muscles. Methods. The participants of the study (n=60) were divided into three groups: group 1 (n=20) was subjected to infrared radiation, group 2 (n=20) was treated by means of local cryotherapy, and group 3 (n=20) designated as the control group. The gastrocnemius muscle fatigue protocol was performed in order to observe the development of DOMS symptoms in the following days. The participants underwent therapeutic procedures for three consecutive days. The efficacy of the therapeutic intervention was evaluated by measuring the muscle tone using a myotonometer on five occasions: prior to the study, and then thrice during its course, with a final assessment after the study had concluded. Results. In groups 1 and 2, a statistically significant decrease in tone was observed between day 1 and 2 (median of 18.3 – 16.4 [Hz]; p=0.009 in group 1 and median of 18.8 – 15.7 [Hz]; p= 0.005 in group 2) and stiffness (median of 291 – 271 [N/m]; p=0.005 in group 1 and median of 337 – 268 [N/m]; p=0.026 in group 2). Lower values were observed in group 2. In group 3, the decrease in tone and stiffness occurred later, only after 2 days. Subsequent to day 2, a decrease in tone and stiffness values was observed in all groups. On day 2, significant differences in tone values were identified (p=0.004; group 1 vs group 3 and p=0.004; group 2 vs group 3) and in stiffness (p=0.003; group 1 vs group 3 and p=0.002; group 2 vs group 3). In addition, on day 4, the decrement values in group 2 decreased below the baseline values (median of 1.35 [log] vs. 1.29 [log]), and the differences observed were statistically significant (p=0.006). Conclusions. It has been demonstrated that local cryotherapy is the most efficacious method for reducing tone and stiffness, and restoring muscle flexibility in the course of delayed onset muscle soreness (DOMS). Beneficial effects were also observed in response to the application of infrared radiation. Both treatment methods were found to be significantly more effective than sham therapy.

Keywords: muscle soreness, cryotherapy, infrared, recovery, myotonometry

Corresponding author: Sebastian Szajkowski, email: s.g.szajkowski@gmail.com

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INTRODUCTION

The manifestation of symptoms of Delayed Onset Muscle Soreness (DOMS) and Delayed Onset Soft Tissue Stiffness (DOSS) is associated with intense physical exertion, resulting in the activation of skeletal muscle tissue [1]. The onset of these symptoms typically occurs within 12 to 72 hours post-exercise, reaching a nadir 48 hours after the cessation of physical activity [2]. The duration of these symptoms is generally limited to five days. Studies have demonstrated that during strenuous physical exertion, the maximum load capacity of muscle fibers and fascia is surpassed, resulting in micro-damage to all layers of both muscle and extra-muscular connective tissue: epimysium, perimysium, and endomysium. These structures are implicated in the delayed onset of soreness and stiffness, which are characteristic features of DOMS [3,4]. The increase in fascial thickness, observed subsequent to exercise, along with the accumulation of hyaluronic acid, also reflects swelling and inflammation resulting from micro-damages. Impairment of the mutual sliding movement of deep fascia and muscle fibers has also been observed. Such limitations of mobility, in combination with micro-damages of connective tissue whose extendibility is limited, may be associated with pain experienced in the course of DOMS. In light of the most recent research findings, the authors propose the term "delayed onset soft tissue stiffness (DOSS) syndrome" as a more precise and accurate descriptor of the delayed clinical symptoms when compared to the term "delayed muscle soreness syndrome (DOMS)" [5].

In accordance with the RICE (rest, ice, compression, and elevation) protocol, cryotherapy is frequently utilized to address pain associated with musculoskeletal disorders. The physiological consequences of cryotherapy treatment procedures encompass reduced local metabolism, diminished capillary osmotic pressure, decreased muscle spindle activity, constricted blood vessels, and subsequent dilation, as well as augmented thresholds for stimulation of sensory receptors. The anticipated outcomes of these processes include the alleviation of inflammation and swelling, the improvement of blood circulation, the provision of analgesic effects, and the reduction of muscle spasms [6,7]. However, recent studies, predominantly those conducted on animal models, have demonstrated that cryotherapy can potentially delay muscle recovery following micro-traumas. Consequently, further research is necessary to ascertain the precise impact of cryotherapy on the prevention of delayed-onset muscle soreness (DOMS). In the inflammatory phase, the application of hyperthermia is not commonly recommended due to its capacity to increase blood flow, which can exacerbate discomfort and swelling [8]. Conversely, it has been reported that an increase in muscle temperature resulting from hyperthermia treatment can induce heat shock proteins (HSPs), dilate peripheral blood vessels, improve local blood supply, and enhance regeneration [9]. Conversely, studies have demonstrated the efficacy of cold and heat therapy in enhancing post-workout regeneration [10]. However, the comparative effectiveness of these therapeutic modalities remains to be elucidated. Consequently, a more efficacious approach to mitigating the effects of DOMS and DOSS can be ascertained through a direct comparison under homogeneous conditions.

The increase in muscle tone and stiffness, observed in the course of delayed-onset muscle soreness (DOMS) and delayed-onset muscle soreness (DOSS), is reflected in the altered values of biomechanical and visco-elastic parameters of muscles. An objective way of assessing the effectiveness of physical medicine and rehabilitation methods is provided by myotonometry, among others. Myotonometry is a non-invasive method of quantitative assessment of mechanical and visco-elastic properties of muscular tissue and connective tissue. It has been shown to effectively replace the subjective examination by palpation and has been comprehensively documented in the literature [12,13]. The reliability estimates (ICC) of the MyotonPro (Myoton Ltd., Tallinn, Estonia) device for muscle stiffness measures ranged from 0.898 to 0.986, regardless of whether based on a single

measurement or the average of three measurements [14,15], suggesting that a single measurement may be sufficient for both clinical and research applications.

The objective of this study was to evaluate the effectiveness of physical medicine treatment methods, including infrared thermotherapy and local cryotherapy, on the mechanical and visco-elastic properties of muscles during the recovery phase of delayed-onset muscle soreness (DOMS) and delayed-onset muscle soreness (DOSS). The primary research question guiding this study is whether the forms of thermotherapy used will contribute to a significantly faster restoration of the initial values of myotonometric parameters. The secondary research question is whether these forms of thermotherapy will help optimize the process of post-workout regeneration of muscles and connective tissue.

MATERIAL AND METHODS

Subject

Sixty healthy volunteers have been qualified for the study (34 men and 26 women), who met the following inclusion criteria: age from 20 to 30 years, both sexes: women and men, BMI in the range: 18.5-29.9 (kg/m²), who do not regularly practice sports and who have been at a similarly low level of training. The study included young adults within a small age range and a specific BMI range, to avoid the influence of morphological and biomechanical changes in muscles that occur with age. The criteria for exclusion from the study were as follows: injuries treated in the last 3 months, skin injuries or unspecified skin lesions at the measurement sites, declaration of general fatigue, fever, suffering from chronic diseases, staying on medication. The participants were required to refrain from physical exertion for 72 hours prior to and throughout the experiment. The participants could resign from participation in the study at their own request at any time during the experiment.

Study design

This prospective clinical trial involved 60 healthy volunteers. The study participants were randomly divided into three groups (Group 1: IR radiation (n=20; 11 men / 9 women), Group 2: local cryotherapy (n=20; 11 men / 9 women), Group 3: control group (n=20; 12 men / 8 women) by block randomization (1:1:1 allocation ratio) and blocks size 3, 6, 9, using Microsoft Excel software. The sequence of performing experimental procedures was as follows: day 0: measurements by means of myotonometer before proceeding with the muscle fatigue protocol, followed by the execution of the muscle fatigue protocol, day 1: measurements with myotonometer before therapeutic intervention (after the muscle fatigue protocol), followed by performing therapeutic intervention, days 2 and 3: measurements taken using myotonometer before the therapeutic intervention and after the intervention performed on the previous day, day 4: measurements with the use of myotonometer. In total, the participants had 3 therapeutic interventions performed (day 1-3) and 5 myotonometric measurements taken (day 0-4); (Figure 1). Subsequent examinations and treatment procedures were preceded by 24-hour regeneration. Measurements and therapeutic interventions were carried out between 09:00 hours and 14:00 hours, observing the proper sequence of participants. Before starting the study, volunteers filled out and signed consent forms to participate in the experiment. During the tests, the same ambient conditions were maintained: air temperature of 22°C and air humidity of 50%.

Ethics

The study was performed in the Didactic and Scientific Centre of Warsaw Medical Academy of Applied Sciences in Warsaw, Poland. The study was conducted in accordance with the Declaration of Helsinki (1964) and its protocol has been accepted by the Bioethics Committee (approval reference number: 2022/09/MUM-01).

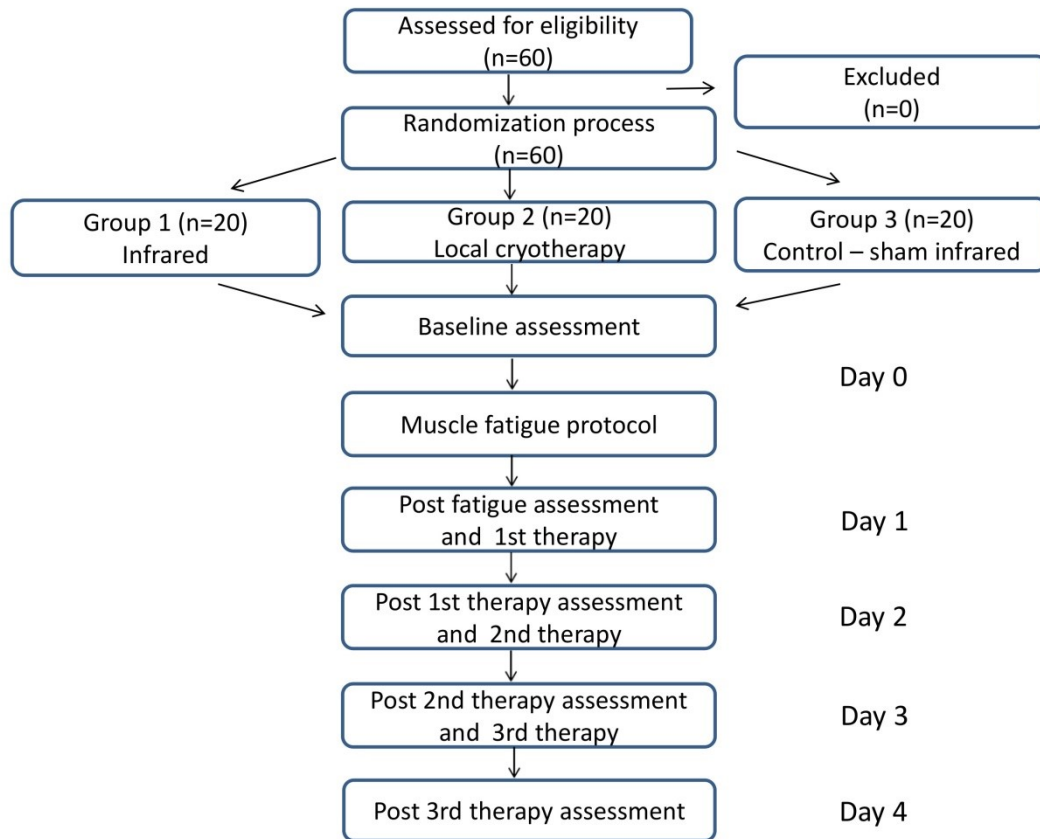


Figure 1. Study design.

Calf raise - muscle fatigue protocol

Participants were requested to place the forefoot of the non-dominant limb at the edge of a step and to make a single leg raise on tiptoes, applying maximum plantar flexion of the ankle joint, then they were asked to lower to the maximum dorsal flexion, as described in the literature [16,17]. The metronome, set at 1.33Hz, was used to control the pace of exercise, i.e., for maximum plantar flexion in one stroke, followed by four controlled lowering strokes to the maximum dorsal flexion. The participants were allowed to slightly lean/rest their fingertips against the wall just in front of them to maintain balance. The participants had the opportunity to get acquainted with the exercise they were asked to perform. The participants performed the exercise continuously until failure. Failure was defined as three consecutive calf raises during which the full range of motion was not achieved or failing to follow the normal pace of exercise. The participants were not aware of the criteria for discontinuing the exercise.

Therapeutic interventions in the form of physical procedures

Group 1 was treated with the most commonly used lamp, namely Sollux Lumina V5.0, Poland, which generates IR radiation in the range of 830 nm. The lamp set consisted of a special tripod, a special bulb, a red filter, a mesh separating the filter (protection in the event of bulb burst), and a snoot limiting the area illuminated by the lamp. Before commencing with the irradiation, the patient assumed comfortable prone position, the area meant for treatment was exposed so that radiation directly affected the skin. The person performing the procedure set the lamp at a distance of 50 cm from the body of the treated person in such a way that the main ray was perpendicular to the place undergoing treatment. During the exposure, the treated person had protective glasses on. The duration of the procedure was 15 minutes [18].

In group 2 local cryotherapy procedures were applied by means of Bryza II device, manufactured by Kriopol, Poland, in which the coolant applied was liquid nitrogen (the temperature at the nozzle outlet was -160°C). Cryotherapy was also performed with the subject in prone position, with the stream of liquid nitrogen directed perpendicularly to the treatment area by performing circular movements with the nozzle. The distance between the nozzle end and the treated surface was 20 cm, and the treatment time was 3 minutes [19].

In group 3 (control), sham therapy was performed applying lamps Sollux Lumina V5.0 Poland, with ordinary LED bulb without filter. The procedure of performing sham treatment was maintained in line with that used in group 1.

Assessment – Myotonometry

MyotonPRO device (Myoton, Estonia) was used to assess the biomechanical parameters of the muscle, it is a digital device consisting of a body and a depth probe ($\text{Ø}3$ mm) that allows non-invasive examination of tissue properties [20]. The myotonometer used utilizes the Mechanical Dynamic Response method, which consists in applying a precise mechanical pulse, registering the dynamic response of the tissue in the form of a signal of physical displacement and acceleration of oscillation, and subsequent calculation of the parameters characterizing the tested biomechanical properties, namely: tone [Hz], stiffness [N/m], and decrement (D) [log], the latter characterizes elasticity – the lower the value, the higher the elasticity and visco-elasticity; relaxation time of mechanical stress [ms], and the ratio of relaxation time to deformation time, characterizing creep [Deborah number]. The probe was applied perpendicularly to the examined tissue. The device automatically exerted a pre-pressure with a force of 0.18 N, and then, after calibration, the automatically generated 5-fold short mechanical pulse with a force of 0.4 N and a duration of 15 ms to deform the tissue. The accelerometer recorded oscillations of the examined tissue [21]. During the test, the coefficient of variation (CV) of each test result was observed, and if the CV exceeded 3%, the test was repeated once again. All MyotonPRO measurements were taken 3 times and averaged for the comparative analyses. The total measurement time was up to 20 s. All the treatment and measurement procedures were performed by an experienced physiotherapist, trained in the field of myotonometry and in conducting scientific research. During the measurements, the subject was in a prone position, lying on his stomach with his knees straight and feet hanging without support beyond the edge of the couch. The ankle joints were placed in a neutral position. The lower limbs were attached to the table by a strap just above the popliteal fossa. Measurements were taken at distance of four finger width below the *sulcus popliteus* in the thickest, most prominent place of the medial head of the gastrocnemius calf muscle, in accordance with frequently used methodology [22]. Bearing in mind the variability of the anatomical structure, the designated place of measurement corresponding to the largest circumference of the calf muscles was additionally verified by means of a tape measure and, if required, a necessary correction was made.

Statistical analysis

Determination of mean and standard deviation was used to represent the average and the typical spread of demographic data. The nature of distribution of the studied variables was tested using the Shapiro–Wilk test. The data were not normally distributed. The results of all measured variables were presented using median and lower-upper quartile (Q1-Q3). Friedman's ANOVA - repeated measures analysis of variance by ranks - was used to examine the changes in examined variables (day 0-4) and Kruskal–Wallis test by ranks was used to examine the changes between groups (1-3). Post-hoc tests with Bonferroni correction was used to analyze the pair-wise comparisons. Effect sizes were calculated using partial eta squared (η^2) and interpreted according to the following criteria: if $0 \leq \eta^2 < 0.05$, there is no effect; if $0.05 \leq \eta^2 < 0.26$, the effect is minimal; if $0.26 \leq \eta^2 < 0.64$, the effect is moderate; and if $\eta^2 \geq 0.64$, the effect is strong [23]. An a priori power

analysis was conducted with the G*power software (version 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany; (<http://www.gpower.hhu.de>) [24]. The repeated ANOVA measure within-between interactions with an effect size of at least 0.25, $\alpha = 0.05$, and $1-\beta = 0.95$, correlation among repeated measures = 0.25, gave a statistical power of 95.1% and the total sample size of 57 subjects. Considering the possibility of withdrawal during the experiment and wanting to ensure equal group sizes, the sample size was planned at 60 subjects. All statistical analyses were performed using PQStat 1.8.6. Statistical significance was set at $p < 0.05$.

RESULTS

The average age in group 1 was 29.55 ± 8.71 years of age, in group 2: 27.7 ± 5.41 years of age and in group 3: 28.44 ± 6.4 years of age. The difference was not statistically significant ($p = 0.315$). The average value of the BMI index was 23.99 ± 3.82 kg/m² in group 1, 24.69 ± 4.07 kg/m² in group 2 and 27.12 ± 3.24 kg/m² in group 3. The difference was not statistically significant ($p = 0.206$).

The results of successive measurements (day 0-4) were compared in each group respectively. In addition, the results obtained in subsequent measurements were compared between groups (group 1-3). In each of the study groups (group 1 and group 2), statistically significant decreases in tone were observed after day 1 (between day 1 and 2), and lower values were observed in group 2. Starting from day 2, in the following days tone decreased in all groups. Only in group 2 tone decreased below the initial value. In the control group (group 3), the tone reduction occurred only after day 2. On day 2, tone values were statistically significantly higher in the control group (group 3) compared to the study groups (group 1 and group 2); (Table 1A and Figure 1A). Post-hoc multiple comparisons (Dunn Bonferroni) revealed statistically significant differences: Group 1: $p = 0.002$ (Day 1 vs Day 0), $p = 0.009$ (Day 1 vs Day 2), $p = 0.005$ (Day 1 vs Day 3), $p = 0.005$ (Day 1 vs Day 4). Group 2: $p = 0.002$ (Day 1 vs Day 0), $p = 0.005$ (Day 1 vs Day 2), $p = 0.001$ (Day 1 vs Day 3), $p < 0.001$ (Day 1 vs Day 4). Group 3: $p = 0.008$ (Day 1 vs Day 0), $p = 0.009$ (Day 1 vs Day 4). Day 2: $p = 0.004$ (Group 1 vs Group 3), $p = 0.004$ (Group 2 vs Group 3).

In the study groups (group 1 and group 2) there was a statistically significant decrease of stiffness after day 1 (between day 1 and 2), with lower values observed in group 2. Starting from day 2, in the following days stiffness decreased in all groups. Only in group 2 did the stiffness decrease below baseline/initial value. In the control group (group 3), the reduction of stiffness was observed only after day 2. On day 2, stiffness values were statistically significantly higher in the control group (group 3) compared to the study groups (group 1 and group 2); (Table 1B and Figure 1B). Post-hoc multiple comparisons (Dunn Bonferroni) revealed statistically significant differences: Group 1: $p < 0.001$ (Day 1 vs Day 0), $p = 0.005$ (Day 1 vs Day 2), $p = 0.005$ (Day 1 vs Day 3), $p = 0.002$ (Day 1 vs Day 4). Group 2: $p = 0.038$ (Day 1 vs Day 0), $p = 0.026$ (Day 1 vs Day 2), $p = 0.006$ (Day 1 vs Day 3), $p < 0.001$ (Day 1 vs Day 4). Group 3: $p = 0.001$ (Day 0 vs Day 2). Day 2: $p = 0.003$ (Group 1 vs Group 3), $p = 0.002$ (Group 2 vs Group 3). Day 4: $p = 0.043$ (Group 2 vs Group 3).

In group 2, the decrement values decreased on day 4 to below baseline/initial values and the differences observed were statistically significant. In the control group (group 3), decrement values increased above baseline values. The differences were also statistically significant. No significant differences were observed in group 1 (Table 1C and Figure 1C). Post-hoc multiple comparisons (Dunn Bonferroni) revealed statistically significant differences: Group 2: $p = 0.022$ (Day 0 vs Day 4), $p = 0.046$ (Day 2 vs Day 4).

Table 1. Changes in A) tone, B) stiffness, C) decrement, D) relaxation and E) creep of the gastrocnemius muscle – results of the MyotonPRO measurements at particular time intervals in groups.

V	G	Median (Q1-Q3)					η^2	**p
		Day 0	Day 1	Day 2	Day 3	Day 4		
A) Tone [Hz]	G1	15.6 (13.8-16.65)	18.3 (16.55-19.32)	16.4 (13.87-17.6)	16.25 (14.17-17.42)	16.35 (13.45-17.2)	0.05	<0.001
	G2	16.2 (15.1-16.9)	18.8 (17.15-20)	15.7 (14.65-17)	15.5 (15-16.3)	15.4 (15-16.2)	0.41	<0.001
	G3	16.5 (15.95-18.05)	19 (17.9-19.95)	19.3 (17.25-21.35)	17.8 (15.75-18.6)	17.1 (15.75-18.06)	0.37	<0.001
η^2		0.08	0.21	0.24	0.02	0.05		
*p		0.062	0.051	0.001	0.212	0.098		
B) Stiffness [N/m]	G1	251 (238-294.25)	291 (268.75-330)	271 (249.75-302.75)	267.5 (248.5-295)	271.5 (255.25-295)	0.30	<0.001
	G2	274 (252.5-301.5)	337 (291.5-355.5)	268 (240.5-299.5)	263 (251-303.5)	259 (249-292)	0.33	<0.001
	G3	296 (262-308.5)	308 (295.5-360.5)	360 (304.5-395.5)	320 (272.5-380.5)	320 (272.5-370.5)	0.31	0.001
η^2		0.05	0.03	0.27	0.08	0.09		
*p		0.092	0.157	<0.001	0.053	0.041		
C) Decrement [log]	G1	1.22 (1.16-1.38)	1.33 (1.23-1.34)	1.32 (1.17-1.5)	1.31 (1.17-1.48)	1.22 (1.17-1.37)	0.05	0.051
	G2	1.35 (1.23-1.42)	1.38 (1.32-1.5)	1.39 (1.33-1.44)	1.3 (1.25-1.44)	1.29 (1.23-1.33)	0.24	0.006
	G3	1.09 (0.98-1.13)	1.19 (1.07-1.26)	1.18 (1.09-1.27)	1.15 (1.11-1.27)	1.17 (1.08-1.24)	0.21	0.002
η^2		0.28	0.32	0.3	0.12	0.08		
*p		0.004	0.001	0.003	0.02	0.056		
D) Relaxation [m/s]	G1	20.4 (19.17-21.75)	18.5 (15.72-20.05)	20.55 (17.35-22.7)	20.8 (18.02-22.92)	20.85 (17.35-22.37)	0.26	<0.001
	G2	20 (17.75-20.45)	15.3 (14.8-17.8)	19.1 (17.4-21.6)	18.8 (17.8-20.5)	18.5 (17.35-19.65)	0.30	0.001
	G3	17.6 (16.8-18.9)	14.7 (13.85-16.1)	13.5 (11.55-18)	15.8 (14.15-18.85)	15.3 (14.15-17.35)	0.35	<0.001
η^2		0.17	0.13	0.26	0.15	0.2		
*p		0.006	0.019	0.001	0.01	0.003		
E) Creep [Deborah No.]	G1	1.29 (1.18-1.36)	1.16 (0.96-1.25)	1.25 (1.07-1.42)	1.28 (1.11-1.38)	1.26 (1.07-1.38)	0.28	<0.001
	G2	1.2 (1.14-1.27)	0.97 (0.91-1.08)	1.19 (1.04-1.29)	1.19 (1.05-1.26)	1.13 (1.03-1.22)	0.25	0.007
	G3	1.08 (1.05-1.14)	0.91 (0.85-0.98)	0.89 (0.8-1.1)	1.02 (0.93-1.15)	1 (0.93-1.1)	0.38	<0.001
η^2		0.17	0.15	0.27	0.12	0.18		
*p		0.007	0.011	0.001	0.022	0.004		

V - Variable, G – group, *p ANOVA Kruskala-Wallis, **p ANOVA Friedmana

Group 3: p=0.019 (Day 1 vs Day 0), p=0.003 (Day 1 vs Day 2), p=0.013 (Day 1 vs Day 3), p=0.037 (Day 1 vs Day 4). Day 0: p<0.001 (Group 2 vs Group 3). Day 1: p=0.011 (Group 1 vs Group 3), p<0.001 (Group 2 vs Group 3). Day 2: p<0.001 (Group 2 vs Group 3). Day 3: p=0.046 (Group 2 vs Group 3).

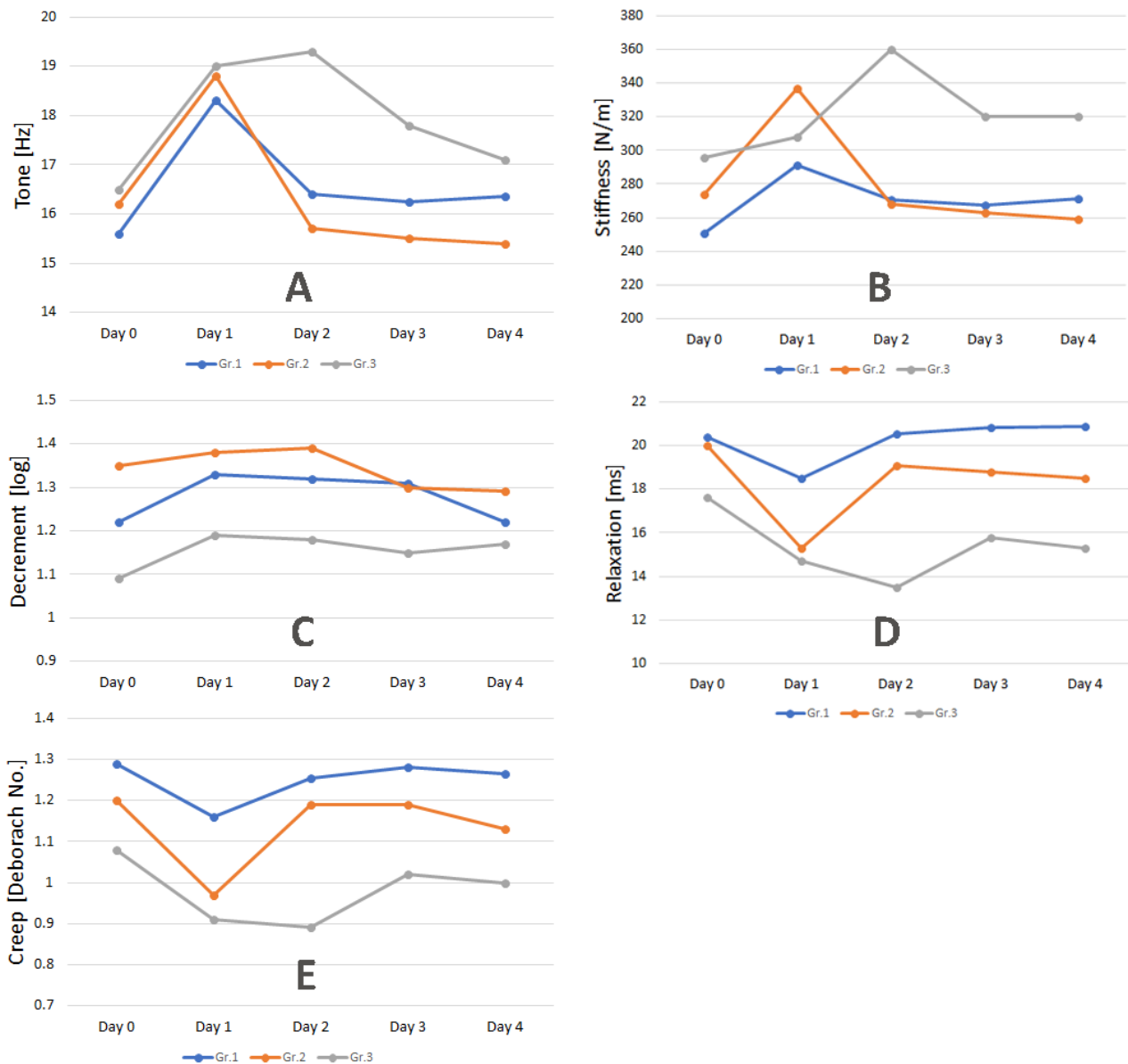


Figure 1. Graphical presentation of changes in gastrocnemius muscle A) tone, B) stiffness, C) decrement, D) relaxation and E) creep from day 1 to 4 in examined groups.

In the study groups (group 1 and group 2) a statistically significant increase in relaxation values after day 1 (between days 1 and 2) was noted. In the control group (group 3), the increase in the relaxation value was observed only after day 2. On day 2, relaxation values were statistically significantly lower in the control group (group 3), compared to those in the study groups (group 1 and group 2); (Table 1D and Figure 1D). Post-hoc multiple comparisons (Dunn Bonferroni) revealed statistically significant differences: Group 1: $p < 0.001$ (Day 1 vs Day 0), $p = 0.003$ (Day 1 vs Day 2), $p = 0.022$ (Day 1 vs Day 3), $p = 0.005$ (Day 1 vs Day 4). Group 2: $p < 0.003$ (Day 1 vs Day 0), $p = 0.018$ (Day 1 vs Day 2), $p = 0.008$ (Day 1 vs Day 3). Group 3: $p < 0.008$ (Day 1 vs Day 0), $p = 0.001$ (Day 2 vs Day 0). Day 0: $p = 0.004$ (Group 1 vs Group 3). Day 1: $p = 0.018$ (Group 1 vs Group 3). Day 2: $p = 0.001$ (Group 1 vs Group 3), $p = 0.01$ (Group 2 vs Group 3). Day 3: $p = 0.007$ (Group 1 vs Group 3). Day 4: $p = 0.002$ (Group 1 vs Group 3).

In the study groups (group 1 and group 2) there was a statistically significant increase in creep values after day 1 (between days 1 and 2). In the control group (group 3), creep increases were observed only after day 2. On day 2, creep values were

statistically significantly lower in the control group (group 3) compared to the study groups (group 1 and group 2); (Table 1E and Figure 1E). Post-hoc multiple comparisons (Dunn Bonferroni) revealed statistically significant differences: Group 1: $p < 0.001$ (Day 1 vs Day 0), $p = 0.001$ (Day 1 vs Day 2), $p = 0.043$ (Day 1 vs Day 3). Group 2: $p = 0.014$ (Day 1 vs Day 0), $p = 0.018$ (Day 1 vs Day 3). Group 3: $p = 0.002$ (Day 1 vs Day 0). Day 0: $p = 0.005$ (Group 1 vs Group 3). Day 1: $p = 0.01$ (Group 1 vs Group 3). Day 2: $p = 0.001$ (Group 1 vs Group 3), $p = 0.01$ (Group 2 vs Group 3). Day 3: $p = 0.018$ (Group 1 vs Group 3). Day 4: $p = 0.003$ (Group 1 vs Group 3).

DISCUSSION

Normal and regular biomechanical and visco-elastic properties of muscles play a key role both in increasing their performance and in preventing injuries [25]. It is commonly assumed that warm and cold thermal stimuli lead to changes in blood supply to muscles, allowing for the reduction of their tone and restoration of their adequate flexibility [26]. The use of heat and cold therapy after physical exertion can eliminate the adverse effects of mechanical damage to muscle fibers, it may also activate anti-inflammatory processes, and alleviate the increased muscle soreness [27]. The study reported here assessed the impact of infrared radiation and local cryotherapy on the normalization of biomechanical and visco-elastic muscle parameters, which are changed in the course of DOMS. The results were also compared with the control group that underwent sham therapy.

The main findings are as follows: Both heat and cold treatment procedures reduced muscle tone and stiffness. They reduced the time in which DOMS symptoms aggravated, resulting in an increase in tone and stiffness by one day, when compared to the control group. Normalization of biomechanical parameters, such as tone and stiffness proceeded faster than in the control group. Reduction of values of these parameters turned out to be more significant, as compared to the control group. Only after local cryotherapy treatment procedures tone and stiffness decreased slightly below the initial values. Also, only after local cryotherapy procedures, muscle elasticity increased significantly, as indicated by higher values of decrement. According to the criteria for the interpretation of parameters, decrement conversely describes flexibility. The values of the parameters characterizing the visco-elastic properties, namely relaxation and creep, changed inversely to tone and stiffness: they decreased initially and then increased. This was also in line with the interpretation criteria: the lower the values of relaxation and creep, the greater those of tone and stiffness. In conclusion, local cryotherapy appears to be efficacious in reducing muscle damage after exercise and in enhancing muscle recovery. The long-term effects of such therapy may reduce the risk of injury by one of the strategies for athletic performance improvement. Practical applications of cryotherapy beyond the temperature of liquid nitrogen may also include widely distributed cold packs and sprays.

In our study, the greatest stiffness of the gastrocnemius muscle in calf was observed 24 hours after the completion of exercises meant to induce DOMS. Our observations have been confirmed by the study conducted by Wolska et al [28], in which the intensity of stiffness also occurred after 24 hours. Our study reported here showed that after a cycle of 4 cryotherapy treatment procedures performed every 24 hours, a significant decrease in muscle stiffness which occurred corresponded to a decrease in the level of creatine kinase activity. Previous studies have shown an inefficiency of a single cryotherapy session in reducing creatine kinase activity and C-reactive protein concentration in the blood after exercise. [29,30]. Siqueira et al. examined other inflammatory blood biomarkers: interleukin (IL)-6, IL-1a, IL-10, and tumor necrosis factor (TNF)- α . Multiple cryotherapy sessions after muscle lesions which occurred in the course of exercising, showed a decrease of the level manifested by these biomarkers in the blood 72 hours after the end of physical exercise sessions. At the same time, a reduction in

stiffness was also noted. No such relationship was observed in the control group in which there was a tendency for increase of creatine kinase activity, starting 24 hours after the completion of exercises [31].

Thermal stimulus – the heat leading to increased muscle congestion - effectively reduces their tone while reducing stiffness and increasing muscle flexibility, as shown by other studies [26]. This is confirmed by our observations, where we have noted a significant reduction in tone and stiffness, as well as improvement in flexibility after treatment procedures using infrared radiation. These changes started 24 hours after the completion of the exercises. Activation of the capillary system in the skin helps to counteract tissue hypoxia and can lead to a decrease in muscle tone [26]. Dilation of blood vessels also increases blood flow through tissues, which is widely used in the treatment of many diseases, mainly in inflammatory conditions. According to Zebrowska et al. [9], vasodilation also initiates an increased blood transmission response, which may be one of the mechanisms of accelerated removal of muscle fatigue markers. Heat therapy increases the flow of intracellular fluid and blood, and allows to quickly deliver nutrients to tissues, increasing muscle strength and reducing muscle spasms. Increased blood flow induced by heat also helps reduce muscle pain and spasms by quickly removing toxic metabolites. Increased concentrations of serotonin and nitric oxide in the blood have also been reported [32]. The infrared irradiation method is used because of its ease of use, convenient temperature control, and convenience of mobility. Radiation penetrates to a depth of 2-3cm into the skin and subcutaneous tissue without irritating its surface. It introduces a number of beneficial effects which include, among others, local dilation of blood vessels, intense congestion, reduction of blood viscosity and increase of local metabolism, allowing to reduce the recovery period by quickly removing inflammatory metabolites, such as prostaglandin, bradykinin and histamine. It is effective in reducing analgesia and muscle spasms. Pain control due to the thermal effect of IR is explained by the Gate Control Theory of Pain [33]. However, literature is short of adequate randomized clinical trials in this area.

So far, many papers have been published which examine DOMS in terms of its mechanisms, therapeutic interventions and preventive strategies. The intensity of symptoms increases during the first 24 hours after the completion of physical exertion and reaches its peak between 24 and 72 hours thereafter. However, it can be inferred from literature that DOMS is difficult to quantify because of the high variability of measuring tools and methods used to determine and quantify the condition. No agreement has been reached concerning the best DOMS assessment and therapy, which makes it difficult to verify whether a specific therapeutic intervention really helps to reduce the symptoms associated with this type of ailment [34,35]. Nevertheless, the knowledge of postoperative reactions and their proper utilization determines the effectiveness of physical treatment in the case of a specific form of energy utilized.

LIMITATIONS OF THE STUDY

The study had several limitations, including: the assumption of baseline parameter values as the norm, which were self-monitored; the lack of assessment of the subcutaneous fat layer thickness [36,37]; the absence of body composition analysis among the study participants; and the lack of quantitative evaluation of muscle contraction strength. The authors of this study recognize the need to conduct a similar experiment to evaluate the effectiveness of the same treatment procedures in preventing the development of DOMS and DOSS symptoms. They propose implementing these procedures on the same day, immediately following the completion of physical exercise.

CONCLUSIONS

Treatment procedures using local cryotherapy are effective in restoring the correct biomechanical and viscoelastic parameters of muscles, which are subject to changes in the course of DOMS and DOSS. They shorten the time of symptoms occurrence and eliminate them faster. Similar but less powerful effects were observed after heat treatment with infrared radiation. Both treatments are significantly more effective than placebo using sham therapy.

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