

Received: 2024.02.15

Accepted: 2024.03.15

Available online: 2024.04.07

Published: 2024.XX.XX

Optimal Duration of Cold and Heat Compression for Forearm Muscle Biomechanics in Mixed Martial Arts Athletes: A Comparative Study

Authors' Contribution:

- Study Design A
- Data Collection B
- Statistical Analysis C
- Data Interpretation D
- Manuscript Preparation E
- Literature Search F
- Funds Collection G

- ABCDEF 1,2 **Robert Trybulski** 
- BCDE 3 **Arkadiusz Stanula** 
- BCDE 4 **Andriy Vovkanych** 
- CEF 5 **Tomasz Halski** 
- EFG 6 **Małgorzata Paprocka-Borowicz** 
- DEF 6 **Robert Dymarek** 
- CDEFG 7 **Jakub Taradaj** 

- 1 Provita Żory Medical Center, Żory, Poland
- 2 Department of Medical Sciences, The Wojciech Korfanty School of Economics, Katowice, Poland
- 3 Institute of Sport Sciences, Academy of Physical Education in Katowice, Katowice, Poland
- 4 Department Physical Therapy and Ergotherapy, Ivan Boberkyj Lviv State University of Physical Culture, Lviv, Ukraine
- 5 Department of Physiotherapy, Jan Grodek State University, Sanok, Poland
- 6 Department of Physiotherapy, Wrocław Medical University, Wrocław, Poland
- 7 Institute of Physiotherapy and Health Sciences, Academy of Physical Education in Katowice, Katowice, Poland

Corresponding Author: Robert Dymarek, e-mail: r.dymarek@gmail.com
Financial support: This work was funded by the Ministry of Science and Higher Education of Poland as a part of a statutory grant of the Wrocław Medical University for maintaining research potential (no. SUBZ.E060.24.036), as well as from the Jerzy Kukuczka Academy of Physical Education in Katowice
Conflict of interest: None declared

Background: Cold and heat therapies for recovery in sports are commonly used, including in the mixed martial arts (MMA). The Game Ready (GR) device can be used for local monotherapy with either heat or cold and for contrast therapy. This study aimed to compare the effects of duration of cold and heat compression on biomechanical changes in the forearm muscles of 20 healthy mixed martial arts athletes.





Material/Methods: Twenty MMA volunteers (26.5±4.5 years old) underwent 3 different phases of the GR: (1) stimulation time 10 min (eGR-10, GR experimental group), (2) 10 min (cGR-10, sham control group) and (3) 20 min (eGR-20, GR experimental group). The following outcomes were assessed: muscle tone (T), stiffness (S), flexibility (E), pressure pain threshold (PPT), microvascular response (PU), and maximum isometric strength (Fmax). All measurements were performed before GR (rest) and after GR stimulation (post).0

Results: Both eGR-10 and eGR-20 significantly improved outcomes T ($p < 0.001$), S ($p < 0.001$), E ($p = 0.001$, and $p < 0.001$, respectively), PPT ($p < 0.001$), PU ($p < 0.001$), and Fmax ($p < 0.001$). Notably, eGR-20 exhibited superior improvements in PU, Fmax, and PPT, with larger effect sizes ($p < 0.001$). While eGR-10 demonstrated more pronounced reductions in T and S ($p < 0.001$), these results underscore the potential for tailored GR therapy durations to optimize specific recovery goals for MMA athletes.

Conclusions: GR stimulation affects muscle biomechanical changes, pain threshold, muscle strength, and tissue perfusion. The study results suggest that 10 min of GR stimulation is sufficient to achieve changes that can be used to optimize recovery for MMA athletes.

Keywords: **Athletes • Biomechanical Phenomena • Muscle Contraction • Muscle Fatigue • Pain Threshold • Perfusion**

Full-text PDF: <https://www.medscimonit.com/abstract/index/idArt/944149>

 4397  1  4  68



Publisher's note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher

Introduction

Mixed martial arts (MMA) is a fighting strategy requiring the ability to perform punches, kicks, throws, and holds, and chokes. The versatility of a fighting style often determines athletic performance. The physiology of muscle exercise is based on alternating aerobic and anaerobic work with isometric contractions and high explosiveness of muscle force [1]. Various cold and heat therapies for recovery in sports are commonly used by athletes and coaches of various sports, including MMA [2].

The impact of contrast therapy after high-endurance or intense-intensity training on muscle power recovery and performance improvement is ambiguous [3]. These effects can be attributed to reduced activation of satellite cells [4], stimulation of angiogenesis and mitochondrial biogenesis in muscles [5], activation of anti-inflammatory pathways [6], and regulation of muscle stiffness and elasticity [7]. According to the theory of Melzack and Wall, activating gate control reduces muscle pain [8].

The efficacy of monotherapy in either cold or warm stimuli appears to have more evidence in the scientific literature than the therapy combining both stimuli, called contrast therapy [2]. Most studies on this topic concern the effects of contrast therapy on the muscular system with the use of warm-cold baths, suggesting their positive impact on post-exercise recovery [3,4]. Significantly, few studies have compared the effects of different types of contrast therapies; in particular, there are no randomized controlled trials [9]. Therefore, which recovery protocol is the most effective has yet to be established. Specifically, no studies have evaluated the effect of duration of therapy on biomechanical changes in muscles [10].

The scientific literature suggests that the use of compression enhances the effect of heat or cold therapy [11,12]. Despite the widespread use of intermittent compression [13] with an emphasis on its role in the alleviation of post-exercise muscle pain [14], there is no clear evidence to support the benefits of this method [11,15]. Wiecha et al [16] suggested that intermittent pneumatic compression does not reduce markers of muscle damage and does not alleviate post-exercise muscle pain.

The relationship between tissue physiology and the post-stimulus response of muscles to alternating heat-cold stimuli has been documented in the scientific literature [17,18]. The most important physiological parameter highlighted by various authors is changes in microvascular blood flow [17,19]. The role of microcirculation has documented effects on regeneration in MMA [20]. Other important muscle parameters that are altered during hot and cold stimulation are biomechanical properties such as muscle tone, elasticity, and muscle stiffness [21,22]. These changes have significant effects on athletes' ability to undertake subsequent physical effort and are a key component of injury prevention in sports [23].

With the increasing popularity of cold and heat contrast therapy, clinicians, practitioners, and athletes have sought quick, portable, and easy-to-use alternatives. An example of such therapy is the Game Ready (GR) device, which can be used both for local monotherapy with either heat or cold and for contrast therapy [24,25]. GR combines the use of an alternating hot and cold stimulus that is applied to a specific tissue in the form of a pressure cuff. The pressure that can be applied is 15-75 mmHg, with the temperature 3-45°C and duration 10-30 min [18,24]. GR is a therapy that combines 3 stimuli – heat, cold, and compression – in the same session. It has been suggested that such a “multistimulus” induces positive regenerative effects in the muscles [26].

The present study aimed to compare the effect of GR therapy duration of 10 and 20 min on muscle tension, muscle stiffness, and elasticity, pressure pain threshold, tissue blood supply, and muscle strength in MMA athletes. The research hypothesis assumed that shortening the regeneration time through GR helps optimize regenerative processes in sports, and assessing the impact of GR time may be a valuable contribution to further research on muscle regeneration of athletes.

Material and Methods

Ethics Statement

The study was approved by the ethics committee of the National Council of Physiotherapists (No. 9/22 of 6 April 2022) and was registered in the clinical trials register under number ISRCTN90040217 and conducted in accordance with the Declaration of Helsinki.

Study Design

This clinical pilot study used a prospective, interventional, non-randomized, single-blinded design. The participants (n=20) were included in 3 GR study phases. The first was provided with a stimulation time of 10 min (eGR-10), the second with 20 mins (eGR-20), and the control group receiving (cGR) sham GR therapy. The same participants were stimulated every 7 days with GR therapy of varying duration and a sham treatment trial (**Figure 1**).

Participants

Twenty volunteers who were MMA fighters (age: 26.5±4.5 years old, BMI: 24.75±3.0, training experience: 10.3±5.0 years) were selected according to the following inclusion criteria: age 18-40 years old, male only, minimum 3 years of MMA training experience, and training at least 4 times per week. Participants had no significant differences in experience, age, and BMI in individual groups. Considering McKay's participant classification

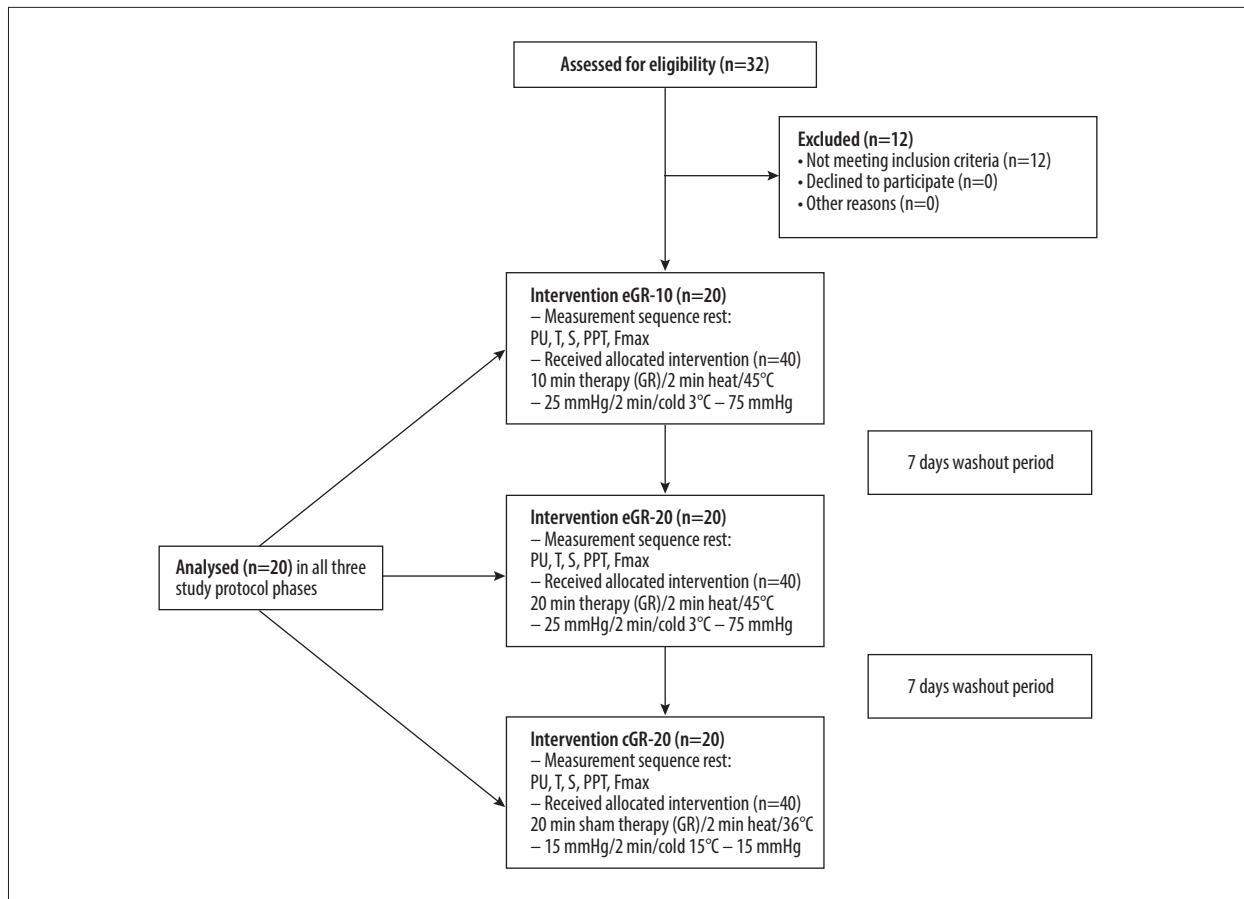


Figure 1. Flow chart of the study participants.

scheme, the group of competitors belonged to Tier 2 and 3: Highly Trained/National [27]. Exclusion criteria were elevated blood pressure prior to the study (blood pressure >140/90 mmHg), currently treated injuries, damaged skin, or unspecified skin lesions at the measurement sites. Participants with a tattoo at the measurement site were also excluded as it would interfere with tissue perfusion measurements. Exclusions were made also in the case of extreme fatigue, fever, infection, or at the explicit request of the participant. Written informed consent was obtained from participants after they were made aware of the study conditions. Participants were required to refrain from training 48 h before the study and for 24 h during the study. In addition, due to tissue perfusion measurements, participants were asked to refrain from consuming ergogenic beverages for 4 h before the study. Participants could be excluded from the study at their own request at any time during the study.

Interventions

A GR contrast therapy device was used for this intervention (Avanos Medical, USA, 2020). Each participant received a familiarization intervention consisting of 10 min of GR stimulation 7 days before the study. The device, through a cuff placed

on the dominant forearm, delivered alternating 2-min cold and heat stimulation (Figure 2). The experimental intervention used 2 different Game Ready time parameters: 10 min and 20 min, and the same pressure values from 25 to 75 mmHg and temperature from 3°C to 45°C, and the control group received temperature from 15°C to 36°C and pressure 15 mmHg. The contrast therapy intervention protocol was developed with reference to the literature [28]. After the intervention, data were collected in the same way as at rest.

Measurements

After determining and marking the widest cross-sectional area of the flexor carpi radialis muscle (FCR) of the dominant hand under ultrasound guidance with a marker [29], the following measurements were taken in all participants: muscle tone (T – [N/Hz]), stiffness (S – [N/m]), elasticity (E – [NaN]), pressure pain threshold (PPT – [N/cm]), microvascular response described in non-reference units (PU), and maximum isometric force (Fmax [kgf]). All participants were tested under these time conditions (between 10 a.m. and 12 p.m.) in a standardized resting position, sitting in a medical chair with elbows bent at 60 degrees and leaning against the chair [20]. The experiment



Figure 2. Game Ready contrast therapy equipment.

was carried out at the Provita Medical Centre. All measurements were taken first at rest (Rest), approximately 1 to 5 min before GR stimulation, and then immediately after GR stimulation from 1 to 5 min (Post). Appropriately trained students and physiotherapists took part in the measurements. The order of measurements was as follows: PU, T, S, E, PPT, Fmax.

Tissue Perfusion

Tissue perfusion was measured first at rest and then after stimulation. Tissue perfusion unit (PU) was analyzed with a laser Doppler flowmeter (LDF) using the Perimed device (Sweden 2004). The wave reflected from the erythrocytes was recorded at a skin tissue volume of 1 mm and a depth of 2.5 mm. The LDF method, because of its reproducibility, high sensitivity, and non-invasiveness, allows precise assessment of the microcirculatory response to physical stimuli or post-stimulus response [30]. The standardization of measurements was as proposed by Chudański et al [31]. The measurement time was 2 min. Published reports suggest that hyperemic responses observed in the skin can be interpreted as changes in muscle tissue [32-34]. During tissue perfusion testing, PU(r) (resting flow) and PU(p) (post-stimulation hyperemia) are most commonly determined. These ratios have no values or reference units and are referred to as PU perfusion [35].

Muscle Elasticity

Myotonometry was performed as the second measurement at rest and after stimulation (**Figure 3**). Measurements were

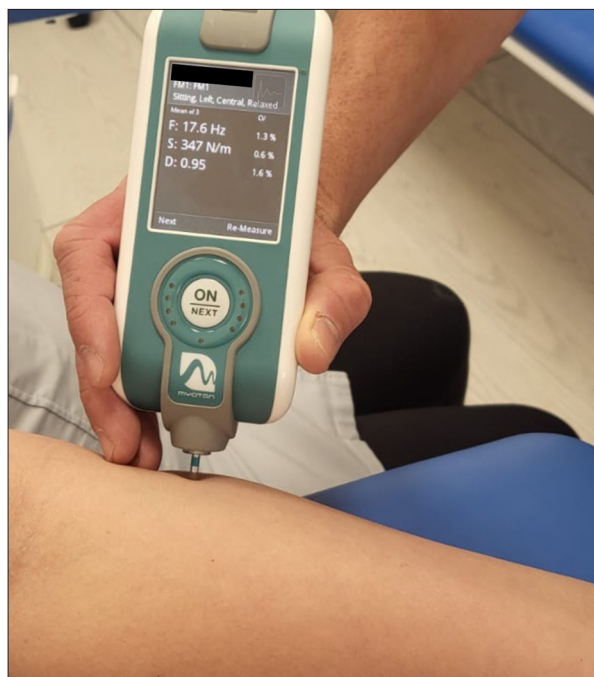


Figure 3. Equipment for myotometric measurements.

taken with a myotonometer (MyotonPRO AS, Myoton Ltd, Estonia 2021). Myoton is a digital device consisting of a device body and a depth probe (\varnothing 3 mm). Through the probe, a pre-pressure (0.18 N) is applied to the surface, which compresses the underlying material. A mechanical impulse (0.4 N, 15 ms) is then released through the device, which deforms the medium for a short time. Myotonometry is a reliable method of measurement and can detect differences in physical properties compared to stretched muscle fibers [36]. The measurement method consists of recording the damped natural vibrations of the soft biological tissue in the form of an acceleration signal and then simultaneously calculating the parameters of the stress state and biomechanical properties. This device enables the assessment of, among other things, muscle tone at rest (T) defined as a damped electromyography (EMG) signal and dynamic stiffness (S). Stiffness assessed with the use of myotonometry is based on the theory of free oscillation and results from the natural oscillation of tissues in response to short-term mechanical exposure of the skin [37]. Tissues can also recover their original shape after deformation. This property, measured in this study, is referred to as elasticity (E). The higher the elasticity, the faster the tissue returns to its original shape [38].

Pain Threshold

Pressure pain threshold (PPT) measurement was performed as the third of all measurements at rest and after stimulation. PPT was measured using the FDIX algometer (Wagner Instruments, Greenwich, CT, USA 2013). The determination of

the pressure pain threshold appears to be an attempt to objectively control the pain threshold [39]. Participants were subjected to a probe compression test 3 times (parameters: $r=4$ mm) in a defined area of tissue (mm), inducing compressive forces. The value of force (kgf) was shown on a digital display, and calculated as the average of the 3 measurements. If the measured value deviated too much, the device signalled the need to repeat the test. Pressure was applied until the test stimulus was signalled as unpleasant [40].

Muscle Force

Maximum forearm muscle force (Fmax) was the last of all measurements taken at rest and after stimulation. The maximum forearm muscle force (Fmax) was measured using an electronic hand dynamometer (EH106 China, 2020). The measurement was performed in a standing position with the arms hanging freely. Based on this, the maximum forearm muscle force expressed in kg was calculated. The grip strength test consisted of a 5-s contraction of the forearm muscles while squeezing the dynamometer. Prior to the test, each participant performed a warm-up that involved exerting maximum pressure on a small ball 10 times, followed by 10-s stretching of the forearm muscles [41].

Data Analysis

Standard statistical procedures were selected to calculate the means and standard deviations (SD). The normality and homogeneity of variance were confirmed using the Shapiro–Wilk and Levene’s tests. The compound symmetry, or sphericity, was assessed using Mauchly’s test. When the assumption of sphericity was not met, the significance of F-ratios was adjusted according to the Greenhouse-Geisser procedure. The effects of the applied GR on the variables – PU, T, S, E, PPT, and Fmax – were evaluated using a two-factor analysis of variance in the repeated measures system. The 2 factors were the study group (eGR-10, eGR-20, cGR) and the time of measurements at rest (Rest) and after an appropriate stimulation time (10 min, 20 min, or sham) of GM therapy (Post).

To determine intragroup and intergroup differences, the procedure of multiple comparisons using the post hoc Bonferroni test was used. The magnitudes of the differences between the results of the rest and post were expressed as absolute (Δ) and relative ($\Delta\%$) differences [$\Delta\% = ((\text{Post}-\text{Rest})/\text{Rest} \times 100)$]. To assess statistical significance, the obtained percentage differences were compared with the Mann-Whitney U test. The dCohen effect was also calculated for absolute differences. The criteria to interpret the magnitude of the effect sizes were as follows: <0.2 , trivial; $0.2-0.6$, small; $0.6-1.2$, moderate; $1.2-2.0$, large; and >2.0 , very large [42]. A priori power analysis was conducted with G*Power software [43]. The level of significance was set at $p \leq 0.05$. The repeated measure ANOVA within-between interactions with an

effect size of at least 0.25, $\alpha=0.05$, and $1-\beta=0.95$ gave a statistical power of 97.37% and a sample size of at least 16 subjects.

Results

General Results

The results of the statistical analysis for the tested parameters are presented in **Table 1**. In addition, **Figure 4** shows the average percentage differences for the results obtained at rest and after the therapy of different duration. The analysis of variance revealed statistically significant interaction effects (Group \times Measures) for all analyzed variables as well as statistically significant effects of the main factor related to the measurement (Measures) for the eGR-10 and eGR-20 groups.

Tissue Perfusion

Based on a detailed analysis, it can be concluded that in terms of PU, both after the therapy lasting 10 min and 20 min, the differences compared to the measurements made at rest were significantly ($p < 0.001$) higher, and a greater effect was obtained after the therapy lasting 20 min ($\Delta=3.78 \pm 1.83$; $\Delta\%=56.8\%$; ES=Very large) than after the one lasting 10 min ($\Delta=2.66 \pm 1.48$; $\Delta\%=43.2\%$; ES=Large) (**Figure 4**).

In terms of Fmax, statistically significant differences ($p < 0.001$) were observed between the values recorded at rest and after therapy lasting 10 and 20 min ($\Delta=4.13 \pm 2.93$; $\Delta\%=8.2\%$; ES=Small, and $\Delta=3.90 \pm 3.69$; $\Delta\%=7.8\%$; ES=Moderate, respectively). However, despite slightly greater absolute and relative differences in eGR-10, dCohen effect sizes are larger in the eGR-20 group (**Figure 4**).

Muscle Tone

A statistically significant ($p < 0.001$) decrease in the value of the T parameter was observed in the eGR-10 and the eGR-20 group, and greater decreases were observed in the eGR-10 group. We determined the absolute and relative differences and the size of the effects in the eGR-10 and eGR-20 groups ($\Delta=-1.72 \pm 1.14$, $\Delta\%=-10.4\%$; ES=Large, and $\Delta=-1.41 \pm 0.98$; $\Delta\%=-7.9\%$ ES=Moderate, respectively).

Of note, only for the T parameter, the percentage differences between the values recorded after the therapy in relation to the resting value for the eGR-10 and eGR-20 groups significantly differed ($p=0.348$) (**Figure 4**).

Muscle Stiffness

A similar tendency was observed in the case of the S parameter, for which the eGR-10 and eGR-20 groups had a statistically

Table 1. Characteristics of the measured parameters for individual groups.

Variable	Group	Rest		Post		Δ (Post-Rest)		Effect size	Measures effect	ANOVA (group×measures)	
		Mean ±SD	±95% CI	Mean ±SD	±95% CI	Mean ±SD	±95% CI	Cohen's d [descr.]	p-value	F _(2,117)	p-value
PU	eGR-10	7.33 ±1.94	6.7; 7.95	9.98 ±1.26	9.58; 10.38	2.66 ±1.48	1.97; 3.35	1.62 [Large]	<0.001	54.49	<0.001
	eGR-20	7.43 ±1.46	6.97; 7.90	11.21 ±1.07	10.87; 11.55	3.78 ±1.83	3.08; 4.47	2.96 [Very large]	<0.001		
	cGR	7.53 ±1.64	7.00; 8.06	7.96 ±1.38	7.52; 8.40	0.43 ±0.9	-0.26; 1.12	0.29 [Small]	n.s.		
Fmax	eGR-10	51.72 ±7.13	49.44; 54	55.84 ±7.75	53.36; 58.32	4.13 ±2.93	2.79; 5.46	0.55 [Small]	<0.001	15.72	<0.001
	eGR-20	50.89 ±5.99	48.98; 52.81	54.79 ±6.94	52.57; 57.01	3.90 ±3.69	2.57; 5.23	0.6 [Moderate]	<0.001		
	cGR	51.97 ±6.57	49.87; 54.07	52.93 ±6.24	50.94; 54.92	0.96 ±1.27	-0.37; 2.3	0.15 [Trivial]	n.s.		
T	eGR-10	16.30 ±1.12	15.94; 16.66	14.59 ±1.25	14.19; 14.98	-1.72 ±1.14	-2.14; -1.29	1.45 [Large]	<0.001	30.51	<0.001
	eGR-20	17.33 ±1.59	16.82; 17.84	15.93 ±1.28	15.52; 16.33	-1.41 ±0.98	-1.83; -0.98	0.97 [Moderate]	<0.001		
	cGR	16.68 ±1.10	16.32; 17.03	16.46 ±1.00	16.14; 16.78	-0.22 ±0.46	-0.65; 0.21	0.21 [Small]	n.s.		
S	eGR-10	269.1 ±29.5	259.6; 278.5	238.2 ±28.4	229.2; 247.3	-30.85 ±28.46	-39.25; -22.45	1.07 [Moderate]	<0.001	25.28	<0.001
	eGR-20	286.7 ±41.0	273.6; 299.8	270.7 ±39.7	258.0; 283.4	-16.00 ±8.10	-24.4; -7.6	0.4 [Small]	<0.001		
	cGR	266.8 ±20.9	260.2; 273.5	264.2 ±20.2	257.7; 270.6	-2.68 ±8.20	-11.08; 5.73	0.13 [Trivial]	n.s.		
E	eGR-10	0.93 ±0.05	0.91; 0.94	0.88 ±0.07	0.86; 0.90	-0.05 ±0.08	-0.08; -0.01	0.7 [Moderate]	0.001	5.09	0.008
	eGR-20	0.96 ±0.09	0.93; 0.99	0.91 ±0.1	0.87; 0.94	-0.05 ±0.07	-0.08; -0.02	0.55 [Small]	<0.001		
	cGR	0.92 ±0.06	0.9; 0.94	0.91 ±0.06	0.89; 0.93	-0.01 ±0.06	-0.04; 0.03	0.1 [Trivial]	n.s.		
PPT	eGR-10	95.2 ±11.8	91.5; 99.0	103.2 ±15.8	97.7; 108.1	7.79 ±13.57	3.65; 11.92	0.56 [Small]	<0.001	10.57	<0.001
	eGR-20	99.4 ±12.70	95.3; 103.5	107.7 ±12.2	103.8; 111.6	8.28 ±6.21	4.15; 12.42	0.66 [Moderate]	<0.001		
	cGR	93.4 ±8.2	90.8; 96.1	93.7 ±8.5	91.0; 96.4	0.27 ±2.46	-3.86; 4.41	0.03 [Trivial]	n.s.		

PU – perfusion unit (non-reference units); Fmax – maximum isometric force (kgf); T – muscle tone (Na Hz); S – stiffness (N/m); E – elasticity (NaN); PPT – pressure pain threshold (N/cm).

APPROVED GALLEY PROOF

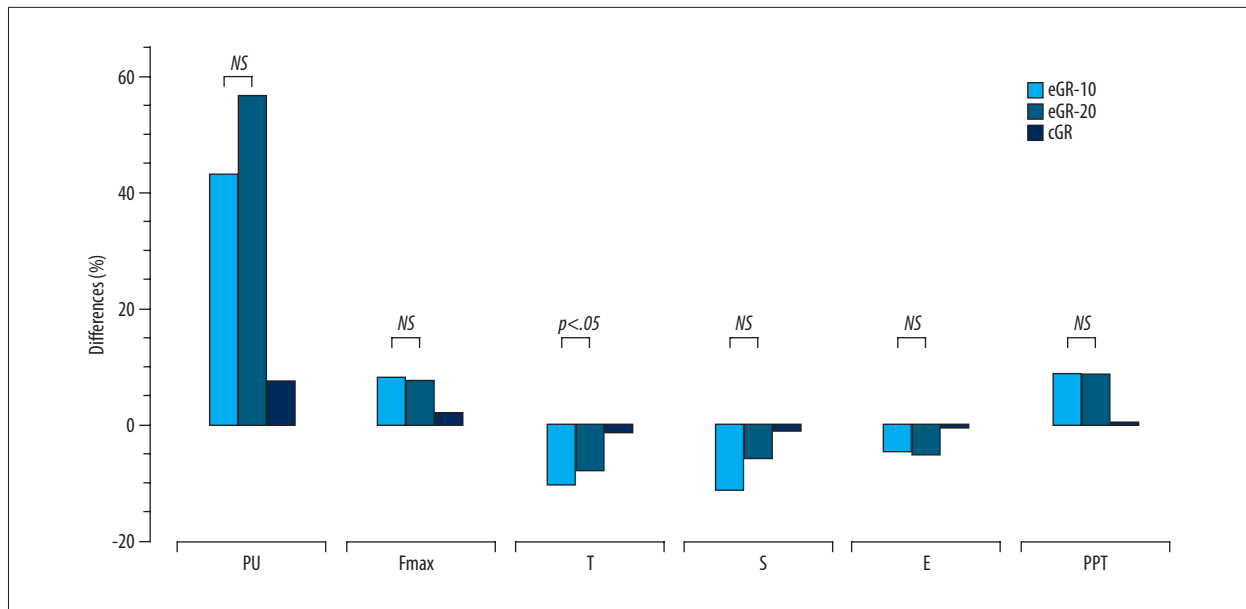


Figure 4. Percentage differences of the analyzed indicators immediately after GR therapy (1-5 min) for the groups: eGR10, eGR20, cGR. Significant difference between groups ($p<.05$); NS – no statistical significance. PU – perfusion unit; Fmax – maximum forearm muscle force; T – muscle tone; S – stiffness; E – elasticity; PPT – pressure pain threshold.

significant ($p<0.001$) decrease in value after the applied therapy. An almost 2-fold decrease in the S value was observed in the eGR-10 group compared to the eGR-20 group ($\Delta=-30.85\pm 28.46$; $\Delta\%=-10.9\%$; ES=Moderate, and $\Delta=-16.00\pm 8.10$; $\Delta\%=-5.6\%$ ES=Small, respectively) (Figure 4).

Muscle Force

Both in the eGR-10 and eGR-20 groups, a statistically significant ($p=0.001$ and $p<0.001$, respectively) decrease in the E value was observed, for which the mean absolute and relative differences were: $\Delta=-0.05\pm 0.08$; $\Delta\%=-4.6\%$; ES=Moderate, and $\Delta=-0.05\pm 0.07$; $\Delta\%=-5.3\%$ ES=Small. However, the effect sizes were different, and a greater effect was obtained in the eGR-10 group (ES=Moderate) compared to the eGR-20 group (ES=Small) (Figure 4).

Pain Threshold

In terms of PPT, statistically significant differences ($p<0.001$) were observed between the values recorded at rest and after therapy lasting 10 and 20 min ($\Delta=7.79\pm 13.57$; $\Delta\%=8.8\%$; ES=Small, and $\Delta=-8.28\pm 6.21$; $\Delta\%=8.8\%$; ES=Moderate, respectively) but it should be emphasized that despite similar absolute and relative differences in both groups, the size of the dCohen effect was larger in the eGR-20 group (Figure 4).

Discussion

This study's main aim was to assess the impact of time on the immediate effects of short-term use of GR on muscle tone, muscle stiffness and elasticity, tissue perfusion, and muscle strength. The results suggest that GR contrast therapy affects the measured parameters, and a time of 10 min seems sufficient to achieve the intended goals. The above system may shorten and optimize the regeneration process in combat sports, providing evidence for a new GR therapy protocol. The most significant problem in contrast therapy is insufficient evidence to optimize post-exercise recovery protocols.

The PPT results of this study showed an effect of GR on reducing muscle pain and they seem to support the general hypothesis of analgesic effects of contrast therapy [44]. There is insufficient evidence in the scientific literature for the use of GR contrast therapy in the treatment of muscle pain. Researchers rather focused on the use of GR to analyze pain changes in sports injuries [45] and other forms of contrast therapy, among which water therapy and compresses predominate [46]. It has been shown in the literature that contrast water therapy eliminates the negative effects of exercise-associated muscle damage (EAMD), inflammation, and delayed onset muscle soreness (DOMS) [47], while increasing the rate of muscle strength recovery [21], and power and joint mobility after debilitating exercise [21,48]. Previous studies of contrast therapy combined with compression (CwC) have not analyzed muscle recovery capacity after intense exercise or the assessment of recovery of intramuscular glycogen stores. The results obtained by the

aforementioned authors are intriguing and suggest a positive effect of CwC on recovery after intense eccentric exercise and recovery of intramuscular glycogen stores associated with EAMD. The results revealed the lack of effectiveness of contrast therapy in eliminating DOMS were presented by Yoshida et al [49]. Their results suggest that heat or cold therapy within the first 30 min after intense eccentric exercise is insufficient to have a preventive effect against DOMS. Yoshida et al [49] used different protocols and stimuli than in the present study. It should be noted that alternating heat and cold therapy has gaps in the scientific literature and results are inconclusive.

Warm-cold contrast has been reported to increase lactate clearance, reduce post-exercise edema, and improve blood flow to fatigued muscles [50]. Stadnyk et al [51] suggested that significant fluctuations in skin temperature caused by hot and cold contrast packs cause vasoconstriction and vasodilation, thereby initiating an increased hyperemic response, which may be one of the mechanisms of accelerated clearance of markers of muscle fatigue [20]. French et al [52] found that contrast bathing (CB) and compression garments (CG) did not promote faster recovery after intense training more effectively than passive conditions, although contrast bathing may temporarily relieve post-exercise soreness.

In the scientific literature, a hypothesis can be found that tissue perfusion reflects the functional response of microcirculation. These changes (flow-mediated dilation; FMD) determine the adaptive capacity of the vascular endothelium, which is reflected in post-exercise recovery processes [53]. A variety of interventions (including heat or cold stress) can result in different hemodynamic responses and improvements in these capacities [54]. The increased blood flow measured with the use of LDF by postulating that hyperemic responses facilitate the recovery process by promoting nutrient delivery. The present study demonstrated the importance of the effect of GR application time on skin perfusion, showing that the 10 min of GR was sufficient to produce significant changes. It should be noted that some authors suggest that skin perfusion measured by LDF can be compared to the muscle perfusion response [55]. An animal experiment by Akasaki et al [56] showed that repeated thermal therapy increased endothelial nitric oxide synthase (eNOS) protein expression, blood flow, and capillary density in ischemic hindlimbs in mice. A key role in the mechanism of local microvascular autoregulation is played by the endothelium as a source of numerous mediators, with nitric oxide (NO) and prostacyclin as the most potent vasodilators, with EDCF1 and EDCF2 being the most potent vasoconstrictors [57].

There is insufficient evidence regarding the effect of GR on improving muscle strength and power. In the present study, the effect of GR improved the maximum isometric strength

score and did not show significant differences between 10 and 20 min. Most studies have focused on analyzing these parameters after the application of a thermal stimulus, indicating heat shock protein (HSP) activity [58]. HSPs are molecular chaperone proteins that play a universal role in maintaining cellular homeostasis. HSPs have been confirmed to be expressed in skeletal muscles, and the induction of their expression varies depending on the histological and even functional characteristics of a muscle [59,60]. Heat increases the expression of genes involved in muscle cell growth and differentiation [61].

The current study showed that contrast therapy promotes better subjective symptoms such as muscle stiffness and fatigue and results in less muscle hardness. Similar conclusions were reached by Sawada et al [62]. Moreover, they observed a relationship between the degree of cooling of skin temperature and reduced muscle hardness. An increase in muscle tone refers to musculoskeletal as well as nervous system abnormalities in the patient, and it is also used as an indicator of muscle condition [63]. Muscle tone, elasticity, and stiffness are mainly maintained through the complex interplay of spinal and supraspinal mechanisms, the disruption of which can cause many changes in the biomechanical properties of muscles [64]. It is widely accepted that a thermal stimulus that causes an increase in muscle hyperemia reduces muscle tone and improves muscle stiffness and elasticity [65]. Although the mechanisms are not clear, non-myogenic regulation of muscle tone associated with increased perfusion is also accepted. Elevated Ca²⁺ concentrations in the cytosol, which occur under hypoxia resulting from impaired perfusion, cause muscle contraction by activating phosphorylation of myosin light chains and subsequent actomyosin cross-bridging, which generates an increase in tone. Activation of the capillary system, which eliminates subclinical manifestations of tissue hypoxia, can therefore reduce muscle tone [65].

Evidence suggests that a more elastic musculotendinous system (and less stiffness) has a greater ability to elongate, allowing it to absorb external forces and create a “mitigating effect on energy production during function” [66]. Stiffness, muscle tone, and elasticity have been the focus of studies by the present authors as the parameters that play an important role in the generation of muscle strength and power and that can influence the risk of injury in sports. Muscles dissipate energy when they are actively lengthening, and energy dissipation affects a wide range of locomotor activities with eccentric function predominating, and it is during these activities that injuries occur. Torn ligaments and pulled muscles are often associated with fast maneuvers that involve deceleration and dissipation of mechanical energy [67].

Ciszek [68] argues that the muscle-tendon unit located between its attachments at each site contains tendon tissue, documenting the hypothesis on histological preparations that the muscle is a “dissected tendon” at the level of the muscle belly. This structure is designed to pack the muscle fibers performing contractile work at this level, transfer energy, and protect the muscle fiber. Previous studies have shown that connective tissue fibers, which encase muscle fibers and retain greater dynamic flexibility during active muscle elongation, can reduce the risk of injury by reducing the exposure of the sarcomere to stress during muscle-tendon unit strain [66].

It should be emphasized that in order to dissipate energy correctly, muscle bundles must be actively elongated (ie, they must maintain the correct elasticity and stiffness) [68]. Both in situ and in vivo studies indicate that the tendon fibers encasing the muscles can delay this elongation during energy-dissipating events by temporarily absorbing impact energy and then releasing energy to work on the muscle bundles. This complex mechanism requires not only appropriate neural control but also blood distribution through microcirculation [66,67]. GR therapy appears to be one of the stimuli affecting these biomechanical properties of muscles.

Limitations

The most important methodological limitation of the present study is the lack of a control group for a measurement time of 10 min. However, the initial observations in the sham therapy and familiarization session did not show significant changes; therefore, the sham therapy of 10 min was abandoned in the main part of the clinical study and used only in the measurement range of 20 min. The measurement tools used, although they objectivize the assessment of the impact of GR therapy, also have their limitations. Most of them do not describe reference values. The disadvantage is that the results indicate an immediate effect. Thus, the measured tissue response may reflect a thixotropic effect, although the magnitude of this effect remains unclear. In addition, the LDF method is extremely sensitive, requiring the ability to perform tests with strict procedures that may distort the observed changes; therefore, we used the assessment of changes in response to the stimulus (in this case, GR).

It should also be noted that, for some individuals, GR therapy is excessively favored and their expectations of effect may influence the level of variables measured. This pilot study included only 20 MMA athletes. There were many difficulties with recruiting full-professional MMA fighters at the same

sport level, so it was decided to use the methodology as presented in this study. In further protocols, it is planned to conduct a multi-center crossover study with 3 separate randomized groups. Undoubtedly, in subsequent studies, these groups should be larger and the time of observation of the changes taking place extended.

In addition, it may be interesting to see the changes in stiffness, resting tone, or elasticity compared to other methods of post-exercise muscle recovery and the effect of GR on these parameters between exercises. Future studies should also focus on evaluating and comparing the effects of GR in individuals with different levels of physical preparation and different sports and also after extreme fatigue in athletes.

Conclusions

This study provides evidence that GR is a stimulus that can influence muscle biomechanical changes, pain threshold, muscle strength, and tissue perfusion. The effect of 10-min therapy seems sufficient to develop possible protocols rather than a 20-min one. This may mean that the impact of shorter GR duration may be worth observing in future studies, creating good conditions for optimizing recovery in sports. The use of contrast therapy in sports still faces many challenges.

Acknowledgments

There were no other contributors to the article than the authors and we received no writing assistance.

Statement

Funding institutions had no role in the design of the study or in collection, analysis, and interpretation of data or writing the manuscript.

Department and Institution Where Work Was Done

Institute of Sport Sciences, Academy of Physical Education in Katowice, Poland.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

References:

- James LP, Haff GG, Kelly VG, Beckman EM. Towards a determination of the physiological characteristics distinguishing successful mixed martial arts athletes: A systematic review of combat sport literature. *Sports Med Auckl NZ*. 2016;46(10):1525-51
- Lindsay A, Carr S, Cross S, et al. The physiological response to cold-water immersion following a mixed martial arts training session. *Appl Physiol Nutr Metab Physiol Appl Nutr Metab*. 2017;42(5):529-36
- Hyldahl RD, Peake JM. Combining cooling or heating applications with exercise training to enhance performance and muscle adaptations. *J Appl Physiol* (1985). 2020;129(2):353-65
- Shibaguchi T, Hoshi M, Yoshihara T, et al. Impact of different temperature stimuli on the expression of myosin heavy chain isoforms during recovery from bupivacaine-induced muscle injury in rats. *J Appl Physiol* (1985). 2019;127(1):178-89
- Chaillou T, Treigyte V, Mosely S, et al. Functional impact of post-exercise cooling and heating on recovery and training adaptations: Application to resistance, endurance, and sprint exercise. *Sports Med Open*. 2022;8(1):37
- Hyldahl RD, Peake JM. Combining cooling or heating applications with exercise training to enhance performance and muscle adaptations. *J Appl Physiol* (1985). 2020;129(2):353-65
- Trybulski R, Kuźdżał A, Bichowska-Pawęska M, et al. Immediate effect of cryo-compression therapy on biomechanical properties and perfusion of forearm muscles in mixed martial arts fighters. *J Clin Med*. 2024;13(4):1177
- Woolf CJ. Pain modulation in the spinal cord. *Front Pain Res*. 2022;3:984042
- Bieuzen F, Bleakley CM, Costello JT. Contrast water therapy and exercise induced muscle damage: A systematic review and meta-analysis. *PLoS One*. 2013;8(4):e62356
- Cochrane DJ. Alternating hot and cold water immersion for athlete recovery: A review. *Phys Ther Sport*. 2004;5(1):26-32
- Draper SN, Kullman EL, Sparks KE, et al. Effects of intermittent pneumatic compression on delayed onset muscle soreness (DOMS) in long distance runners. *Int J Exerc Sci*. 2020;13(2):75-86
- Abaidia AE, Lamblin J, Delecroix B, et al. Recovery from exercise-induced muscle damage: Cold-water immersion versus whole-body cryotherapy. *Int J Sports Physiol Perform*. 2017;12(3):402-9
- Wiśniowski P, Cieśliński M, Jarocka M, et al. The effect of pressotherapy on performance and recovery in the management of delayed onset muscle soreness: A systematic review and meta-analysis. *J Clin Med*. 2022;11(8):2077
- Cranston AW, Driller MW. Investigating the use of an intermittent sequential pneumatic compression arm sleeve for recovery after upper-body exercise. *J Strength Cond Res*. 2022;36(6):1548-53
- Chleboun GS, Howell JN, Baker HL, et al. Intermittent pneumatic compression effect on eccentric exercise-induced swelling, stiffness, and strength loss. *Arch Phys Med Rehabil*. 1995;76(8):744-49
- Wiecha S, Jarocka M, Wiśniowski P, et al. The efficacy of intermittent pneumatic compression and negative pressure therapy on muscle function, soreness and serum indices of muscle damage: A randomized controlled trial. *BMC Sports Sci Med Rehabil*. 2021;13(1):144
- AlSabagh AT, Rao MS, Renno WM. The impact of heat therapy on neuromuscular function and muscle atrophy in diabetic rats. *Front Physiol*. 2022;13:1039588
- Alexander J, Jeffery J, Rhodes D. Recovery profiles of eccentric hamstring strength in response to cooling and compression. *J Bodyw Mov Ther*. 2021;27:9-15
- Selkow NM, Herman DC, Liu Z, et al. Microvascular perfusion increases after eccentric exercise of the gastrocnemius. *J Ultrasound Med*. 2013;32(4):653-58
- Zebrowska A, Trybulski R, Rocznik R, Marcol W. Effect of physical methods of lymphatic drainage on postexercise recovery of mixed martial arts athletes. *Clin J Sport Med*. 2019;29(1):49-56
- Colantuono VM, Oakley R, Hatfield DL, et al. Contrast with compression therapy enhances muscle function recovery and attenuates glycogen disruption after exercise. *Sports Health*. 2023;15(2):234-43
- Goswami S, Jelly P, Sharma SK, et al. The effect of heat therapy on pain intensity, duration of labor during first stage among primiparous women and Apgar scores: A systematic review and meta-analysis. *Eur J Midwifery*. 2022;6:66
- Bahr R, Holme I. Risk factors for sports injuries – a methodological approach. *Br J Sports Med*. 2003;37(5):384-92
- Allan R, Malone J, Alexander J, et al. Cold for centuries: A brief history of cryotherapies to improve health, injury and post-exercise recovery. *Eur J Appl Physiol*. 2022;122(5):1153
- DuPont WH, Meuris BJ, Hardesty VH, et al. The effects combining cryo-compression therapy following an acute bout of resistance exercise on performance and recovery. *J Sports Sci Med*. 2017;16(3):333-42
- Diouf JD, Diao S, Sy MH, et al. Effects of intermittent dynamic compression (Game Ready) on treatment of musculo-skeletal injuries: About 12 basketball professionals. *J Orthop Rheumatol Sports Med*. 2018;2(2):7
- McKay AKA, Stellingwerff T, Smith ES, et al. Defining training and performance caliber: A participant classification framework. *Int J Sports Physiol Perform*. 2022;17(2):317-31
- Alexander J, Jeffery J, Rhodes D. Recovery profiles of eccentric hamstring strength in response to cooling and compression. *J Bodyw Mov Ther*. 2021;27:9-15
- Hohenauer E, Costello JT, Stoop R, et al. Cold-water or partial-body cryotherapy? Comparison of physiological responses and recovery following muscle damage. *Scand J Med Sci Sports*. 2018;28(3):1252-62
- Roberts KA, van Gent T, Hopkins ND, et al. Reproducibility of four frequently used local heating protocols to assess cutaneous microvascular function. *Microvasc Res*. 2017;112:65-71
- Chudański M, Liana R, Ponikowska I. Standardization of laser flowmetry – own standards. *Medica*. 2009;10(2):58-64
- Choi PJ, Brunt VE, Fujii N, Minson CT. New approach to measure cutaneous microvascular function: An improved test of NO-mediated vasodilation by thermal hyperemia. *J Appl Physiol* (1985). 2014;117(3):277-83
- Poole DC. Edward F. Adolph distinguished lecture. contemporary model of muscle microcirculation: Gateway to function and dysfunction. *J Appl Physiol* (1985). 2019;127(4):1012-33
- Eriksson E, Germann G, Mathur A. Microcirculation in muscle. *Ann Plast Surg*. 1986;17(1):13-16
- Szyguła R, Wierzbicka M, Sondel G. Influence of 8-week aerobic training on the skin microcirculation in patients with ischaemic heart disease. *J Aging Res*. 2020;2020:4602067
- Bartsch K, Brandl A, Weber P, et al. Assessing reliability and validity of different stiffness measurement tools on a multi-layered phantom tissue model. *Sci Rep*. 2023;13(1):1-10
- Melo ASC, Cruz EB, Vilas-Boas JP, Sousa ASP. Scapular dynamic muscular stiffness assessed through myotonometry: A narrative review. *Sensors*. 2022;22(7):2565
- Feng YN, Li YP, Liu CL, Zhang ZJ. Assessing the elastic properties of skeletal muscle and tendon using shearwave ultrasound elastography and MyotonPRO. *Sci Rep*. 2018;8(1):17064
- Park G, Kim CW, Park SB, et al. Reliability and usefulness of the pressure pain threshold measurement in patients with myofascial pain. *Ann Rehabil Med*. 2011;35(3):412
- Trybulski R, Stanula A, Żebrowska A, et al. Acute effects of the dry needling session on gastrocnemius muscle biomechanical properties, and perfusion with latent trigger points – a single-blind randomized controlled trial in mixed martial arts athletes. *J Sports Sci Med*. 2024;23(1):136-46
- Zebrowska A, Trybulski R, Rocznik R, Marcol W. Effect of physical methods of lymphatic drainage on postexercise recovery of mixed martial arts athletes. *Clin J Sport Med*. 2019;29(1):49-56
- Cohen J. A power primer. *Psychol Bull*. 1992;112(1):155-59
- Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175-91
- Lubrano E, Mazas PF, Freiwald J, et al. An international multidisciplinary delphi-based consensus on heat therapy in musculoskeletal pain. *Pain Ther*. 2023;12(1):93-110
- Diouf JD, Diao S, Sy MH, et al. Effects of intermittent dynamic compression (Game ready) on treatment of musculo-skeletal injuries: About 12 basketball professionals. *J Orthop Rheumatol Sports Med*. 2018;2(2):5686721
- Wang Y, Lu H, Li S, et al. Effect of cold and heat therapies on pain relief in patients with delayed onset muscle soreness: A network meta-analysis. *J Rehabil Med*. 2022;54:jrm00258

47. Bieuzen F, Bleakley CM, Costello JT. Contrast water therapy and exercise induced muscle damage: A systematic review and meta-analysis. *PLoS One*. 2013;8(4):e62356
48. Cochrane DJ. Alternating hot and cold water immersion for athlete recovery: A review. *Phys Ther Sport*. 2004;5(1):26-32
49. Yoshida R, Nakamura M, Ikegami R. The effect of single bout treatment of heat or cold intervention on delayed onset muscle soreness induced by eccentric contraction. *Healthcare (Basel)*. 2022;10(12):2556
50. Xiao F, Kabachkova AV, Jiao L, et al. Effects of cold water immersion after exercise on fatigue recovery and exercise performance--meta analysis. *Front Physiol*. 2023;14:1006512
51. Stadnyk AMJ, Rehrer NJ, Handcock PJ, et al. No clear benefit of muscle heating on hypertrophy and strength with resistance training. *Temperature (Austin)*. 2017;5(2):175-83
52. French DN, Thompson KG, Garland SW, et al. The effects of contrast bathing and compression therapy on muscular performance. *Med Sci Sports Exerc*. 2008;40(7):1297-306
53. Chiesa ST, Bhowruth DJ, Trangmar SJ. Short-term heat therapy: Sufficient stimulus for structural vascular adaptations? *J Physiol*. 2017;595(11):3667-68
54. Kim J, Jung H, Yim J. Effects of contrast therapy using infrared and cryotherapy as compared with contrast bath therapy on blood flow, muscle tone, and pain threshold in young healthy adults. *Med Sci Monit*. 2020;26:e922544
55. Humphrey JD. Vascular adaptation and mechanical homeostasis at tissue, cellular, and sub-cellular levels. *Cell Biochem Biophys*. 2008;50(2):53-78
56. Akasaki Y, Miyata M, Eto H, et al. Repeated thermal therapy up-regulates endothelial nitric oxide synthase and augments angiogenesis in a mouse model of hindlimb ischemia. *Circ J*. 2006;70(4):463-70
57. Minson CT, Berry LT, Joyner MJ. Nitric oxide and neurally mediated regulation of skin blood flow during local heating. *J Appl Physiol (1985)*. 2001;91(4):1619-26
58. Kim K, Monroe JC, Gavin TP, Roseguini BT. Skeletal muscle adaptations to heat therapy. *J Appl Physiol (1985)*. 2020;128(6):1635-42
59. Liu Y. Changes in skeletal muscle heat shock proteins: Pathological significance. *Front Biosci*. 2001;6(1):d12
60. Xie Y, Song L, Weng Z, et al. Hsp90, Hsp60 and sHsp families of heat shock protein genes in channel catfish and their expression after bacterial infections. *Fish Shellfish Immunol*. 2015;44(2):642-51
61. McGorm H, Roberts LA, Coombes JS, Peake JM. Turning up the heat: An evaluation of the evidence for heating to promote exercise recovery, muscle rehabilitation and adaptation. *Sports Med*. 2018;48(6):1311-28
62. Sawada T, Okawara H, Nakashima D, et al. Effects of alternating heat and cold stimulation using a wearable thermo-device on subjective and objective shoulder stiffness. *J Physiol Anthropol*. 2022;41(1):1
63. Kim K, Monroe JC, Gavin TP, Roseguini BT. Local heat therapy to accelerate recovery after exercise-induced muscle damage. *Exerc Sport Sci Rev*. 2020;48(4):163-69
64. Graven-Nielsen T, Arendt-Nielsen L, Mense S. Thermosensitivity of muscle: High-intensity thermal stimulation of muscle tissue induces muscle pain in humans. *J Physiol*. 2002;540(Pt 2):647
65. Kim K, Reid BA, Casey CA, et al. Effects of repeated local heat therapy on skeletal muscle structure and function in humans. *J Appl Physiol (1985)*. 2020;128(3):483-92.
66. Roberts TJ, Konow N. How tendons buffer energy dissipation by muscle. *Exerc Sport Sci Rev*. 2013;41(4):186-93
67. Nuñez FJ, Ritzmann R, Hernandez-Abad F, et al. Muscle architecture, morphology, and mechanical and functional properties of biceps femoris long head in professional soccer players with a prior healed injured hamstring. *J Clin Med*. 2022;11(23):7222
68. Ciszek B. Editorial comment on: Zbigniew Czyrny Muscles – histology, micro/macroeconomy and US anatomy, a brand new perspective. *J Ultrason*. 2012;12(50):358