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

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

Corresponding Author: Robert Dymarek, e-mail: r.dymarek@gmail.com

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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).

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

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Introduction

Mixed martial arts (MMA) is a fighting strategy requiring the ability to perform punches, kicks, throws, 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 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

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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 – [Na 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

<table>
<thead>
<tr>
<th>Assessed for eligibility (n=32)</th>
<th>Excluded (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Not meeting inclusion criteria (n=12)</td>
<td>• Declined to participate (n=0)</td>
</tr>
<tr>
<td>• Other reasons (n=0)</td>
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<table>
<thead>
<tr>
<th>Intervention eGR-10 (n=20)</th>
<th>7 days washout period</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Measurement sequence rest:</td>
<td></td>
</tr>
<tr>
<td>PU, T, S, PPT, Fmax</td>
<td></td>
</tr>
<tr>
<td>– Received allocated intervention (n=40)</td>
<td></td>
</tr>
<tr>
<td>10 min therapy (GR)/2 min heat/45°C</td>
<td></td>
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<tr>
<td>– 25 mmHg/2 min/cold 3°C – 75 mmHg</td>
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<table>
<thead>
<tr>
<th>Intervention eGR-20 (n=20)</th>
<th>7 days washout period</th>
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<tbody>
<tr>
<td>– Measurement sequence rest:</td>
<td></td>
</tr>
<tr>
<td>PU, T, S, PPT, Fmax</td>
<td></td>
</tr>
<tr>
<td>– Received allocated intervention (n=40)</td>
<td></td>
</tr>
<tr>
<td>20 min therapy (GR)/2 min heat/45°C</td>
<td></td>
</tr>
<tr>
<td>– 25 mmHg/2 min/cold 3°C – 75 mmHg</td>
<td></td>
</tr>
</tbody>
</table>

| Intervention cGR-20 (n=20) | |
|---------------------------||
| – Measurement sequence rest: | |
| PU, T, S, PPT, Fmax | |
| – Received allocated intervention (n=40) | |
| 20 min sham therapy (GR)/2 min heat/36°C | |
| – 15 mmHg/2 min/cold 15°C – 15 mmHg |

Figure 1. Flow chart of the study participants.

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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 taken with a myotonometer (MyotonPRO AS, Myoton Ltd, Estonia 2021). Myoton is a digital device consisting of a device body and a depth probe (Ø 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 algesimeter (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 Mauchley’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 (Measures) for the eGR-10 and eGR-20 groups. 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 (Δ=3.78±1.83; Δ%−56.8%; ES=Very large) than after the one lasting 10 min (Δ=2.66±1.48; Δ%−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 (Δ=3.90±3.69; Δ%−7.8%; ES=Large). 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 (Δ=−1.72±1.14, Δ%−10.4%; ES=Large, and Δ=−1.41±0.98; Δ%−7.9% ES=Large). 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 effect size of at least 0.25, α=0.05, and 1-β=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×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 (Δ=14.3±2.93; Δ%−8.2%; ES=Small, and Δ=3.90±3.69; Δ%−7.8%; ES=Large, respectively). However, despite slightly greater absolute and relative differences in eGR-10, dCohen effect sizes are larger in the eGR-20 group (Figure 4).
### Table 1. Characteristics of the measured parameters for individual groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Mean ±SD</th>
<th>±95% CI</th>
<th>Mean ±SD</th>
<th>±95% CI</th>
<th>Mean ±SD</th>
<th>±95% CI</th>
<th>Cohen’s d [descr.]</th>
<th>p-value</th>
<th>ANOVA (group×measures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
<td>eGR-10</td>
<td>7.33 ±1.94</td>
<td>6.7; 7.95</td>
<td>9.98 ±1.26</td>
<td>9.58; 10.38</td>
<td>2.66 ±1.48</td>
<td>1.97; 3.35</td>
<td>1.62 [Large]</td>
<td>&lt;0.001</td>
<td>54.49 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>eGR-20</td>
<td>7.43 ±1.46</td>
<td>6.97; 7.90</td>
<td>11.21 ±1.07</td>
<td>10.87; 11.55</td>
<td>3.78 ±1.83</td>
<td>3.08; 4.47</td>
<td>2.96 [Very large]</td>
<td>&lt;0.001</td>
<td>54.49 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>cGR</td>
<td>7.53 ±1.64</td>
<td>7.00; 8.06</td>
<td>7.96 ±1.38</td>
<td>7.52; 8.40</td>
<td>0.43 ±0.9</td>
<td>-0.26; 1.12</td>
<td>0.29 [Small]</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Fmax</td>
<td>eGR-10</td>
<td>51.72 ±7.13</td>
<td>49.44; 54</td>
<td>55.84 ±7.75</td>
<td>53.36; 58.32</td>
<td>4.13 ±2.93</td>
<td>2.79; 5.46</td>
<td>0.55 [Small]</td>
<td>&lt;0.001</td>
<td>15.72 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>eGR-20</td>
<td>50.89 ±5.99</td>
<td>48.98; 52.81</td>
<td>54.79 ±5.64</td>
<td>52.57; 57.01</td>
<td>3.90 ±2.69</td>
<td>2.57; 5.23</td>
<td>0.60 [Moderate]</td>
<td>&lt;0.001</td>
<td>15.72 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>cGR</td>
<td>51.97 ±6.57</td>
<td>49.87; 54.07</td>
<td>52.93 ±6.24</td>
<td>50.94; 54.92</td>
<td>0.96 ±1.27</td>
<td>-0.37; 2.3</td>
<td>0.15 [Trivial]</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>T</td>
<td>eGR-10</td>
<td>16.30 ±1.12</td>
<td>15.94; 16.66</td>
<td>14.59 ±1.25</td>
<td>14.19; 14.98</td>
<td>-1.72 ±1.14</td>
<td>-2.14; -1.29</td>
<td>1.45 [Large]</td>
<td>&lt;0.001</td>
<td>30.51 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>eGR-20</td>
<td>17.33 ±1.59</td>
<td>16.82; 17.84</td>
<td>15.93 ±1.28</td>
<td>15.52; 16.33</td>
<td>-1.41 ±0.98</td>
<td>-1.83; -0.98</td>
<td>0.97 [Moderate]</td>
<td>&lt;0.001</td>
<td>30.51 &lt;0.001</td>
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<tr>
<td></td>
<td>cGR</td>
<td>16.68 ±1.10</td>
<td>16.32; 17.03</td>
<td>16.46 ±1.00</td>
<td>16.14; 16.78</td>
<td>-0.22 ±0.46</td>
<td>-0.66; 0.21</td>
<td>0.21 [Small]</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>S</td>
<td>eGR-10</td>
<td>269.1 ±29.5</td>
<td>259.6; 278.5</td>
<td>238.2 ±28.4</td>
<td>229.2; 247.3</td>
<td>-30.85 ±28.46</td>
<td>-39.25; -22.45</td>
<td>1.07 [Moderate]</td>
<td>&lt;0.001</td>
<td>25.28 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>eGR-20</td>
<td>286.7 ±41.0</td>
<td>273.6; 299.8</td>
<td>270.7 ±39.7</td>
<td>258.0; 283.4</td>
<td>-16.00 ±8.10</td>
<td>-24.4; -7.6</td>
<td>0.40 [Small]</td>
<td>&lt;0.001</td>
<td>25.28 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>cGR</td>
<td>266.8 ±20.9</td>
<td>260.2; 273.5</td>
<td>264.2 ±20.2</td>
<td>257.7; 270.6</td>
<td>-2.68 ±8.20</td>
<td>-11.08; 5.73</td>
<td>0.13 [Trivial]</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>E</td>
<td>eGR-10</td>
<td>0.93 ±0.05</td>
<td>0.91; 0.94</td>
<td>0.88 ±0.07</td>
<td>0.86; 0.90</td>
<td>-0.05 ±0.08</td>
<td>-0.08; -0.01</td>
<td>0.70 [Moderate]</td>
<td>0.001</td>
<td>5.09 0.008</td>
</tr>
<tr>
<td></td>
<td>eGR-20</td>
<td>0.96 ±0.09</td>
<td>0.93; 0.99</td>
<td>0.91 ±0.1</td>
<td>0.87; 0.94</td>
<td>-0.05 ±0.07</td>
<td>-0.08; -0.02</td>
<td>0.55 [Small]</td>
<td>&lt;0.001</td>
<td>5.09 0.008</td>
</tr>
<tr>
<td></td>
<td>cGR</td>
<td>0.92 ±0.06</td>
<td>0.9; 0.94</td>
<td>0.91 ±0.06</td>
<td>0.89; 0.93</td>
<td>-0.01 ±0.06</td>
<td>-0.04; 0.03</td>
<td>0.10 [Trivial]</td>
<td>n.s.</td>
<td>n.s.</td>
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<tr>
<td>PPT</td>
<td>eGR-10</td>
<td>95.2 ±11.8</td>
<td>91.5; 99.0</td>
<td>103.2 ±15.8</td>
<td>97.7; 108.1</td>
<td>7.79 ±13.57</td>
<td>3.65; 11.92</td>
<td>0.56 [Small]</td>
<td>&lt;0.001</td>
<td>10.57 &lt;0.001</td>
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<tr>
<td></td>
<td>eGR-20</td>
<td>99.4 ±12.70</td>
<td>95.3; 103.5</td>
<td>107.7 ±12.2</td>
<td>103.8; 111.6</td>
<td>8.28 ±6.21</td>
<td>4.15; 12.42</td>
<td>0.66 [Moderate]</td>
<td>&lt;0.001</td>
<td>10.57 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>cGR</td>
<td>93.4 ±8.2</td>
<td>90.8; 96.1</td>
<td>93.7 ±8.5</td>
<td>91.0; 96.4</td>
<td>0.27 ±2.46</td>
<td>-3.86; 4.41</td>
<td>0.03 [Trivial]</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

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).
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 (D = −30.85±28.46; D% = −10.9%; ES = Moderate, and D = −16.00±8.10; D% = −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: Δ = −0.05±0.08; Δ% = −4.6%; ES = Moderate, and Δ = −0.05±0.07; Δ% = −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 (Δ = 7.79±13.57; Δ% = 8.8%; ES = Small, and Δ = 8.28±6.21; Δ% = 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 of 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 [21,48]. 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
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 [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.

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]. 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.

Warm-cold contrast has been reported to increase lactate clearance, reduce post-exercise edema, and improve blood flow to fatigued muscles [50]. Elevated Ca2+ concentrations in the cytosol, which occur during 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 enlace 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.

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Department and Institution Where Work Was Done

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

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