**Original article**

# Effects of lymphatic drainage and local cryo exposition regeneration after high-intensive exercises

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## Summary

***Background:*** **Recovery from exercise and competition is important in sports medicine, particularly when rest periods are short. The objective is to determine the efficacy of cryo exposition (CRY) and manual lymphatic drainage (MLD) to hasten short term recovery of muscle performance after eccentric contractions.**
***Methods:*** **In a randomized controlled trial, 30 healthy sport students (21 males, 9 females; age: 25.7±2.8 years) performed 4×20 eccentric contractions of knee extensors, followed by 30 min MLD, CRY, or rest (RST) under controlled laboratory environment. Maximal voluntary contractions (MVC), electrically induced muscle fatigue (FI), and electrically induced tetani (EIT) at low (T2: 20 Hz) and high frequencies were tested.**
***Results:*** **Force decline and recovery kinetics regarding MVC, FI, and EIT did not differ significantly (p<0.05) between groups. That is, 24 h after the intervention, MVC (MLD: 80.9±5.5%; CRY: 81.1±8.5%; RST: 83.5±7.3%), FI (MLD: 83.2±23.7%; CRY: 81.2±38.8%; RST: 93.2±22.9%), and EIT (T1: MLD: 53.0±29.5%; CRY: 39.0±32.9%; RST: 46.3±26.1%; T2: MLD: 84.2±27.2%; CRY: 64.2±24.2%; RST: 66.6±22.3%) were similarly depressed irrespective of applied treatments.**
***Conclusion:*** **Neither CRY nor MLD hastened the recovery of muscle performance, when applied for 30 min. Identification number of the Primary Registry Network: DRKS00007608.**

*KEY WORDS: cryo exposition manual lymphatic drainage, eccentric contraction, muscle performance, recovery.*

## Abbreviations

| | |
|---|---|
| CK | Creatine kinase |
| CG | Control group |
| CRY | Local cryo exposition |
| DOMS | Delayed-onset muscle soreness |
| EC | Treatment group |
| EIT | Electrically induced tetani |
| FI | Fatigue index |
| GOT | Glutamic-oxaloacetic transaminase |
| LDH | Lactate dehydrogenase |
| MLD | Manual lymphatic drainage |
| MP | Motor points |
| MVC | Maximal voluntary contractions |
| PLFFD | Prolonged low frequency force depression |
| RST | Rest |

## Introduction

Recovery from exercise and competition is increasingly important in sports medicine. This especially holds true for sports in which the interbout rest periods are short. In practice, a broad range of physical agents and modalities are applied to enhance the rate of recovery, although only a minority of these approaches is based on good scientific evidence[1]. Some previously published studies in this field of research proposed that increasing blood flow velocity in affected muscle groups (e.g. by light exercise) helps to restore muscle function due to an improved removal of accumulated metabolites from muscle tissue[2]. By contrast, others found that passive recovery in terms of rest and massage reveals beneficial effects[3].
The aim of the present study was to investigate, if lymphatic drainage and locally applied cryo exposition are capable to enhance short term (24 h) recovery after a single bout of strenuous eccentric exercise. These two frequently applied treatments were selected for the present study because both of them have been suggested to support the physiological recovery process despite partially opposing effects on lymph- and blood flow of treated muscles. More concretely, the lymph flow velocity can be increased by lymphatic drainage up to 8-fold of resting condition, depending on the treatment duration and therapists'

experience[4]. In addition, the venous blood flow increases concomitantly[5], without inducing a reactive hyperemia owing to the low-frequency and pressure of the technique specific handgrips[5]. These effects increase the amount of fluid, which is removed from peripheral tissues per time, resulting in both, an edema reducing effect and an increased clearance of fatty acids, white blood cells, and muscle enzymes from the extracellular space[6]. The latter is supported by a previously published meta-analysis that reported beneficial effects of the lymphatic drainage on serum enzyme levels in patients with acute skeletal muscle cell damage as well as reduction of edema after sprains and bone fractures[7].

By contrast, low temperatures decrease the lymph-flow significantly during the cooling process, followed by a rebound of lymph-flow velocity with rewarming, as shown in animal models[8]. Similarly, arterial and venous blood flow are reduced, when cryotherapy is applied[9]. However, there are some controversies regarding the type of vasodilation that follows the intense vasoconstriction. While some reported a cyclic response consisting of alternating dilation and constriction[10], others reported a slow and steady vasodilation[11]. Nevertheless, cryotherapy is used for rehabilitation of sports-injuries and overuse symptoms, and to hasten recovery between training and competition sessions[12]. The regenerating potential of cryotherapy is thought to be based on analgesic, anti-swelling, anti-inflammatory, relaxing, as well as overall rejuvenating effects leading to a decrease in skin and tissue temperature[13]. Hausswirth et al.[14] found a better muscle strength output and positive effects on perceived tiredness or pain in well-trained runners after a damaging trail run simulated on a motorized treadmill after cryo exposition.

Therefore, the primary aim of the present study was to investigate if the frequently applied local cryo exposition and the manual lymphatic drainage are capable of enhancing short-term recovery. The results of the present study may help sport medicine specialists and physical therapists to improve their treatment strategies.

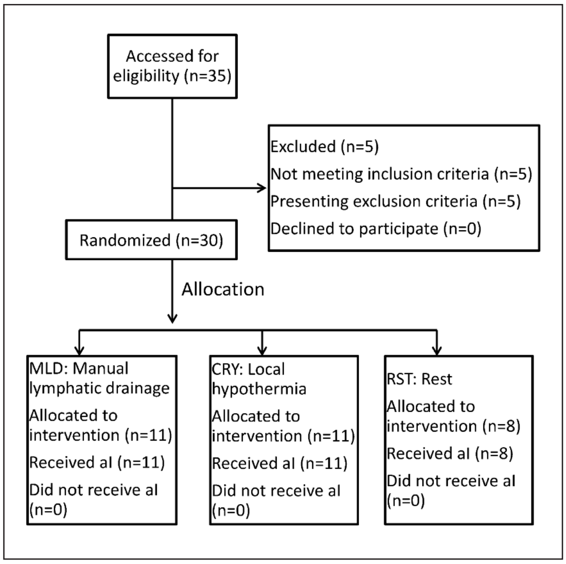


Figure 1. Enrollment of participants and study design. AI = Allocated intervention.

## Materials and methods

### *Subjects*

In this randomized controlled study a total of 35 male and female sport students were recruited as a sample of convenience from our University. Five participants were excluded as they presented exclusion criteria, defined as injuries of the musculoskeletal system within 6 months prior to the study or any cardiovascular and metabolic diseases. All participants were engaged in at least two hours of physical activity per week at enrollment. To avoid interference from other activities on muscle performance, subjects were instructed to refrain from intense or prolonged physical activity three days prior to and 24 h post intervention. To further standardize individual activity levels, subjects were asked to wear a step counter (Omron, step counter walking style III, OMRON Healthcare Europe B.V, Hoofddorp, Netherlands) and to take 5000 - 10000 steps between 1 h and 24 h post exercise, corresponding to an activity level rating from “low” to “somewhat active”[15].

By drawing lots, included subjects were randomly assigned to a manual lymphatic drainage group (MLD, n = 11), a cryo exposition group, (CRY, n = 11), or a control group (RST, n = 8) (Fig. 1). To reduce interference from subjects’ hydrational status fluid intake (not further specified) of 20-25 ml/ kg body weight was recommended (2 ml/ kg body weight within the 1$^{st}$ h following the exercise protocol, 5ml/ kg body weight from the 2$^{nd}$ to the 4$^{th}$ h and 15-18 ml/ kg body weight within the remaining 20 h). Subjects were instructed to refrain from food consumption two hours prior to the onset of pre-test measuring procedures. The study was approved by the local ethics committee of the German Sport University Cologne and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Further, the present study meets the ethical standards of the journal as laid down in the editorial published by Padulo et al.[16]. All subjects provided informed written consent prior to participation in the study. Two weeks prior to the intervention, subjects were invited to the laboratory to get familiarized with the training and testing procedures. However, subjects were only allowed to perform the planned exercise protocol with a light resistance in order to avoid blunted responses of tested parameters in terms of a repeated bout effect.

### *Exercise protocol*

The intervention consisted of 4x20 repetitions on a knee extensor machine (Edition Line, gym80 International, Gelsenkirchen, Germany) with 1 min rest between each set. During the concentric phase of the movement (1 s), the subjects lifted the weight from a ~90° knee angle with both legs, whereas the weight was lowered constantly with only the dominant leg (2 s) until a knee angle of ~5° was reached. The resistance was set to one third of the individual maximal voluntary contraction (MVC) of knee extensors of the eccentric leg, tested prior to the intervention (see below). Back pad and padded lever arm adjustments were used to provide a standardized subject starting positioning (i.e. 90° inner knee and hip angle), which was held constant for all tests. A seat belt was fastened around the subjects' hips to ensure correct subject positioning throughout the intervention.

Following the exercise protocol, participants underwent manual lymphatic drainage (MLD) according to the protocol presented by Emil Vodder[17] or a local cryo exposition (CRY), or rested on an examination bench for an equal amount of time (RST). Interventions were performed by a state-approved physical therapist with more than 6 years of work experience. The treatment duration was set to 30 min, according to common intervention periods in practice and current guidelines of treatment recommended and followed in German physiotherapy (Intelli Med GmbH 2011).

Local cryo exposition was applied to the previously loaded muscle by soft gel cool packs (Gello GmbH Geltechnik, Ahaus, Germany) wrapped around the thigh by a custom-made harness with four bags and a hook-and-loop fastener. Every 10 min the cool packs were replaced by fresh packs from the freezer (-20°C). Cutaneous temperature from frontal upper thigh muscles, room temperature, and humidity were measured using an infrared thermal image scanner (Testo 882 series, Testo Inc., Sparta, USA) prior to and after the physical therapy treatments in order to quantify the effects of CRY on surface temperature of the thigh.

#### *Maximal voluntary contraction (MVC)*

Following a standardized warm-up protocol consisting of 15 repetitions, subjects were instructed to maximally push against the fixed padded lever arm of the knee extensor machine, by forcefully contracting the knee extensors of their dominant leg against an insurmountable resistance. After rest periods of 1 min, the MVC was repeated once. Force data were recorded by the measuring- and data-management software Digi Max (Mechatronic, Hamm, Germany) with a sampling frequency of 100 Hz. The mean value of both MVC tests was used to calculate the weight for the intervention protocol.

#### *Electrically induced tetani (EIT) and fatigue index (FI)*

For electrical stimulation during EIT and FI, a commercially available myostimulator (Compex 3 Professional Stimulator/ mi-sensor System, Freiburg, Germany) and self-adhesive stimulating gel electrodes (Dura-Stick plus, DJO Global, Vista, USA) were used. The electrodes were placed over the motor points (MP) of the rectus femoris and the vastus medialis and lateralis muscles and a reference electrode was placed on the proximal thigh (~5 cm below the ilio-inguinal ligament). EIT and FI measurements were performed on the afore mentioned knee extensor machine.

FI: to assess the effects of the different treatments on fatigue resistance of the knee extensors, a 1 min involuntary, single leg fatigue protocol was performed on the leg extension machine using electrically induced short tetani of the knee extensors. Since it has previously been shown that the stimulation intensity does not significantly impact the rate of force decline[18], stimulation intensity was set to a current that induced a force development of only 15% of the mean MVC. Frequency, impulse width, and duty cycle settings were 60 Hz, 400 $\mu$s, and 0.5 (2 s on, 2 s off), respectively. Force data were recorded by the measuring- and data-management software Digi Max (Mechatronic, Hamm, Germany) with a sampling frequency of 100 Hz. The fatigue index (FI) was defined as the mean tetanic force produced by the last tetanus of the fatigue run (= $15^{th}$ tetanus) expressed as a percentage of the mean force output of the first tetanus.

EIT: to assess the impact of the two different treatments (MLD, CRY) on the recovery of muscle performance, the force response to four different electrically induced tetani before (pre), immediately after (post), as well as 1 h, 4 h, and 24 h after the intervention were tested. The selected stimulation settings were as follows: (T1) 100 Hz, 400 $\mu$s impulse width, (T2) 20 Hz, 400 $\mu$s impulse width. Each stimulation pattern was applied over a period of 2 s.

## Statistical analysis

Overall differences between experimental conditions were examined using an analysis of variance (ANOVA) for repeated measures (group × time). Where significant F values were identified, the *post-hoc* Bonferroni test was used for a more detailed analysis of differences between treatment means. These analyses were performed with Statistica (Statistica for Windows, 7.0, Statsoft, Tulsa, OK). An *a priori* estimation of the required sample size for the repeated measures ANOVA (within-between interaction) using G*Power 3.1.3 (University Kiel, Germany) revealed a total sample size of n = 27. The following input parameters were used: effect size f = 0.25, alpha error probability = 0.05, power = 0.8, number of groups = 3, number of measurements = 5, correlation among repeated measures = 0.5, nonsphericity correction = 1. All data are expressed as mean ± standard deviation of the mean. Statistics with a value of $p < 0.05$ were considered significant.

## Results

None of the participants were injured or dropped-out during the study (Fig. 1). Statistical analyses revealed

Table I. Anthropometric values of participants and activity during the observation period including taken steps and covered distance.

| Group | n | Age [yrs] | Height [cm] | Body weight [kg] | Body Fat [%] | Distance [km] |
|---|---|---|---|---|---|---|
| MLD | 11 | 26.5 ± 2.9 | 175.8 ± 6.8 | 71.4 ± 8.8 | 16.3 ± 6.3 | 5.3 ± 1.7 |
| CRY | 11 | 26.1 ± 3.0 | 180.7 ± 9.4 | 78.6 ± 9.3 | 13.5 ± 5.2 | 5.9 ± 3.6 |
| RST | 8 | 24.0 ± 1.7 | 180.8 ± 10.1 | 75.5 ± 16.1 | 11.7 ± 3.8 | 6.8 ± 4.3 |
| Total | 30 | 25.7 ± 2.8 | 178.9 ± 8.8 | 75.1 ± 11.4 | 14.0 ± 5.5 | 5.9 ± 3.2 |

MLD: Manual lymphatic drainage, CRY: Local cryo exposition, RST: Rest

that the data met the assumption of normality. Anthropometric values did not differ between the three groups investigated (Tab. I). Further, no pre-test differences between groups were present for EIT, FI and MVC force (Fig. 2). The mean step count was 7179.7±2029.0, 7348.3±3009.3, 7042.7±3488.7 for MLD, CRY, and RST, respectively. Room temperature (23.0±1.6° C) and humidity (33.8±6.9%) remained fairly constant over all measurement time points. Surface temperature from the gel cool packs, measured by thermal imaging, increased from -16.8±1.8° C at pre to -9.9±0.5° C at post test. When covered by the cotton harness, a temperature of 1.9±0.5° C and -0.1±0.4° C was measured at pre and post test, respectively. The skin temperature of the treated thighs in CRY changed from 30.6±0.9° C pre - to 20.4±2.1° C at post test, while they remained constant for MLD and RST (pre: 30.3±1.1° C; post: 30.8±1.1° C).

The applied current during EIT was 27.95±3.99 mA, 25.46±3.93 mA, and 29.37±8.56 for MLD, CRY, and RST, respectively. Irrespective of frequency (100 Hz *vs.* 20 Hz), EIT force level were significantly reduced in all groups immediately following the eccentric exercise protocol, but recovery kinetics did not differ as a function of applied treatments (Tab. II, Fig. 2). In none of the analyzed groups, an interaction between stimulation frequency and time was observed, indicating that prolonged force depression was not limited to low stimulation frequencies.

Similarly, force measured during MVC tests at post-test was significantly reduced (Fig. 2, Tab. III). However, the force of these voluntary contractions did not recover in the time course of follow-up measurements regardless of the applied treatment and no significant group by time interaction was found. Fatigue rate of exercised muscles, measured as FI, was not affected by the present protocol (Fig. 2, Tab. III). The applied current during the FI tests were the same as for the EIT tests.

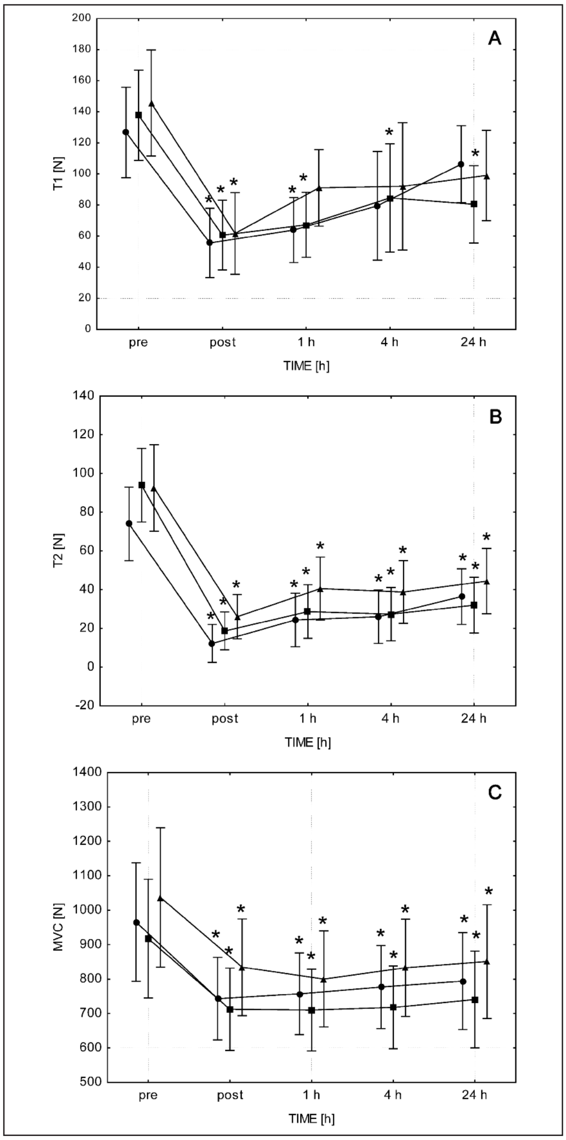


Figure 2. Mean force generated by the quadriceps femoris, when stimulated with 2 s tetani at 100 Hz (T1) (A); mean force generated by the quadriceps femoris, when stimulated with 2 s tetani at 20 Hz (T2) (B); mean force generated by the quadriceps femoris in percent of baseline value, when maximally voluntarily contracted (MVC) (C). Time point measurements were before (pre), immediately after (post), as well as 1 h, 4 h, and 24 h after the eccentric exercise protocol (CRY, circles; MLD, squares; RST, triangles).

## Discussion

### *Statement of principal findings*

This study was designed to compare the effects of two different treatment modalities on the recovery of muscle performance after a bout of eccentric contrac-

Table II. Mean values and standard deviations of EIT tests (absolute values).

| Group | pre | post | 1 h | 4 h | 24 h |
|---|---|---|---|---|---|
| **T1 [N]** | | | | | |
| MLD | 126.6 ± 42.8 | 55.6 ± 41.8* | 63.9 ± 29.1* | 79.5 ± 32.6* | 106.3 ± 41.0* |
| CRY | 137.7 ± 56.7 | 60.6 ± 29.3* | 67.3 ± 34.1* | 84.5 ± 82.1 | 80.5 ± 35.0 |
| RST | 145.6 ± 36.3 | 61.8 ± 36.2* | 91.0 ± 39.2 | 92.0 ± 33.0 | 99.0 ± 45.2 |
| Total | 135.8 ± 46.0 | 59.1 ± 34.9 | 72.4 ± 34.6 | 84.7 ± 54.6 | 94.9 ± 40.4 |
| **T2 [N]** | | | | | |
| MLD | 73.9 ± 31.5 | 12.2 ± 16.7* | 24.4 ± 18.9* | 26.0 ± 16.3* | 36.4 ± 20.0* |
| CRY | 93.9 ± 35.3 | 18.6 ± 15.7* | 28.6 ± 21.9* | 27.3 ± 27.8* | 32.0 ± 20.7* |
| RST | 92.5 ± 21.1 | 26.0 ± 14.6* | 40.5 ± 27.1* | 38.8 ± 20.9* | 44.4 ± 30.0* |
| Total | 86.2 ±31.1 | 18.2 ± 16.2 | 30.2 ± 22.6 | 29.9 ± 22.2 | 36.9 ± 23.0 |

EIT: Electrically induced tetani, MLD: Manual lymphatic drainage, CRY: Local cryo exposition, RST: Rest, Stars (*) represent time effects in reference to the pre measurement time point, pound key (#) represent group effects.

Table III. Mean values and standard deviations of MCV (absolute values) and FI tests (percent value).

| Group | pre | post | 1 h | 4 h | 24 h |
|---|---|---|---|---|---|
| **MVC [N]** | | | | | |
| MLD | 917.3 ± 232.1 | 712.1 ± 179.9* | 710.0 ± 189.6* | 717.5 ± 176.0* | 740.6 ± 190.1* |
| CRY | 965.5± 234.1 | 742.8 ± 166.4* | 757.1 ± 184.1* | 776.7 ± 187.4* | 794.1 ± 241.8* |
| RST | 947.7 ± 379.8 | 834.3 ± 242.0* | 800.1 ± 206.5* | 832.6 ± 227.3* | 850.9 ± 254.3* |
| Total | 966.8 ± 273.1 | 755.9 ± 193.2 | 751.3 ± 188.9 | 742.5 ± 219.9 | 789.6 ± 224.0 |
| **FI [%]** | | | | | |
| MLD | 51 ± 14 | 44 ± 28 | 57 ± 21 | 56 ± 22 | 44 ± 22 |
| CRY | 59 ± 0.11 | 53 ± 0.14 | 38 ± 20 | 41 ± 21 | 55 ± 16 |
| RST | 57 ± 13 | 61 ± 16 | 60 ± 17 | 60 ± 4 | 56 ± 18 |
| Total | 56 ± 12 | 56 ± 12 | 52 ± 21 | 52 ± 18 | 52 ± 18 |

MLD: Manual lymphatic drainage, CRY: Local cryo exposition, RST: Rest. Stars (*) represent time effects in reference to the pre measurement time point.

tions. Main findings of this study were that neither MLD nor CRY enhanced recovery, measured as MVC, EIT, and FI (Tabs. II, III), when applied for 30 min. That is, the present data do not support the use of MLD or CRY for short term recovery from damaging exercises.

The fact that the generated force during MVC and the majority of EIT tests were significantly ($p < 0.05$) reduced immediately after the eccentric knee extensions until the 24 h measurement indicates that the chosen protocol resulted in a prolonged muscle fatigue. However, the tested physical agent (CRY) and modality (MLD), did not affect the rate of recovery of the knee extensors following the performed bout of eccentric contractions. Further, the force response to low-frequency stimulation (T2) was more affected by the applied protocol than that to high-frequency stimulation (T1). This is a well-known feature of a long-term force depression and is assumed to reflect that low frequencies are at the steep part of the force-calcium relationship, which are therefore more susceptible to reduced myofibrillar calcium sensitivity and/or tetanic calcium concentrations[19].

Interestingly, the ratio between the mean force of the 15$^{th}$ and the 1$^{st}$ tetanus of performed fatigue runs was virtually unaffected by the present investigation. More precisely, irrespective of group or measurement time point, force dropped about 40- 60% from the 1$^{st}$ to the 15$^{th}$ tetanus. However, it needs to be taken into account that similar to the results presented for T1 and T2, the force of the first tetanus of the fatigue runs was significantly reduced after the exercise protocol.

Therefore, FI data from repeated short tetani indicate that the rate of force decline was similar at all measurement time points, though the absolute force values were reduced.

### *Strengths and weaknesses of the study*

To the best knowledge of the Authors, this is the first study to investigate the effects of the commonly applied MLD and CRY on recovery after eccentric contractions. The main strength of the present investigation lies in the combination of voluntary (MVC force) and involuntary measures (FI) of muscle performance, which allows for a robust estimation of the effect of the applied MLD and CRY on muscle recovery. Further, we tried to improve data accuracy and reliability by having the same experienced physiotherapist applying all treatments and performing all measurements at all time points. By contrast, one of the limitations of the present study was the short follow-up time of 24 h after the intervention. Thus we possibly missed effects that occurred thereafter. For example, Pournot et al.[20] reported that whole-body cryotherapy exerted effects on the inflammatory response at least up to 96 h after a simulated trail running race, as evident from selected biomarkers. However, the main focus of the present study was to investigate if MLD or CRY are able to improve the short-term recovery of muscle performance after strenuous exercises, which becomes increasingly important in many sports. By contrast, we did not assess any biomarkers. Though biomarkers cannot replace muscle performance tests they may help to estimate the amount of muscle damage, systemic inflammation, and immune cell mobilization[21]. Previous data indicate that the response of such biomarkers is particularly high, when the performed exercise is unaccustomed, prolonged, and includes eccentric contractions[22]. For example, the muscle damage marker creatine kinase has been reported to significantly increase after unilateral eccentric knee extensions to values of 680.4±594.0IU·L-1[23]. Therefore, we believe that the applied protocol of the present study also resulted in an increase of damage and inflammation associated markers in the blood and measuring these biomarkers may have resulted in a more complete picture.
Another weakness of the study may be that the respective treatments were applied for only 30 min. As outlined above, this was adopted in accordance with the common intervention periods in practice and current guidelines of treatment recommended and followed in German physiotherapy. However, longer intervention durations might have shown different results. Further, it needs to be taken into account that the applied protocol of the present study differs from sport specific training programs and competitions in professional sports. Therefore, the observed results cannot be easily transferred to professional sports. Nevertheless, we believe that the results are important for a better understanding about the potential of the applied treatments to hasten the recovery from exercise induced muscle damage.

### *Strengths and weaknesses in relation to other studies, discussing particularly any differences in results*

The force response to low-frequency stimulation (T2) was more affected than that to high-frequency stimulation (T1). However, we found that recovery kinetics of 100 Hz tetani (T1) did not significantly differ from that of 20 Hz tetani (T2). This stays in contrast to the data presented by Edwards et al.[18], who reported that the response to high-frequency stimulation is virtually unaffected following different fatiguing protocols, while low-frequency stimulation presents a long lasting force decline.
Schillinger et al.[4], who examined the influence of MLD on serum levels of muscle enzymes following endurance treadmill exercise, found a faster reduction in enzymes such as glutamic-oxaloacetic transaminase (GOT) and LDH in subjects that were treated twice for 45 min with MLD. The Authors concluded that this may indicate an improved regeneration after muscle damage. Similarly, MLD was shown to significantly affect the lactate concentration in blood, when compared with classical massage techniques[24]. However, serum levels of muscle proteins and other biomarkers like lactate unreliably reflect the extent of muscle damage and performance deprivation[25]. Instead, functional measurements like maximal voluntary torque, electrically elicited contractions, or range of motion are considered to be more appropriate in assessing damage, fatigue, and recovery of muscle tissue[26]. Unfortunately, no other study to date has investigated the effects of MLD on functional parameters. A recently published systematic review on the efficacy of MLD in sports medicine and rehabilitation found only three randomized controlled trials that provided pertinent information about the efficacy of this method in sports medicine[7]. However, of these, only the aforementioned study of Schillinger et al.[4] dealt with the recovery from exercise. The two other trials investigated the effects of MLD following radial wrist fractures[27] and acute ankle sprains[28]. Against this background it must be stated that neither the current literature nor the present study provides any evidence to suggest MLD after strenuous exercise in order to enhance recovery of muscle performance.
More data, by contrast, are available on the effects of other massage techniques on the recovery of athletes. For example, Zainuddin et al.[29] found significant effects of a standard 10-minute sports massage, conducted 3 h after 60 isokinetic contractions of the elbow flexors, on the delayed-onset muscle soreness (DOMS) and on muscle swelling. The DOMS could be dampened by about 30%. However, in line with the present data, no effect was found on muscle function, measured as maximal voluntary isometric and isokinetic elbow flexions, and on range of motion. According to a recently published article reviewing the effectiveness of sports massage for recovery of skeletal muscle from strenuous exercise, there is limited evidence to support the sole use of massage in this context[30]. While some case series[31] and random-

ized controlled trials[32] found a positive impact on functional parameters, the vast majority of identified studies failed to support these findings. Nevertheless, it should be taken into account that the gentle rhythmical movements applied by the MLD acting on lymphatic system substantially differs from other massage techniques, making a direct comparison to the present data impossible.

When compared to MLD, the role of CRY in enhancement of recovery has been more frequently addressed in literature. However, the results are far from homogeneous. Crystal et al.[33] investigated the effects of a 20 min ice bath (5° C) on muscle recovery after a 40 min downhill run (-10%) and found that the treatment was ineffective at attenuating strength loss and DOMS after muscle-damaging exercise. Similarly, Pointen et al.[34] reported that CRY had no effect on muscle performance following 6 × 25 maximal concentric and eccentric contractions of knee extensors in ten resistance-trained males. But in contrast to the study presented by Crystal et al.[33], Pointen et al.[34] found positive effects on DOMS following CRY. Further, Costello et al.[35] reported that whole-body cryotherapy did not lessen muscle damage following eccentric muscle contractions. While these studies failed to find positive CRY effects on muscle recovery, the study presented by Hausswirth et al.[14] found both enhanced recovery of muscle strength and perceived sensations (i.e. pain, tiredness, and well-being) following a muscle damage protocol on a motorized treadmill. However, due to the within-subject design of that study, the data was largely affected by the well-known repeated bout effect, making a comparison among different treatments in nine subjects debatable. Further, the applied whole-body cryotherapy may have elicited additional systematic changes, like core temperature reduction and cardiovascular or endocrine changes potentially responsible for the outcome. According to two previously published reviews there is some evidence to suggest that cryotherapy may hasten the return to participation[36] and decreases the pain that is associated with soft tissue injury[37]. Nevertheless, both reviews concluded that the quality of available trials in that field of research is poor and that high-quality studies are needed to provide evidence based guidelines for the application of cryotherapy.

The effect of cooling on performance recovery of trained athletes was also subject of a recently published meta-analysis of 21 relevant, peer-reviewed randomized controlled trials[38]. It turned out that the average effect of cooling on recovery was small (Hedges' g = 0.28), but the weighted average 2.4% increase in performance may be large enough for competitive athletes under appropriate conditions. The greatest effect sizes were reported for sprint performance (g = 0.69), whereas effects on strength were distinctly lower (g = 0.1). Interestingly, the effects were greatest when evaluated 96 h after the exercise. Further, cold water immersion (g = 0.34) and cryogenic chambers (g = 0.25) were found to be most efficacious among the various cryotherapy methods. The effect of CRY via cooling packs reached an effect size close to zero (g = -0.07). Therefore, the selected CRY method, in combination with the short follow-up period, likely explains the missed group-by-time interactions of the present study. When compared to pretest values, the slight insignificant reduction in FI values as a response to CRY 1 and 4 h after the exercise protocol, may be interpreted as a result of a delayed clearance of metabolites from the muscle cells. This is somewhat supported by the fact that the FI values increased at these early time points in MLD, where metabolite clearance was likely increased due to increased lymph flow[6]. However, the present results leave this assumption to be highly speculative.

### *Meaning of the study: possible mechanisms and implications for clinicians or policymakers*

Effective treatment modalities that enhance the rate of recovery after strenuous exercises not only improve the performance for the next of closely spaced competitions, but may also help to prevent fatigue related injuries. Despite the reputed benefits and frequent use CRY and MLD in praxis, the efficacy of these treatments for short term recovery could not be confirmed, when applied for only 30 min. This outcome is important for sport medicine specialists and physical therapists who design recovery strategies for athletes. That is, other treatment strategies than those tested by the present study should be applied to improve the rate of recovery after strenuous exercises.

### *Unanswered questions and future research*

The mechanisms for the contradictory results concerning the high- and low-frequency stimulation (T1, T2) remain unclear and were beyond the scope of the present investigation. Further studies are needed to investigate if longer therapy durations (>30 min) are able to hasten recovery or if longer time point measurements beyond 24 h post exercise show different results. Also following investigations should include additional blood values such as creatine kinase or myoglobin as well as validated psychological questionnaires that measure the perceived discomfort, sleeping quality and well-being and VAS pain values. Urine concentration might be examined prior to the start of the study to determine the hydration status. To assess the general effects of MLD it is as well reasonable to create another group receiving MLD without any physical exercise before.

## Conflict of interests

The Authors have no financial involvement and have no conflicts of interest.

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