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Research article

Comparing The Effects of Compression Contrast Therapy and Dry Needling on Muscle Functionality, Pressure Pain Threshold, and Perfusion after Isometric Fatigue in Forearm Muscles of Combat Sports Athletes: A Single-Blind Randomized Controlled Trial

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Abstract

The aim of this study was to compare the acute effects of compression contrast therapy (CT) and dry needling therapy (DN) on muscle tension (MT), muscle strength (Fmax), pressure pain threshold (PPT), and perfusion (PU) following fatigue of forearm muscles (e.g., flexor carpi radialis) in combat sports athletes. A single-blind randomized controlled trial was employed. Participants first underwent muscle fatigue induction, which involved sustaining an isometric handgrip at 60% of their maximum voluntary contraction in 5-second cycles. This was followed by exposure to one of the regenerative therapies. Forty-five participants were randomly assigned to one of three groups: CT/DN (n = 15), CT/ShDN (n = 15), and ShCT/DN (n = 15). The sham condition (Sh) involved a simulated version of the technique. Measurements were taken at four time points: (i) at rest; (ii) immediately after exercise that led to a state of fatigue; (iii) 5 minutes after therapy (PostTh5min); and (iv) 24 hours after therapy (PostTh24h). Each participant was exposed to one experimental condition and one control condition, thereby undergoing evaluation in two sessions. Significant differences between groups were found in MT during the PostTh5min ($p = 0.005$), as well as in PU during the PostTh5min ($p < 0.001$) and PU during the PostTh24h ($p < 0.001$). All groups showed significant improvements at 5 minutes post-therapy compared to immediately post-muscle fatigue. As conclusions, CT/DN seems to be significantly better for enhancing MT and PU after 5 minutes of muscle fatigue induction. Using either CT, DN, or both combined is recommended to enhance the recovery of muscle functionality and properties, favoring recovery and potentially speeding up performance enhancement.

Key words: Martial arts, exercise recovery, athletic performance, muscle strength, physical therapy modalities, therapeutics.

Introduction

Martial arts, including mixed martial arts, judo, and Brazilian jiu-jitsu, place significant physical demands on practitioners, particularly concerning muscle fatigue in the upper limbs (Andreato et al., 2017). These sports require a combination of dynamic and isometric contractions, often at high intensity and for extended periods (James et al., 2016). Studies indicate that the repetitive gripping, pulling, and striking actions inherent in these martial arts lead to substantial muscle fatigue (Wąsacz et al., 2023), primarily in the biceps, triceps, forearms, and shoulders. This fatigue is characterized by a decline in muscle performance, reduced force production, and slower contraction speed, attributable to metabolic disturbances such as the accumulation of lactate and depletion of intramuscular energy stores (Place and Westerblad, 2022). Prolonged or intense training sessions may worsen these effects, impairing functionality and increasing the risk of injury when fatigue continues without adequate recovery during repeated training sessions (Detanico et al., 2015). Recovery strategies are essential to mitigate these impacts (López-Laval et al., 2021). However, incomplete recovery can lead to chronic fatigue and long-term performance deficits (Nederhof et al., 2008). This evidence emphasizes the need for recovery protocols to optimize performance and reduce the risk of injury in martial arts practitioners (Origua Rios et al., 2018).

Recovery therapies, defined as techniques aimed at reducing impairment following fatigue, play a crucial role in optimizing muscular recovery and functionality after intense training sessions or combat engagements in martial arts (Boguszewski, 2015). Among these therapies, compression contrast therapy (CT) and dry needling (DN) have gained recognition for their potential in enhancing recovery (Surhoff, 2014; Tang and Song, 2022). CT involves alternating between the application of compression garments (Xiong and Tao, 2018) and exposure to contrasting temperatures. This therapy may facilitate vasodilation and vasoconstriction, promoting circulation and the removal of metabolic byproducts such as lactate, thereby reducing inflammation and accelerating muscle repair processes, while reducing muscle soreness (Marqués-Jiménez et al., 2016). Additionally, DN, a form of acupuncture, targets myofascial trigger points with thin filiform needles to alleviate muscle tension, improve blood flow, and enhance tissue healing (Dunning et al., 2014). Research suggests that these therapies can alleviate post-exercise muscle soreness (Diciolla et al., 2021), restore range of motion (Haser et al., 2017), and expedite muscular recovery, ultimately preserv-

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ing muscular function and performance (Trybulski et al., 2024b).

Muscle fatigue may significantly impact muscle tension (MT), perfusion unit (PU), pressure pain threshold (PPT), and maximal isometric force (Fmax), all of which are key factors in evaluating athletic performance and recovery strategies. MT and Fmax decrease with fatigue (Macgregor et al., 2016), leading to reduced performance in activities requiring strength and endurance. PU diminishes with fatigue (Zebrowska et al., 2019), potentially impairing metabolic waste removal, thereby prolonging recovery. A lowered PPT with fatigue reflects increased sensitivity to discomfort (Zebrowska et al., 2019), potentially hindering training intensity and consistency. Analyzing these variables enables a better understanding of the impact of regenerative strategies and ultimately contributes to improving strategies that enhance the performance of martial arts athletes.

Research into recovery strategies, specifically CT and DN, in martial arts is still expanding, with only a few examples currently documented (Trybulski et al., 2024b). For example, a study examining the effects of DN on mixed martial arts athletes showed significant benefits in muscular recovery compared to a control group (Trybulski et al., 2024b). DN significantly increased blood perfusion and enhanced the biomechanical properties of the gastrocnemius muscle, resulting in improved muscle power (Trybulski et al., 2024b). Furthermore, the study revealed that DN also provided analgesic effects, which were sustained up to 24 hours (Trybulski et al., 2024b). In a study examining the effects of CT (Trybulski et al., 2024a), it was observed that cryo-compression therapy significantly enhanced the recovery of forearms in terms of biomechanical properties, pain threshold, strength, and tissue perfusion in combat sports.

Despite the progressive increase in reports on CT and DN for muscle functionality recovery in combat sports, there is still a need for a larger volume of evidence to confirm the trend of results. Additionally, there is a need for comparative experimental studies to identify the most appropriate techniques for accelerating and enhancing recovery in these sports. Identifying the most suitable recovery strategies and their effects on muscle functionality could be crucial for coaches in selecting approaches to mitigate the impact of intense training sessions or competitions, and to enhance athletes' ability to recover, thereby sustaining performance and reducing the risk of injury due to significant declines in muscular properties. Therefore, given the importance of maintaining higher levels of force while ensuring greater pain thresholds, appropriate muscle stiffness, and perfusion, it is crucial to explore the effects of recovery techniques on these key parameters linked to functional recovery.

Therefore, the current experimental study aims to analyze the acute effects of CT and DN on muscle tension, muscle strength, pressure pain threshold, and perfusion after isometric fatigue of forearm muscles in martial arts athletes. Considering the potential combined effects, we hypothesize that the combination of CT and DN will produce significantly greater recovery outcomes than each technique alone. The results of our research have the potential to significantly contribute to the optimization of regeneration strategies in sports, providing new opportunities for enhancing athlete performance and recovery.

Methods

This study followed to the CONSORT guidelines for reporting randomized trials (Merkow et al., 2021). The study received preliminary approval from the ethical committee of the National Council of Physiotherapists (Approval No. 9/22 dated April 6, 2022) and was registered in the clinical trials register under the identifier ISRCTN90040217. Furthermore, it was conducted in adherence to the Declaration of Helsinki. Prior to participation, all participants were informed about the study's design, associated risks and benefits. Subsequently, they provided their informed consent by signing a document defining their right to withdraw from the study at any time without penalty. Additionally, measures were taken to ensure privacy and confidentiality of the data collected, maintaining its integrity through blinded procedures.

Study design

This is a single-blind, randomized, parallel study with repeated measures, where only the researcher knows which treatment or intervention the participant is receiving until the trial is over. All participants were randomly assigned (simple randomization 1:1 using randomizer.org, free research to assign participants randomly to experimental conditions) to one of three groups: CT/DN, CT/ShDN, or ShCT/DN. Randomization occurred before baseline measurements to ensure allocation concealment. Moreover, all the groups underwent both the intervention and a control situation where they received sham therapy (Sh). The sham condition involved a simulated version of the recovery technique. Participants were exposed to one of the three experimental interventions as well as to the control condi-

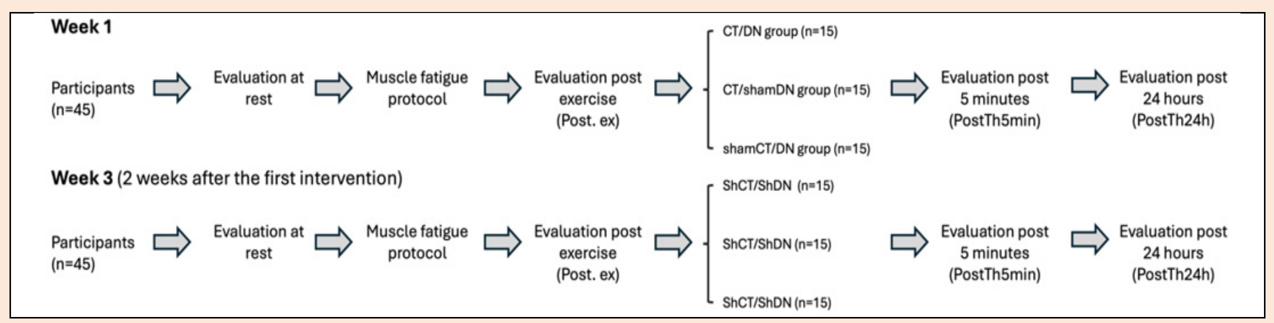

Figure 1. Study design. CT: compression contrast therapy; DN: dry needling; Sh: sham (control condition).

tion, which was the same for all participants (Figure 1). Participants remained unaware of their assigned intervention throughout the study. Additionally, participants were instructed to abstain from training for 48 hours both before and after the intervention.

Convenience sampling was employed to recruit participants. The recruitment procedure entailed reaching out to martial art academies in the local area through direct communication with the academy leaders and administration. Following this, information about the study was circulated among the fighters associated with these academies.

Participants

The sample size was determined a priori, referencing a previous study on DNT in combat sports (Trybulski et al., 2024b). Employing a repeated measures ANOVA within-between interaction, accounting for three groups, four measurements, and an effect size (f) of 0.7581577, derived from a partial eta squared of 0.365 achieved in stiffness (Trybulski et al., 2024b), with a significance level of 0.05 and a power of 0.95, G*power software recommended retrieving a minimum sample of 9 participants. Despite the requirement for only 9 athletes, our aim was to recruit additional participants to safeguard against reductions in the sample size. This approach also aimed to mitigate the common dropout rates observed in experimental studies.

Upon establishing the necessary participant number, the recruitment process started (Figure 2). Subsequently, interested individuals underwent evaluation to ascertain their eligibility. The inclusion criteria were as follows: (i) aged between 18 and 40 years; (ii) possessing over 3 years of experience in martial arts and attaining at least Tier 2 status (Highly Trained/National Level) according to the participant's classification framework (McKay et al., 2022); (iii) maintaining good health without any injuries or illnesses during the experiment and within the month preceding the study; (iv) abstaining from any drugs, ergogenic drinks, or medications during the experiment; and (v) being men athletes. Study exclusions encompassed: (i) elevated pre-test blood pressure (blood pressure > 140/90 mm Hg); (ii) current treatment for injuries, compromised skin, or unspecified skin lesions at the measurement sites; (iii) individuals with tattoos at the measurement site, as it may interfere with tissue perfusion measurement; (iv) and those taking any medications, including painkillers. Additionally, exclusions were implemented in cases of extreme fatigue, fever, infection, or at the explicit request of the participant (Holwerda et al., 2013).

After the initial recruitment phase, 45 volunteers were identified, all of whom met the established inclusion criteria. These volunteers comprised forty-five men martial arts athletes from mixed martial arts, judo, and Brazilian jiu-jitsu, with a mean age of 27.6 ± 4.0 years, 179.9 ± 6.7 cm, 81.9 ± 9.4 kg, a body mass index of 25.5 ± 2.8 kg/m^2, and a training experience of 10.9 ± 4.2 years (Table 1). Additionally, all participants were classified as Tier 2 status (Highly Trained/National Level) according to the participant classification framework (McKay et al., 2022). They reported engaging in training 3 to 4 times per week, with a focus on competition preparation.

Experimental regenerative therapies

The participants (n = 45) were randomly assigned to three experimental groups, each undergoing a unique combination of CCT and DNT: (i) The CT/DN group (n = 15) received a DNT session followed immediately by CCT for 10 minutes. After a 2-week break, this group received a sham therapy as a control (ShCT/ShDN); (ii) The CT/ShDN group (n = 15) underwent a sham DNT session followed immediately by CCT for 10 minutes. After a 2-week break, this group received a sham therapy as a control (ShCT/ShDN); (iii) The ShCT/DN group (n = 15) underwent a DNT session followed immediately by sham CCT for 10 minutes. After a 2-week break, this group received a sham therapy as a control (ShCT/ShDN).

The DN procedure was performed by safety rules, which included disinfection of the injection site. Sterile 0.30x30 mm soma needles were used. Each puncture was performed with one needle for one trigger point (TrP), and

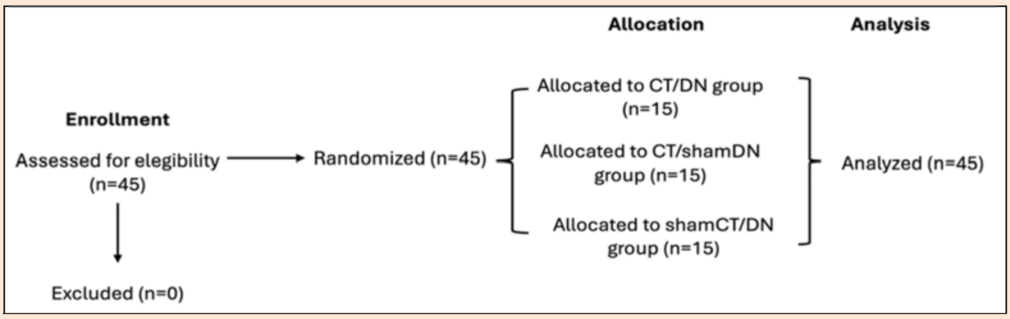

Figure 2. Participants flowchart. CT: compression contrast therapy; DN: dry needling.

Table 1. Descriptive statistics (mean ± standard deviation) of the groups.

	CT/DN group (n=15)	CT/ShDN group (n=15)	ShCT/DN group (n=15)
Age (years old)	25.5 ± 3.6	28.9 ± 4.0	28.3 ± 3.8
Height (cm)	180.0 ± 9.7	180.4 ± 5.4	179.3 ± 4.1
Body mass (kg)	76.9 ± 4.2	85.3 ± 8.7	83.2 ± 7.9
Body mass index (kg/m^2)	23.6 ± 1.8	26.9 ± 3.1	25.9 ± 2.4
Experience (years)	8.9 ± 4.2	12.8 ± 3.1	10.8 ± 3.6

CT: compression contrast therapy; DN: dry needling; Sh: sham the local twitch response (LTR) was monitored. TrP was defined as palpable tenderness in the tense 7-8 cm below the antecubital fossa in the dominant hand's flexor carpi radialis (FCR) muscle. The therapy was performed on the dominant forearm. An experienced clinician performed a maximum of 5 pushes in the TrP area without removing the needle from the skin but changing its direction. If no LTR is observed after five punctures, rotate the needle around its long axis toward tissue tension and wait 30 seconds (Perreault et al., 2017). After this time, the dry needling session was considered completed. While performing DN, the participant was asked to turn his head and not look at the DN therapy, which was intended to make it difficult to differentiate between natural and sham treatment. The entire procedure lasted from 15 to 30 seconds. A register of side effects was kept, and in 4 cases, the participants reported moderate pain and a clinically insignificant burning sensation during the procedure.

Then, a Game Ready CT device (Avanos Medical, USA, 2020) was used with a cuff placed on the forearm. This device provided alternating stimulation for one minute with cold at a temperature of 3°C and a pressure of 75 mmHg (10 kPa) and then one minute with heating at 45°C and compression at 15 mmHg (3.33 kPa). The total treatment time was 10 minutes (Trybulski et al., 2024b).

The ShDN session used a quasi-needle that did not pierce the skin. The quasi-needle contained a spring, which, combined with a unique technique, allowed for a sensation similar to the needle used in DN. Additionally, the needle was blunt (telescopic needle - sham therapy) (Braithwaite et al., 2019). The ShCT session used the same procedure, including 1 minute of cold stimulus and 1 minute of warm stimulus over 10 minutes. The temperature was 15°C for a cold stimulus (lowest possible GR regulation) and a pressure of 15 mmHg (lowest possible GR regulation) and 36°C for a warm stimulus (neutral stimulus) at a pressure of 15 mmHg (Trybulski et al., 2024b).The least intense parameters were selected for the control group and the most intense ones for the experimental group to obtain the most significant effect, assuming that the body's reaction is proportional to the applied stimulus, i.e., within a safe range for the participants.

Muscle fatigue protocol

After determining the maximum isometric strength of the forearm muscles (averaging three measurements) denoted as Fmax, participants in the study underwent a specific isometric test for the forearm muscles as outlined in existing literature (Maciejczyk et al., 2022; Limmer et al., 2022). This test required participants to sustain an isometric handgrip strength equivalent to 60% (±10%) of their maximum voluntary contraction strength on an electronic dynamometer for a 5-second exercise cycle followed by a 2-second rest period. Each participant completed five sets of this exercise until reaching their limit. Participants were seated with their upper limbs bent at an elbow angle of 6-70 degrees (Stien et al., 2019). To prevent fatigue in the synergistic muscles of the shoulder girdle, the limb was supported on a couch (Zebrowska et al., 2019). Throughout the study, participants regulated the exercise duration and the intensity of their handgrip under the supervision of an assistant involved in the survey. Prior to commencing the exercise, participants engaged in a 3-minute warm-up for the forearm muscles, which included squeezing a ball, hanging from a bar, and flexing the forearm muscles.

Measurements

Using an ultrasonic device manufactured by SONOSCAPE P20 in 2021, researchers identified the widest cross-section of the flexor carpi radialis (FCR) muscle. They marked the measuring point with a marker based on a previous study (Trybulski et al., 2024a). A line was drawn from the styloid process to the medial epicondyle of the humerus, creating a perpendicular line extending 7.5 ± 0.5 cm from the epicondyle, as described in a previous study (Iivarinen et al., 2011). All measurements were consistently taken from the dominant hand of participants who maintained a relaxed sitting position with approximately 60 degrees of elbow flexion, following a previous methodology (Zebrowska et al., 2019).

The measurements conducted on all study participants included PU, MT, PPT, and Fmax, with assessments performed at four intervals: (I) at rest, (II) immediately after exercise, (III) 5 minutes after therapy, and (IV) 24 hours post-therapy. These evaluations were conducted between 9:00 and 12:00 at the Provita Medical Center, where ambient temperature remained consistent at 21°C. Trained physiotherapists administered the measurements throughout the study period.

Tissue perfusion -Perfusion Unit (PU)

Tissue perfusion was assessed using laser Doppler flowmetry (LDF) with a Perimed device manufactured in Sweden in 2004. LDF is widely recognized as the gold standard for evaluating microcirculatory responses due to its high sensitivity and measurement repeatability (Gemae et al., 2021). The LDF measurements were conducted at a skin tissue volume of 1 mm³ and a depth of 2.5 mm, employing two contact laser probes placed on the tip of the index finger of both hands (Liana et al., 2009; Gemae et al., 2021).

This method utilizes monochromatic laser light within a narrow band from red to near-infrared, as described by Babos et al (Babos, 2013). The emitted radiation penetrates deep into the tissue, where it encounters moving blood cells, causing a change in their vibration frequency due to the Doppler effect, as explained by Saumet et al. (Saumet et al., 1988). The returning light is then analyzed by a photodetection system, with the resulting voltage directly proportional to the speed and quantity of moving blood cells, allowing for the assessment of blood supply in the examined tissue area, following the principles outlined by Kvandal et al. (Kvandal et al., 2006). The outcome obtained from the data collection was the PU, measured in arbitrary units (A.U.).

Muscle Tension (MT)

Measurements were conducted using a myotonometer (MyotonPRO AS, Myoton Ltd, Estonia 2021). This digital device comprises a body and a depth probe with a diameter of 3 mm. The probe applies a pre-pressure of 0.18 N to the surface, compressing the underlying material. Subsequently, a mechanical impulse of 0.4 N lasting 15 milliseconds is released, causing rapid deformation of the medium (Trybulski et al., 2024a). Myotonometry is recognized as a reliable measurement technique capable of discerning differences in physical properties compared to stretched muscle fibers (Melo et al., 2022; Bartsch et al., 2023). This method involves registering the damped natural vibrations of soft biological tissue as an acceleration signal, followed by simultaneous calculation of parameters related to stress state and biomechanical properties (Bartsch et al., 2023). The outcome obtained from the data collection was the MT, measured in Hz.

Pressure Pain Threshold (PPT)

The pressure pain threshold (PPT) was assessed using an FPIX algometer (Wagner Instruments, Greenwich, CT, USA, 2013). This method of determining PPT aims to objectively measure pain thresholds and is known for its high repeatability and reliability (Park et al., 2011). Participants underwent a compression test with a probe measuring 4 mm in diameter, exerting compressive forces on a specific marked area that remained constant throughout the test. The force value in Newtons per square centimeter (N/cm²) was digitally displayed on the screen and calculated as the average of three measurements. Pressure was applied until participants signaled the test stimulus as unpleasant (Trybulski et al., 2024a). The outcome obtained from the data collection was the PPT, measured in N/cm.

Isometric muscle force (Fmax)

Maximum forearm muscle force (Fmax) was measured using an electronic hand-held dynamometer (EH106 China, 2020). Participants underwent the measurement in a standing position, with their arms hanging freely. Based on these measurements, the maximum strength of the forearm muscles was calculated and expressed in kilograms-force ([kgf]).

The grip strength test involved participants exerting a maximum five-second contraction of their forearm muscles while squeezing the dynamometer. This method is known for its high repeatability and reliability (Venegas-Carro et al., 2022). Prior to the test, each participant engaged in a warm-up routine, consisting of exerting maximum pressure on a small ball ten times, followed by a 10-second stretch of the forearm muscles (Trybulski et al., 2024a). The outcome obtained from the data collection was the Fmax, measured in kgf.

Statistical analysis

Descriptive statistics, including the mean and standard deviation, were presented. Normality was assessed using the Kolmogorov-Smirnov test ($p > 0.05$), while homogeneity was evaluated with Levene's test ($p > 0.05$). Once both normality and homogeneity assumptions were confirmed, a mixed ANOVA test (time*group) was conducted to compare pre- and post-intervention outcomes across different groups. The effect size was measured using partial eta squared (η_p^2). The effect sizes were evaluated against the following thresholds (Ferguson, 2009): 0.04 for minimum effect size, 0.25 for moderate effect size, and 0.64 for strong effect size. All statistical analyses were performed using SPSS (version 28.0.0.0, IBM, USA), with a significance threshold set at $p < 0.05$.

Results

Significant interactions (group*time) were observed in PPT ($F = 3.957$; $p = 0.005$; $\eta_p^2 = 0.159$), MT ($F = 3.128$; $p = 0.002$; $\eta_p^2 = 0.130$), PU ($F = 23.208$; $p < 0.001$; $\eta_p^2 = 0.525$), and Fmax ($F = 4.153$; $p < 0.001$; $\eta_p^2 = 0.165$).

Table 2 presents the descriptive statistics of the outcomes analyzed at different moments of assessment. No significant differences ($p > 0.005$) were found between groups at the baseline (rest) moment. Significant differences between groups were found in MT during the PostTh5min ($F = 5.967$; $p = 0.005$; $\eta_p^2 = 0.221$), as well as in PU during the PostTh5min ($F = 85.020$; $p < 0.001$; $\eta_p^2 = 0.802$) and PU during the PostTh24h ($F = 32.726$; $p < 0.001$; $\eta_p^2 = 0.609$).

Table 2. Descriptive statistics (mean ± standard deviation) of the outcomes analyzed in the different moments of assessment.

		CT/DN (n = 15)	CT/ShDN (n = 15)	ShCT/DN (n = 15)	Between-groups analysis
PPT (N/cm)	**Baseline**	84.3 ± 7.6	86.2 ± 6.2	85.6 ± 5.6	$F = 0.320$; $p = 0.728$; $\eta_p^2 = 0.015$
	Post. exe	78.3 ± 7.7	81.3 ± 7.2	80.7 ± 6.2	$F = 0.719$; $p = 0.493$; $\eta_p^2 = 0.033$
	PostTh5min	82.7 ± 7.7	86.3 ± 7.1	83.7 ± 5.8	$F = 1.076$; $p = 0.350$; $\eta_p^2 = 0.049$
	PostTh24h	85.3 ± 7.4	87.5 ± 6.0	85.5 ± 5.6	$F = 0.564$; $p = 0.573$; $\eta_p^2 = 0.0026$
MT (Hz)	**Baseline**	19.6 ± 0.8	19.3 ± 0.7	19.3 ± 0.6	$F = 0.896$; $p = 0.416$; $\eta_p^2 = 0.041$
	Post. exe	24.7 ± 1.2	24.3 ± 0.9	24.2 ± 0.9	$F = 0.941$; $p = 0.398$; $\eta_p^2 = 0.043$
	PostTh5min	14.7 ± 1.2[b]	16.2 ± 1.0[a]	15.4 ± 1.3	$F = 5.967$; $p = 0.005$*; $\eta_p^2 = 0.221$
	PostTh24h	16.5 ± 0.8	17.2 ± 0.9	16.5 ± 1.2	$F = 2.833$; $p = 0.070$; $\eta_p^2 = 0.119$
PU (A.U.)	**Baseline**	10.1 ± 0.7	10.2 ± 0.7	9.9 ± 0.7	$F = 0.576$; $p = 0.567$; $\eta_p^2 = 0.027$
	Post. exe	13.4 ± 0.5	13.1 ± 0.7	13.3 ± 0.5	$F = 1.413$; $p = 0.255$; $\eta_p^2 = 0.063$
	PostTh5min	18.2 ± 1.2[b,c]	15.7 ± 1.0[a,c]	13.6 ± 0.5[a,b]	$F = 85.020$; $p<0.001$*; $\eta_p^2 = 0.802$
	PostTh24h	13.0 ± 0.9[b,c]	11.7 ± 0.8[a,c]	10.7 ± 0.6[a,b]	$F = 32.726$; $p<0.001$*; $\eta_p^2 = 0.609$
Fmax (kgf)	**Baseline**	50.7 ± 4.9	51.2 ± 5.5	51.8 ± 4.7	$F = 0.167$; $p = 0.847$; $\eta_p^2 = 0.008$
	Post. exe	45.5 ± 5.1	46.2 ± 5.1	44.0 ± 2.8	$F = 0.968$; $p = 0.388$; $\eta_p^2 = 0.044$
	PostTh5min	50.5 ± 5.7	50.0 ± 5.0	53.6 ± 5.2	$F = 2.037$; $p = 0.143$; $\eta_p^2 = 0.088$
	PostTh24h	53.4 ± 5.6	51.1 ± 4.6	52.9 ± 5.5	$F = 0.813$; $p = 0.450$; $\eta_p^2 = 0.037$

CT: compression contrast therapy; DN: dry needling; Sh: sham; Fmax: isometric muscle strength; MT: muscle tension; PPT: pressure pain threshold; PU: perfusion unit; Post. exe: post muscle fatigue; PostTh5min: post 5 minutes of the intervention; PostTh24h: post 24 hours of the intervention; a: significantly different ($p < 0.05$) from CT/DN; b: significantly different ($p < 0.05$) from CT/ShDN; c: significantly different ($p < 0.05$) from ShCT/DN; *: significantly different ($p < 0.05$).

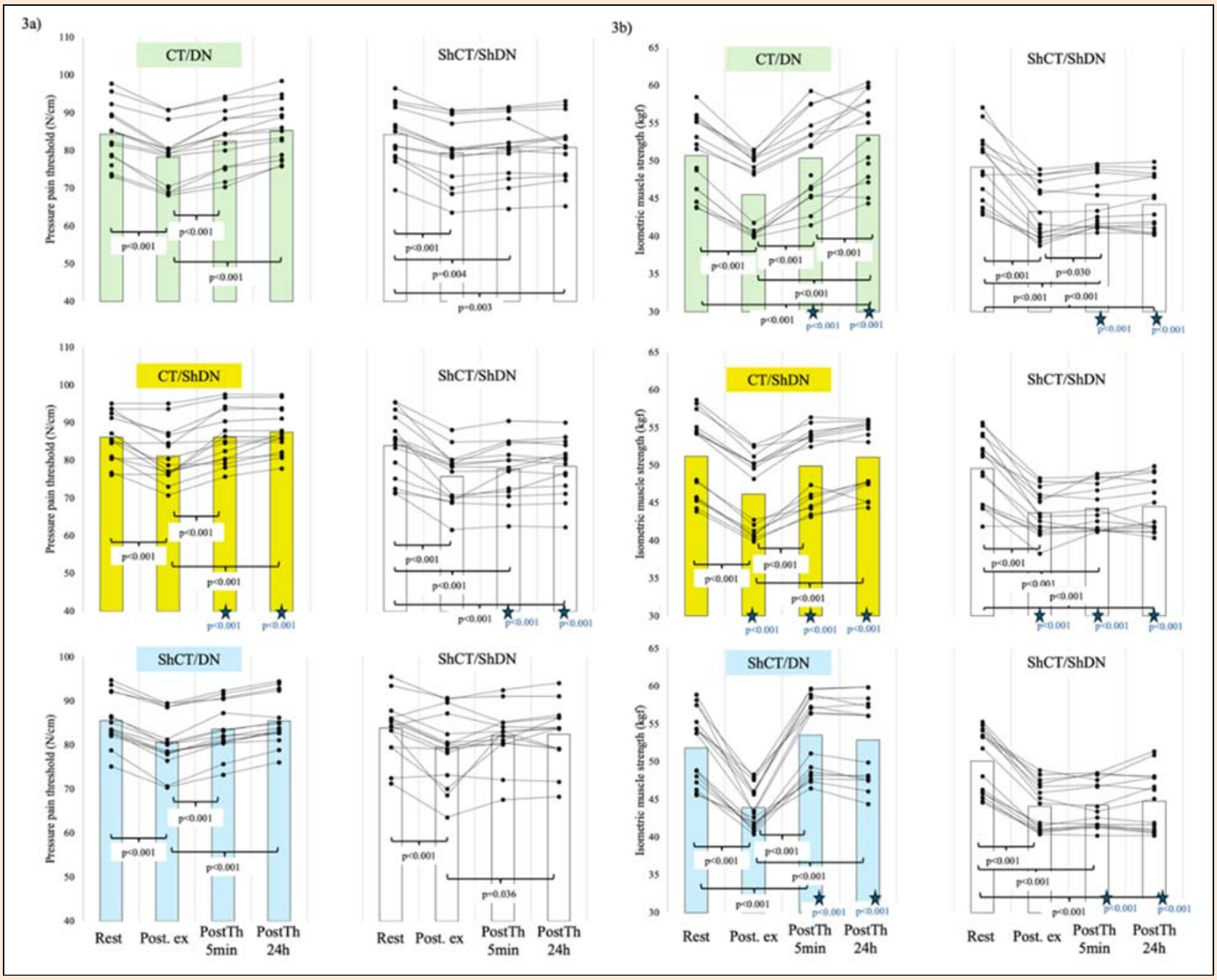

Figure 3. Descriptive statistics and intra-individual variations of (a) pressure pain thresholds and (b) isometric muscle strength of the participants in the three experimental groups and sham conditions. The star icon indicates significant within-group differences compared to the same measurement in the control condition (ShCT/ShDN). CT: Compression Contrast Therapy; DN: Dry Needling; Sh: Sham.

In the PostTh5min, CT/ShDN presented significantly greater MT than CT/DN (1.467 Hz; $p = 0.004$). Additionally, in the PostTh5min, PU was significantly greater in CT/DN compared to CT/ShDN (2.533 A.U.; $p < 0.001$) and ShCT/DN (4.600 A.U.; $p < 0.001$). CT/ShDN was also significantly greater than ShCT/DN (2.067 A.U.; $p < 0.001$). At PostTh24h, the CT/DN group presented significantly greater PU than CT/ShDN (1.267 A.U.; $p < 0.001$) and ShCT/DN (2.333 A.U.; $p < 0.001$). CT/ShDN was also significantly greater than ShCT/DN (1.067 A.U.; $p = 0.002$).

Figure 3 presents the descriptive statistics and intra-individual variations of PPT and Fmax for participants in the three experimental groups and sham conditions. For PPT (Figure 3a), the CT/ShDN group had significantly greater values at PostTh5min ($p < 0.001$) and PostTh24h ($p < 0.001$) than during the sham protocol moments (i.e., ShCT/ShDN). Additionally, in the experimental condition, the CT/ShDN group significantly increased PPT after the intervention at both PostTh5min ($p < 0.001$) and PostTh24h ($p < 0.001$) compared to the immediate post-exercise moment.

In the within-group analysis for Fmax (Figure 3b), it was observed that in the CT/DN group, both PostTh5min ($p < 0.001$) and PostTh24h ($p < 0.001$) were significantly greater than the same periods in the ShCT/ShDN. The same evidence was observed in the ShCT/DN group ($p < 0.001$). In the CT/ShDN group, the findings revealed that in addition to PostTh5min ($p < 0.001$) and PostTh24h ($p < 0.001$), the immediate post-exercise moment also had significantly greater Fmax than the analogous moment in the sham condition. All three experimental group conditions (CT/DN, CT/ShDN, and ShCT/DN) exhibited similar trends, specifically, there was a significantly lower Fmax observed immediately post-exercise compared to PostTh5min ($p < 0.001$) and PostTh24h ($p < 0.001$). Additionally, in the case of CT/DN, it was also observed that there was a significantly higher Fmax at PostTh24h compared to PostTh5min ($p < 0.001$).

Figure 4 presents the descriptive statistics and intra-individual variations of MT and PU for participants in the three experimental groups and sham conditions. In the within-group analysis for MT (Figure 4a), it was observed that in the CT/DN group, both PostTh5min ($p < 0.001$) and PostTh24h ($p < 0.001$) were significantly greater than the same periods in the ShCT/ShDN. The same evidence was observed in the ShCT/DN group ($p < 0.001$) and CT/ShDN group ($p < 0.001$). It was further noted that immediately post-exercise, all three groups exhibited significantly higher muscle tension compared to rest (p < 0.001), PostTh5min (p < 0.001), and PostTh24h (p < 0.001). This evidence was consistent across all experimental groups. In the case of ShCT/ShDN it was also observed that the MT was significantly greater in PostTh24h than in PostTh5min (p < 0.001).

In the within-group analysis for PU (Figure 4b), it was observed that in the CT/DN group, both PostTh5min (p < 0.001) and PostTh24h (p < 0.001) exhibited significantly higher values compared to the equivalent periods in the ShCT/ShDN. Similar findings were noted in the CT/ShDN group (p < 0.001). However, in the case of the ShCT/DN group, significant differences were observed only in PostTh5min (p < 0.001). Furthermore, in the CT/DN and CT/ShDN groups, the PostTh5min period showed significantly higher values than post-exercise (p < 0.001), whereas such differences were not significant in the ShCT/DN group. Regarding the comparisons between PostTh5min and PostTh24h, significantly higher PU values were observed in PostTh5min in the CT/DN (p < 0.001), CT/ShDN (p < 0.001), and ShCT/DN (p < 0.001) groups.

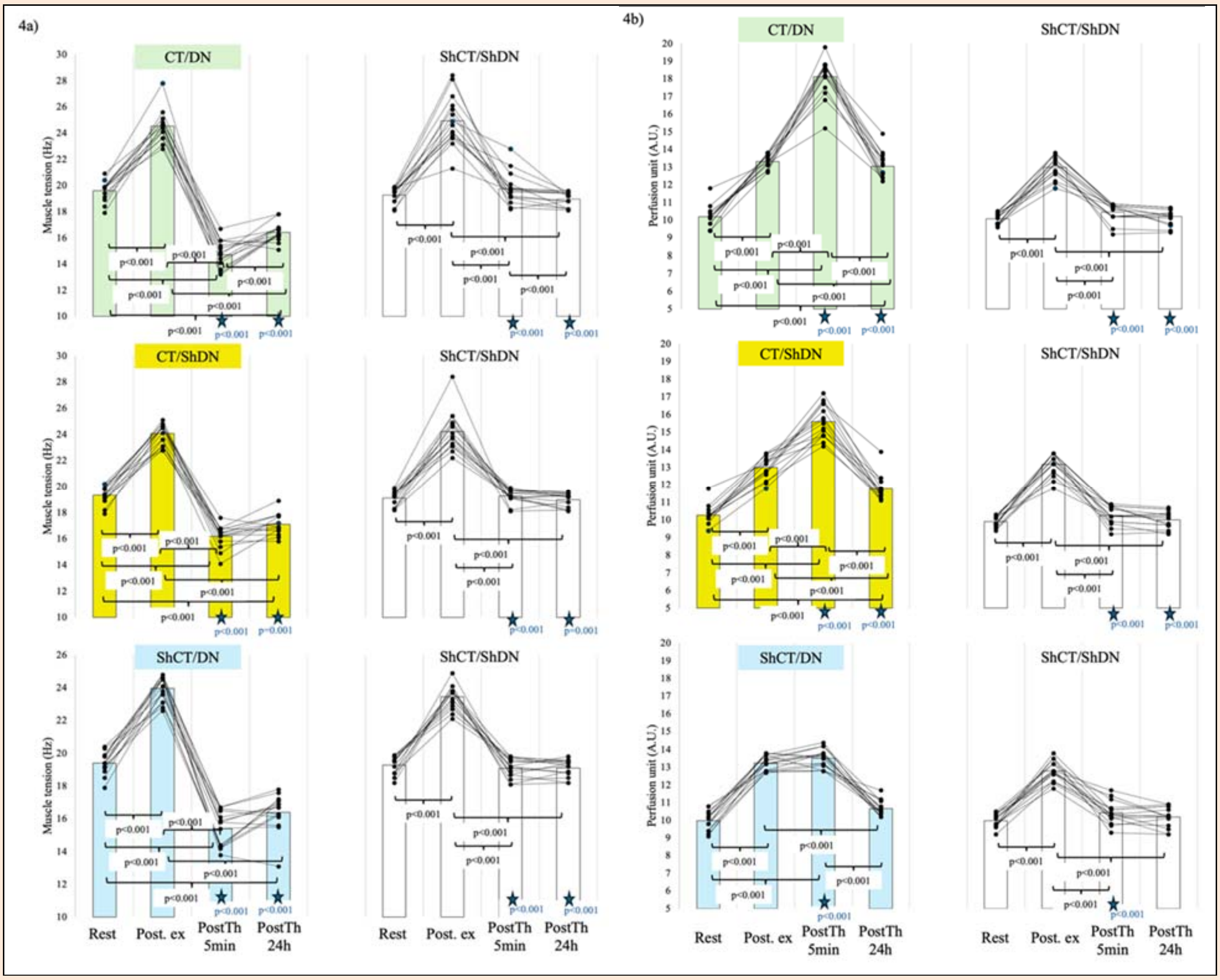

Figure 4. Descriptive statistics and intra-individual variations of (a) muscle tension and (b) perfusion unit of the participants in the three experimental groups and sham conditions. The star icon indicates significant within-group differences compared to the same measurement in the control condition (ShCT/ShDN). CT: Compression Contrast Therapy; DN: Dry Needling; Sh: Sham.

Discussion

The findings of the present experimental study indicate that while CT/DN, CT/ShD, and ShCT/DN yielded comparable positive effects within their respective groups by significantly enhancing MT, PU, and Fmax following the employed regenerative technique, these improvements persisted from 5 minutes post-intervention up to 24 hours thereafter. Specifically, it was noted that the combination of CT/DN significantly enhanced the athlete's performance compared to the isolated approach in improving both MT and PU after 5 minutes of inducing muscle fatigue. However, employing either a combined approach or isolation yielded similar enhancements in Fmax and PPT. Thus, contrary to our hypothesis, for most outcomes, utilizing a single recovery technique alone appears to be as effective as combining both techniques, with the exception of MT and PU after 5 minutes. In clinical practice, it is suggested that a single recovery technique is sufficient to ensure favorable recovery outcomes after muscle fatigue.

The CT/DN strategy led to significant improvements in MT compared to approaches that used only one method. It also induced significantly improvements 5 minutes after muscle fatigue, lasting up to 24 hours. A previous study revealed the benefits of each approach in isolation for enhancing MT (Trybulski et al., 2024b). The same study observed that DN significantly enhanced MT in the gastrocnemius muscle of martial arts athletes after fatigue induction (Trybulski et al., 2024b). Similarly, another study observed improvements in muscle tension recovery when cryo-compression therapy was used after muscle fatigue in the forearms and hand muscles of martial arts athletes (Trybulski et al., 2024a). However, due to the lack of evidence comparing these strategies in isolation against their combination, it was noteworthy to find that the combined approach appears to enhance recovery processes. This is likely due to the reducing inflammation and promoting vasoconstriction in the case of CT, while DN may facilitate muscle relaxation and release trigger points, collectively enhancing muscle recovery and thickness.

The combination of CT and DN shown to significantly enhance the recovery of muscle tension in martial arts athletes post-fatigue possibly due to the synergistic effects of these modalities on physiological processes. CT alternates between periods of compression and decompression, which promotes blood flow, reduces inflammation, and enhances lymphatic drainage (Ward et al., 2024). This increased circulation aids in the removal of metabolic waste products, such as lactic acid, that accumulate during muscle fatigue (Barnett, 2006). Concurrently, DN targets myofascial trigger points, which are hyperirritable spots within a muscle that contribute to sustained muscle tension and pain (Fernández-de-Las-Peñas and Nijs, 2019). By inserting fine needles into these trigger points, DN disrupts the tight bands of muscle fibers, leading to a reduction in muscle stiffness and improved range of motion (Alaei et al., 2021; Sánchez-Infante et al., 2021). The immediate benefits observed within 5 minutes can be attributed to the rapid increase in local blood flow and the mechanical disruption of muscle knots, which quickly alleviates tension (Thomas, 2023). Additionally, the initial mechanical and neuromodulatory effects of DN contribute to sustained reduction in muscle tension by inducing biochemical changes that normalize muscle tone and reduce nociceptive sensitivity (Koppenhaver et al., 2015). These combined mechanisms may create an optimal environment for muscle recovery, promoting faster return to functional performance in martial arts athletes.

The combination of CT/DN has showed significantly more effective than employing regenerative technique alone in mitigating PU following 5 minutes of muscle fatigue, with enduring effects observed up to 24 hours post-intervention. Although we did not find similar studies directly comparing these combinations, research on the individual techniques has shown significant improvements in post-exercise recovery of perfusion units using both DN (Trybulski et al., 2024b) and CT (Trybulski et al., 2024a).

While CT alternates between vasoconstriction and vasodilation, promoting efficient blood flow (Hing et al., 2008), DN induces localized micro-trauma that stimulates a healing response through increased blood flow and the release of growth factors and endorphins (Roch et al., 2022). The synergy of these therapies results in more efficient muscle recovery by optimizing vascular function and reducing MT, thereby enhancing PU recovery. The observed benefits at both 5 minutes and 24 hours post-intervention suggest that the combined approach provides both immediate and sustained improvements in PU. CT quickly reduces inflammation and edema (Rabe et al., 2020), enhancing acute blood flow dynamics (Vaile et al., 2016), while DN's effects on muscle fibers and trigger points promote longer-term healing and muscle function restoration (de la Cruz-Torres et al., 2019). This dual mechanism likely results in a more robust and rapid resolution of muscle fatigue and damage.

The combination of CT/DN, as well as their individual application (i.e., ShCT/DN and CT/ShDN), have been shown to significantly enhance the recovery of Fmax in martial art athletes, particularly at 5 minutes and 24 hours post-muscle fatigue induction. The neurophysiological mechanisms underlying the benefits of CT and DN on the recovery of Fmax in martial art athletes may be primarily centered around their effects on neuromuscular function and pain modulation (Cagnie et al., 2013). CT enhances proprioceptive feedback and neuromuscular control through repetitive cycles of pressure application (Michael et al., 2014), which may stimulate mechanoreceptors in the skin and muscles (Donath and Faude, 2016). This stimulation can improve motor unit recruitment and synchronization (Belbasis and Fuss, 2018), leading to more effective force production. Moreover, DN impacts neuromuscular function by inducing local twitch responses in myofascial trigger points, which results in a reflexive relaxation of tight muscle fibers (Jiménez-Sánchez et al., 2022). This process improves motor unit firing patterns and reduces inhibitory signals to the central nervous system (Dunning et al., 2014), allowing for more efficient muscle contraction.

Interestingly, regarding the impact on PPT, it was observed that the CT/DN and ShCT/DN conditions did not significantly differ from the control condition. Only the CT/ShDN condition produced significant improvements in the outcome compared to the control. CT's rhythmic compression may activate mechanoreceptors (Ward et al., 2024), inhibiting nociceptive signaling through the gate control theory of pain, thereby providing immediate and sustained analgesic effects (Liu and Kelliher, 2022). In contrast, DN, while effective at targeting myofascial trigger points, primarily induces localized mechanical and biochemical changes that may not offer the same comprehensive circulatory and neuromodulatory benefits as CT. The combination of CT and DN might dilute the specific advantages of each modality due to their differing mechanisms of action, leading to less pronounced improvements in PPT.

Although the present experimental study may provide valuable insights into the efficacy of CT and DN techniques in enhancing muscle recovery following fatigue induction in martial arts athletes, study limitations and avenues for future research emerge. Firstly, the study focused solely on short-term outcomes (up to 24 hours), warranting investigations into the long-term effects of CT/DN on muscle recovery and athletic performance. Additionally, while the synergistic effects of CT and DN on neuromuscular function and pain modulation were highlighted, further research is needed to elucidate the precise mechanisms underlying their combined impact. Future studies should also explore individual differences in athlete response to CT/DN interventions, considering factors such as training background, or morphological and genetic predispositions. Moreover, comparative analyses with other regenerative techniques and diverse athletic populations could offer a more comprehensive understanding of the optimal approach for muscle recovery in martial arts and beyond.

The findings from this study offer practical implications for both martial arts practitioners and coaches seeking to optimize recovery strategies and enhance performance. By incorporating a combined approach of CT and DN, athletes can potentially expedite muscle recovery, alleviate post-exercise fatigue, and improve overall athletic readiness. Coaches can utilize these techniques strategically in training programs or during competitions in between combats to mitigate the negative effects of muscle fatigue, ultimately facilitating athletic performance. Therefore, applying CT within 10 minutes after muscle fatigue sets in or completing a maximum of 5 pushes on the TrP in the case of DN may suit for achieving the fastest recovery.

Conclusion

Our experimental study found that both CT and DN, whether used together or individually, similarly improved MT, Fmax, and PU in martial arts athletes after inducing muscle fatigue. Compared to the sham intervention, none were significantly better regarding PPT. Generally, the three regenerative approaches (combined or isolated) produced similar improvements in outcomes from 5 minutes after muscle fatigue induction up to 24 hours. Comparisons between strategies revealed that all had similar effects on PPT and Fmax (whether techniques were combined or isolated). However, regarding MT and PU, the combined approach (CT/DN) showed the most significant improvements 5 minutes after exercise. Practitioners and coaches are recommended to use regenerative techniques, either CT or DN, combined or not, to mitigate the impact of exercise-induced fatigue, enhance recovery, and restore muscle functionality and properties.

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Key points

- CT and DN enhanced MT and PU 5 minutes after muscle fatigue induction compared to other interventions.
- All groups showed comparable improvements in Fmax and PPT from 5 minutes up to 24 hours post-therapy.
- CT and DN, used individually or together, enhanced muscle functionality recovery and mitigated exercise-induced fatigue.

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