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Section II – Exercise Physiology and Sports Medicine

The Effects of Dry Needling and Tecar Therapy on Post-Exercise Gastrocnemius Muscle Recovery in Mixed Martial Arts and Crossfit Athletes

by
Adrian Kużdżał [1,], Gracjan Olaniszyn [2,3], Małgorzta Smoter [4], Adam Kawczyński [5], Filipe Manuel Clemente [6,7,8], Robert Trybulski [3,9]*

This study investigated the recovery effects of combining dry needling (DN) with Tecar therapy (T) compared to each treatment alone on gastrocnemius muscle recovery in Mixed Martial Arts (MMA) and CrossFit athletes after a fatigue protocol. Forty-eight athletes were randomly assigned to one of the four groups: DN/T, DN/sham T, shamDN/T, and a control group. DN involved needling three trigger points per muscle, while Tecar therapy used electromagnetic waves applied via capacitive transfer. Assessments of perfusion (PU), elasticity (ME), the pain threshold (PPT), and the reactive strength index (RSI) were taken at rest, post-fatigue, post-treatment, and 48 hours post-treatment. A mixed ANCOVA showed the DN/T group had significantly higher PU scores post-treatment compared to all other groups ($p < 0.001$). ME was significantly lower in the DN/T group at both post-treatment and 48 hours into recovery ($p < 0.05$). PPT was significantly higher in the DN/T group at both time points, particularly compared to the control condition ($p < 0.05$ to $p < 0.001$). The RSI was also significantly higher in the DN/T group at both time points compared to all other groups ($p < 0.001$). In conclusion, combining DN with T demonstrated superior recovery benefits for blood perfusion, muscle elasticity, the pain threshold, and reactive strength compared to either treatment alone or control, suggesting a synergistic effect beneficial for athletes' muscle recovery.

Keywords: *recovery; muscle pain; tissue perfusion; muscle strength; exercise*

Introduction

The gastrocnemius muscle, located in the posterior compartment of the lower leg, plays a crucial role in various athletic movements, such as Mixed Martial Arts (MMA) and CrossFit (Toledo et al., 2022), and is equally important in daily activities like walking, climbing stairs, and maintaining balance. Its primary function is plantarflexion of the foot at the ankle joint, which is essential for activities such as jumping, running, and squatting (Johanson et al., 2009). In CrossFit, the gastrocnemius is heavily engaged in exercises like box jumps, double-unders, and thrusters (Giordano and Botros, 2023), where explosive plantarflexion generates power and propels the body upward or forward. Additionally, the gastrocnemius contributes to knee flexion, aiding movements like squats and lunges (Gao et al., 2023). It also plays a key role in maintaining

[1] *Institute of Physiotherapy, Faculty of Health Sciences and Psychology, Collegium Medicum, University of Rzeszów, Rzeszów, Poland.*
[2] *Olaniszyn Physiotherapy Centre, Racibórz, Poland.*
[3] *Faculty of Medicine, Katowice Business University, Katowice, Poland.*
[4] *Department of Basic Physiotherapy, Gdansk University of Physical Education and Sport, Gdansk, Poland.*
[5] *Faculty of Medicine, Wrocław University of Science and Technology, Wrocław, Poland.*
[6] *Applied Research Institute (i2A), Polytechnic University of Coimbra, Coimbra, Portugal.*
[7] *Sport Physical Activity and Health Research & Innovation Center, Coimbra, Portugal.*
[8] *Department of Biomechanics and Sport Engineering, Gdansk University of Physical Education and Sport, Gdansk, Poland.*
[9] *Provita Żory Medical Center, Żory, Poland.*
* Correspondence: akuzdzal@ur.edu.pl

balance and stability during dynamic exercises by controlling ankle positioning, thereby reducing the risk of excessive pronation and supination (Lima et al., 2014).

Rope jumping is a frequent and dynamic exercise in MMA training and CrossFit that heavily engages the gastrocnemius through repeated concentric-eccentric contractions, enhancing strength, endurance, and power (Yang et al., 2019). Its plyometric nature improves the muscle's ability to store and release elastic energy, which is crucial for jumping performance (Singh et al., 2022). Electromyographic studies indicate heightened gastrocnemius activation, particularly during the eccentric phase when the muscle lengthens under tension (Ferri-Caruana et al., 2024). Different jumping techniques, such as the bounce jump (BJ) and the alternate jump (AJ), influence muscle recruitment differently, with the BJ involving greater gastrocnemius activation (di Cagno et al., 2020). Thus, it requires technical proficiency and gradual progression to prevent excessive strain.

Due to the repetitive and high-intensity nature of rope jumping, athletes may experience delayed onset muscle soreness (DOMS), leading to discomfort and impaired function (Chen et al., 2020). This necessitates effective interventions to alleviate muscle pain and facilitate recovery (Marocolo et al., 2025; Trybulski et al., 2024d). Muscle pain during exertion may also be linked to myofascial pain syndrome (MPS), a common musculoskeletal disorder characterized by myofascial trigger points (TrPs) in skeletal muscle and fascia (Gerwin, 2010). These hypersensitive nodules can cause spontaneous or induced pain and movement restrictions (Fernández-De-Las-Peñas et al., 2021; Hong, 2004). The complexity of MPS lies in its multifactorial etiology and challenging diagnosis. Scientific evidence suggests that TrPs result from a combination of the muscle overload, microtrauma, and sustained muscle contraction, which disrupt the local blood flow and metabolic balance, leading to ischemia and sensitization of nociceptors (Gerwin, 2010). Moreover, central sensitization mechanisms may amplify pain perception, complicating clinical presentation (Fernández-de-las-Peñas et al., 2023). The interplay between peripheral trigger points and the central nervous system changes underscores why MPS symptoms can be persistent and resistant to standard treatments. Additionally, MPS often coexists with other musculoskeletal disorders, further complicating diagnosis and management (Fernández-de-las-Peñas and Dommerholt, 2014). MPS is often underdiagnosed, as its symptoms may be mistaken for other musculoskeletal conditions (Fernández-de-las-Peñas and Dommerholt, 2014). If left untreated, MPS can negatively impact athletic performance and quality of life, underscoring the importance of targeted therapeutic interventions (Kuan et al., 2012).

Dry needling (DN) and Tecar therapy are widely used techniques for managing muscle pain and enhancing recovery (Jones et al., 2024; Trybulski et al., 2024d). DN involves inserting sterile acupuncture needles into TrPs and moving them in a controlled pressing motion (typically 5 to 15 repetitions per TrP) to release muscle stiffness, reduce excessive tension, and modulate pain (Jiménez-Sánchez et al., 2021; Trybulski et al., 2024b). This therapy is particularly beneficial for athletes experiencing post-exercise muscle stiffness, flexibility issues, and MPS. DN has been shown to improve quality of life, reduce pain, and enhance muscle function (Kelly et al., 2021; Santos et al., 2021). However, despite its widespread use in sports medicine, there is no consensus on the optimal number of DN sessions, treatment intervals, or its combination with other therapies such as Tecar therapy.

Tecar therapy, a form of endogenous thermotherapy, is increasingly recognized for its therapeutic benefits in sports medicine (Sivkov et al., 2023). This treatment uses radiofrequency energy to penetrate deep into tissues, stimulating vascular growth factors, promoting collagen synthesis, and enhancing cellular repair. Tecar therapy generates heat within the body, accelerating musculoskeletal healing and regeneration. It is particularly valued for its non-invasive nature and minimal side effects, making it a preferred choice among athletes for treating and preventing injuries. Additionally, Tecar therapy provides analgesic, anti-inflammatory, muscle relaxant, and tissue regenerative effects, which are beneficial for both acute and chronic sports injuries (Szabo et al., 2022). For instance, Tecar therapy has been shown to induce temperature changes in the medial gastrocnemius muscle (Yeste-Fabregat et al., 2021).

Despite its promising applications, Tecar therapy is often used in conjunction with other treatments, including pharmacological interventions, rather than as a standalone solution. This combined usage has made it challenging to isolate and fully understand the specific physiological and biochemical effects of Tecar therapy on muscle recovery. Additionally, the current literature lacks comprehensive, standardized methods for assessing these effects, highlighting a significant gap in knowledge that must be addressed to optimize the clinical use of Tecar therapy in sports medicine. The decision to conduct this study on martial arts and CrossFit athletes stems from the demands and injury profiles associated with these sports. Both sports disciplines frequently engage in high-intensity, repetitive, and plyometric activities such as rope jumping, which place considerable stress on the gastrocnemius muscle. These athletes often experience muscle soreness, stiffness, and risk of injury due to the intense nature of their training regimens. Investigating muscle recovery in this population is therefore highly relevant, as effective recovery strategies could directly impact their performance, training consistency, and injury prevention. Moreover, the modalities chosen for comparison—DN and Tecar therapy—are both emerging therapeutic interventions widely used within sports rehabilitation but with different mechanisms of action. Evaluating these treatments in a controlled setting will provide a critical report into their relative effectiveness specifically for recovery of the gastrocnemius muscle after rope jumping, a common exercise in these athletes. Therefore, the main objective was to evaluate the relative effectiveness of these therapeutic modalities in reducing muscle soreness and accelerating recovery. To achieve this, quantitative data on muscle recovery markers were collected, including pain levels, muscle elasticity, tissue hyperemia, and strength assessments before and after treatment. We hypothesized that both DN and Tecar therapy may significantly enhance gastrocnemius muscle recovery following rope jumping in martial arts and CrossFit athletes; however, Tecar therapy—by potentially promoting deep tissue repair and improving microcirculation through capacitive-resistive electrical transfer—may be more effective than DN in reducing muscle soreness, increasing muscle elasticity, and accelerating recovery.

Methods

This report was prepared in accordance with the CONSORT (Consolidated Standards of Reporting Trials) guidelines for randomized controlled trials.

Study Design

A single-blind, randomized controlled trial (RCT) was conducted. To maintain the integrity of the blinding procedure, a researcher not involved in the subsequent assessments supervised the randomization process. Participants were assigned to particular groups using a simple randomization method in dedicated software (Research Randomizer), with a 1:1 ratio. To ensure unbiased allocation, the randomization occurred before the participants' first assessments. Participants were randomly assigned to one of the four groups: (1) DN/T sham group (n = 12): sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); (2) DN sham/T group (n = 12): sham dry needling (superficial needle insertion) plus active Tecar therapy; (3) DN/T group (n = 12): active dry needling plus active Tecar therapy; and (4) a control group (n = 12): no intervention. Randomization occurred before baseline measurements to ensure allocation concealment.

Participants

The sample size for this study was determined based on results from a previous investigation into DN in combat sports (Kużdzał et al., 2024). To analyze interactions within and between groups at four measurement points, a repeated measures ANOVA was performed. The effect size (f) of 0.758, derived from a partial eta squared of 0.341 found in pressure pain threshold data (Kużdzał et al., 2024), was incorporated into the analysis. Using a significance level of 0.05 and a target power of 0.95 for two groups and 8 measurements, G*Power software calculated that at least 6 participants would be necessary. Despite this statistical minimum, we chose to recruit additional participants to account for potential dropouts and maintain an adequate sample size. Consequently, our recruitment target was >30 participants, which is generally considered sufficient to apply the Central Limit Theorem, ensuring the sampling distribution approximates a normal distribution.

A convenience sampling strategy was employed, leveraging established partnerships between the research center and local MMA and CrossFit clubs. Flyers announcing the study, detailing its purpose, eligibility criteria (including age, training level, and experience), and time commitment, were designed by the research team and distributed to athletes and coaches at the partner clubs. Coaches also made verbal announcements about the study during training sessions. Interested athletes were invited to contact the research team via a dedicated study email address. During this initial contact, participants were pre-screened for basic eligibility criteria. Participants who met the criteria were then provided with a detailed informed consent form outlining the study's procedures and risks, which they were required to sign before participating.

Participants were included in the study if they were adults over 18 years old, had at least three years of training experience in either MMA or CrossFit, trained a minimum of three times per week, and were classified as Tier 2 (Trained/Developmental) or higher according to the study's Participant Classification Framework. Individuals were excluded if they had a resting blood pressure above 140/90 mm Hg, any musculoskeletal injuries within the past six months, or presented with skin lesions or tattoos near potential surgical sites, needle phobia, fever, artificial implants (e.g., intraspinal leg wires, cardioverters), infection, pregnancy, nickel allergy, or extreme fatigue.

To control for potential influence on blood perfusion and strength, participants were asked to abstain from ergogenic drinks for six hours and from training for 24 h before and 48 h after testing. All participants provided informed consent, completed a health questionnaire, and were repeatedly reminded of their right to withdraw from the study at any time, without needing to provide an explanation.

Following a recruitment phase, 48 athletes volunteered to participate in the study (Figure 1). The overall group comprised 38 men and 10 women, with a mean age of 27.9 ± 4.3 years. A detailed breakdown of demographic and anthropometric characteristics by group is presented in Table 1.

Based on self-reported training logs collected during the initial screening, participants trained on average 4.8 ± 1.2 sessions per week, with each session lasting approximately 75–120 min. CrossFit athletes typically engaged in a combination of strength, metabolic conditioning, and skill-based workouts, while MMA athletes followed a mixed regimen including striking, grappling, strength and conditioning, as well as technical drills. Across both groups, training intensity was reported as moderate to high (6–8 on a 10-point perceived exertion scale at the 10-point CR-Borg scale).

The study was approved by the ethics committee of the National Council of Physiotherapists, Poland (approval number: 26/2022; approval date: 12 January 2023) and registered as a clinical trial (ISRCTN10378682), adhering to the Declaration of Helsinki guidelines. All participants provided written informed consent after a full explanation of the study's purpose, procedures, and potential risks, including the right to withdraw at any time without consequence. A health questionnaire was also completed, specifically the McGill Pain Questionnaire.

Therapeutic Interventions

The therapeutic intervention using DN and Tecar therapy included a familiarization phase that took place 14 days before the study began. During this phase, participants were introduced to the DN and Tecar dry needling protocol and its significance. However, they were not informed about which specific intervention they would undergo during the actual treatment phase. The familiarization session involved a single DN treatment on the calf muscle of the dominant leg at a single point, performed in a standard position. A maximum of three needle punctures were applied, without breaking the skin. The intervention was conducted on Mondays, as this was considered the most favorable day to study athletes, who typically rested over the weekend.

The experimental therapy consisted of four sessions at the following time intervals: (i) the first session immediately after the exercise protocol, between 10 a.m. and 12 p.m., (ii) the second session 8 h after the fatigue protocol, between 6 p.m. and 8 p.m., (iii) the third session 24 h after the fatigue protocol, between 10 a.m. and 12 p.m., and (iv) the fourth session 32 h after the fatigue protocol, between 6 p.m. and 8 p.m. All variables were measured the next day, 48 h after the fatigue protocol.

DN was performed with the participant in a standardized supine position, with the feet hanging freely from the table. The distance between the ankles was approximately 30–40 cm. Sterile needles (0.30×30 mm; Soma; Japan) were used for the DN procedure. Each puncture was made with one needle on one trigger point (TrP), and the induced local twitch response (LTR) was monitored. For each head of the gastrocnemius muscle, three TrPs were identified (six punctures total). A TrP was defined as a palpable, painful point in the tense band of the muscle, exhibiting hypersensitivity to pressure. An experienced therapist (DN instructor with at least 3 years of clinical practice) performed an average of five needle thrusts per TrP without removing the needle from the skin. If no LTR was observed after five punctures, the procedure was stopped, and the next TrP was addressed. The entire DN procedure took approximately 30 s per TrP.

There is no consensus in the scientific literature on the optimal number of punctures for DN therapy, with suggestions ranging from 5 to 15 insertions to locate hidden trigger points (Perreault et al., 2017). We limited the number of punctures to a maximum of five to avoid excessive muscle trauma, which could confound our measurements. A record of adverse effects was maintained, and 10 participants reported moderate pain and a burning sensation during the DN procedure. If a burning sensation occurred, the procedure was immediately discontinued. Throughout the procedure, we took care to avoid excessive muscle trauma from needle insertions, which could potentially affect the accuracy of our measurements. A record of adverse effects was kept, with 10 participants reporting moderate pain and burning during the DN procedure.

For the sham DN intervention, a quasi-needle was used. This device did not pierce the skin but could simulate sensations similar to those of the actual DN needle. It is important to note that the needle in the placebo intervention was blunt. During the procedure, both groups were instructed not to observe the treatment site, making it difficult to distinguish between actual dry needling and quasi-needle stimulation.

Following the DN procedure, participants underwent 30 min of Tecar therapy (15 min per calf) (Yoon et al., 2018). The TECAR device (Zimmer, Germany, 2021), known for its ability to generate endogenous heat, was used to deliver the therapy. The device emitted electromagnetic waves at a length of 200 m and frequencies of 460 kHz/480 kHz, using decoupled capacitive transfer mode (CET) and electrodes with a diameter of 70 mm. The therapy involved circular movements of the electrode over the gastrocnemius muscle, between the distal and proximal tendinous areas. The second electrode was placed under the patient's thigh while they were lying on the bed. Tecar therapy was conducted using a specialized cream applied to the skin in the treatment area.

In the sham Tecar intervention, the same electrode was used, but no energy was applied because the device settings were not activated. The control group continued their regular routines without any recovery strategy.

Fatigue Protocol

The fatigue protocol was preceded by a standardized 8- to 10-min warm-up designed to activate major muscle groups relevant to combat sports and Crossfit and prepare participants for the physical demands of the exercise session. The warm-up included 20 bodyweight squats, two minutes of free jumping on a skating rink surface to engage lower-limb muscles, hamstring stretching to increase flexibility and reduce injury risk, ankle raises with a slow 5-s eccentric phase while holding a barbell to activate the gastrocnemius and soleus muscles, and one minute of calf rolling to enhance blood flow and tissue mobility. In addition to regular exercise and a healthy diet, the American Heart Association strongly recommends jumping the rope as part of physical activity ("Jump Rope for Heart Guidelines", Dallas: American Heart Association, 1989). Jumping the rope is considered a strenuous activity and is commonly used as a warm-up in combat sports (Ojeda-Aravena et al., 2023). These energy demands are comparable to those experienced in high-intensity combat sports bouts. Research indicates that jumping the rope requires both aerobic and anaerobic capacities, similar to the physical demands of combat sports (Zhao et al., 2023). The main muscles engaged during jumping the rope are the calves, which are essential for controlling kicks and overall movement in the ring or the octagon. Jumping the rope was selected because it had been shown to effectively induce fatigue in participants (Bruce et al., 2017).

A limitation of jumping the rope is that it requires coordination and skill in handling the rope. In this study, participants jumped the rope for 5 min with a 1-min rest interval, repeating this cycle 5 times to simulate the calf effort required during combat sports bouts (3 rounds of 3 or 5 min). The tempo was set at 135–145 jumps per minute. The assistant counted the number of jumps performed during each session.

Outcomes

Outcome measures, including blood perfusion (PU), muscle elasticity (ME), the pressure pain threshold (PPT), and the relative strength index (RSI) (jump height/contact time), were assessed at four time points: (1) at baseline (pre-fatigue protocol), (2) immediately post-fatigue protocol (postFat: 15 min), (3) immediately post-treatment (PostTre: 30 min post-fatigue protocol), and (4) 48 h post-fatigue protocol (48hPost: following the fourth treatment session). All assessments were conducted between 10:00 and 12:00 at the Provita Medical Center in Poland by trained physiotherapists, blinded to group assignment, in the following standardized order: (1) BP, (2) ME, (3) PPT, and (4) RSI.

Due to the large number of measurements, it was decided to measure the gastrocnemius muscle on each limb at a single point, based on scientific literature indicating this location as having high measurement repeatability. The reference lines were marked between the medial epicondyle of the thigh and the lateral malleolus, using a flexible ruler. A marker was placed at a point corresponding to 15% of this length (Nguyen et al., 2024) (Figure 2).

Blood Perfusion (PU)

Laser Doppler flowmetry (LDF), a widely used method for in vivo microcirculation assessment, was carried out using the Perimed PeriFlux 6000 Combined System (Stockholm, Sweden). The blood flow was measured by positioning a probe at the skin's laser light measurement site. The protocol specified a depth of 2.5 mm and a volume of 1 mm^3, with the procedure lasting two minutes. Known for its repeatability, sensitivity, and non-invasive nature, LDF enables precise microcirculation evaluation both at rest and in response to physical stimuli. Recognized as the gold standard for measuring microcirculatory function, this technique demonstrates exceptional accuracy and repeatability (Rajan et al., 2009). For example, a study (Grodzicki et al., 2003) showed that LDF using the PeriFlux system provided reliable measurements of forearm skin perfusion in 40 healthy individuals, reporting high inter-investigator correlation coefficients (r = 0.80–0.95) and good reproducibility during reactive hyperemia tests (r = 0.64–0.72). These findings underscore the method's robustness and suitability for longitudinal or comparative studies. All perfusion values obtained were expressed in perfusion units (PU), reflecting relative blood flow intensity.

Muscle Elasticity (ME)

Elasticity of the gastrocnemius muscle was measured using a portable myotonometer (MyotonPRO, AS, Myoton Ltd, Estonia 2021). The device's validity and reliability in this study were confirmed by prior testing (Trybulski et al., 2024c). The measurement process started with the probe applying a pre-pressure of 0.18 N to compress the tissue's surface. Afterward, a mechanical pulse (0.4 N, 15 ms) was released, momentarily deforming the tissue. This device assesses elasticity, which is a biomechanical property indicating how well soft tissues return to their original shape after deformation (Bravo-Sánchez et al., 2021). A quicker decay of tissue vibrations following deformation means a faster pulse dissipation, suggesting higher elasticity. The resulting elasticity value is determined through a logarithmic formula and expressed in relative arbitrary units [arb].

Pressure Pain Threshold (PPT)

The FPIX algometer (Wagner Instruments, Greenwich, CT, USA, 2013) was used to assess the pressure pain threshold (PPT). This method, renowned for its reliability and high repeatability, allows for an objective measurement of pain thresholds. This approach has demonstrated excellent reliability, with intraclass correlation coefficients exceeding 0.9 (Koh et al., 2023). During the test, a 4-mm diameter probe applied compressive force to a marked area, with the location remaining constant throughout. The pressure value, displayed digitally in newtons per square centimeter (N/cm²), was calculated as the average of three measurements. Pressure was gradually applied until participants described the sensation as unpleasant. The resulting PPT was recorded in N/cm².

Reactive Strength Index (RSI)

The RSI, used to assess the reactive strength of lower limb muscles, has been previously validated for its reliability in measuring kinematic performance variables, particularly during skydiving. The Force Decks ground reaction force plate (Vald-Performance, Australia, 2012) was used to perform the measurements. This method gauges an athlete's reactive strength by evaluating how quickly they can transition from eccentric to concentric muscle contraction. Participants were asked to jump off a 40-cm box and, upon landing on the force plate, immediately perform a maximum vertical jump. Before testing at points 1 and 4, they underwent a warm-up, including one minute of passive lower limb stretching, two sets of 3 free jumps, and one set of 10 squats. A research assistant provided guidance on the jumping technique and allowed three practice attempts before the actual measurements. The highest jump attempt was selected for analysis. For the RSI calculation the following formula was applied: RSI = Jump height / Contact time ($m \cdot s^{-1}$).

Randomization

To maintain the integrity of the blinding procedure, a researcher not involved in the subsequent assessments supervised the randomization process. Participants were assigned to groups using a simple randomization method in dedicated software (Research Randomizer), with a 1:1 ratio. To ensure unbiased allocation, the randomization occurred before the participants' first assessments.

Blinding

The physiotherapists and evaluators were aware of the DN/T protocols throughout the experiment, while only the participants remained blinded.

Statistical Analysis

Sample normality was assessed using the Kolmogorov-Smirnov test, with results indicating no significant deviation from a normal distribution ($p > 0.05$). Homogeneity of variances was evaluated via the Levene's test, also yielding non-significant results ($p > 0.05$). A mixed ANCOVA was subsequently conducted to examine the interaction between time (three time points: postFat; postTre; 48post) and the group (DN/T Sham; DN Sham/T; DN/T; Control), using values at rest as covariables. Cohen's d was employed to determine effect sizes for pre- and post-intervention comparisons. Effect sizes were interpreted using established thresholds: small (0.10), moderate (≥ 0.30), large (≥ 1.2), and very large (≥ 2.0). Bonferroni post-hoc tests were used for pairwise comparisons. SPSS software (version 28.0, IBM Corp., Armonk, N.Y., USA) was used for all statistical analyses, with a significance level set at $p < 0.05$.

Results

Table 2 presents the descriptive statistics for PU and ME across the groups. Significant interactions between time and group were found for PU in the right ($F = 39.833$; $p < 0.001$; $\eta_p^2 = 0.735$), and in the left leg ($F = 27.564$; $p < 0.001$; $\eta_p^2 = 0.658$). Additionally, significant interactions were observed for ME in the right ($F = 20.095$; $p < 0.001$; $\eta_p^2 = 0.584$) and in the left leg ($F = 13.828$; $p < 0.001$; $\eta_p^2 = 0.491$).

Comparisons between groups showed that postTre, the DN/T group had significantly higher PU scores for the right leg compared to the DN/shamT group (mean difference: 6.6 P.U.; $p < 0.001$), shamDN/T group (mean difference: 1.9 P.U.; $p < 0.001$), and the control group (mean difference: 6.3 P.U.; $p < 0.001$). Similarly, for the left leg, the DN/T group exhibited significantly greater PU scores post-treatment compared to DN/shamT (mean difference: 5.0 P.U.; $p < 0.001$), shamDN/T (mean difference: 2.9 P.U.; $p < 0.001$), and control groups (mean difference: 6.0 P.U.; $p < 0.001$).

Comparisons among groups revealed that postTre, ME in the right leg was significantly lower in the DN/T compared to DN/shamT (mean difference: −0.191 A.U.; $p < 0.001$), shamDN/T (mean difference: –0.166 A.U.; $p < 0.001$), and control groups (mean difference: –0.147 A.U.; $p < 0.001$). Similarly, on the left leg, postTre ME was significantly lower in the DN/T group than in DN/shamT (mean difference: –0.140 A.U.; $p < 0.001$), shamDN/T (mean difference: –0.110 A.U.; $p = 0.002$), and control groups (mean difference: –0.114 A.U.; $p = 0.027$).

Interestingly, 48 h post-treatment, ME in the right leg remained significantly lower in the DN/T group compared to DN/shamT (mean difference: –0.123 A.U.; p < 0.001) and control groups (mean difference: –0.103 A.U.; p = 0.005). Similarly, 48 h post-treatment, ME on the left leg was significantly lower in the DN/T group compared to the DN/shamT group (mean difference: –0.129 A.U.; p < 0.001) and the control group (mean difference: –0.124 A.U.; p < 0.001).

Table 3 presents the descriptive statistics for the PPT and the RSI across the groups. Significant interactions between time and the group were found for the PPT on the right leg (F = 21.004; p < 0.001; η_p^2 = 0.594), and the PPT on the left leg (F = 24.715; p < 0.001; η_p^2 = 0.633). Additionally, significant interactions were observed for the RSI (F = 5.921; p < 0.001; η_p^2 = 0.292).

Comparisons between groups revealed that post-treatment, the PPT on the right leg was significantly higher in the DN/T compared to the control group (mean difference: 4.311 N/cm; p = 0.046). On the left leg, the post-treatment PPT was significantly higher in the DN/T compared to both the shamDN/T (mean difference: 4.352 N/cm; p < 0.001) and control groups (mean difference: 5.750 N/cm; p < 0.001).

Interestingly, 48 h post-treatment, the PPT on the right leg remained significantly higher in the DN/T compared to the DN/shamT group (mean difference: 4.031 N/cm; p < 0.014), shamDN/T (mean difference: 5.783 N/cm; p < 0.001) and control groups (mean difference: 9.782 N/cm; p < 0.001). Similarly, 48 h post-treatment, the PPT on the left leg was significantly higher in the DN/T compared to the shamDN/T group (mean difference: 5.815 N/cm; p < 0.001) and control groups (mean difference: 9.374 N/cm; p < 0.001).

Regarding the RSI, post-treatment, the DN/T group showed a significantly higher RSI than the DN/shamT group (mean difference: 0.182 m/s; p = 0.002). Interestingly, 48 h post-treatment, the DN/T group had a significantly higher RSI than DN/shamT (mean difference: 0.134 m/s; p < 0.001), shamDN/T (mean difference: 0.095 m/s; p = 0.005), and control groups (mean difference: 0.162 m/s; p < 0.001).

Figure 3 illustrates blood perfusion in participants across time points, stratified by group. In the DN/T group, PU in the right leg significantly decreased from postFat to postTre (p = 0.007) and from postTre to 48hpost (p < 0.001). A similar trend was observed in the shamDN/T group (p < 0.001). However, in both the DN/T and control groups, no significant differences were found between postTre and 48hpost (p > 0.05). For the left leg, PU progressively and significantly decreased from postFat to postTre and from postTre to 48hpost (p < 0.001) in the experimental groups (DN/T, DN/shamT, and shamDN/T). In contrast, the control group showed significant declines only from post-Fat to post-Tre (p < 0.001).

Figure 4 illustrates ME in participants across time points, stratified by group. In the DN/T group, ME in the right leg significantly increased from postFat to postTre (p = 0.007), but not from postTre to 48hpost (p = 0.113). In both the shamDN/T and DN/shamT groups, significant differences were found between postFat to postTre (p < 0.05) and from postTre to 48hpost (p < 0.001). For the left leg, ME progressively and significantly increased from postFat to postTre and from postTre to 48hpost (p < 0.05) in the experimental groups (DN/T, DN/shamT, and shamDN/T). In contrast, the control group showed significant increases only from postFat to postTre (p < 0.001).

Figure 5 illustrates the PPT in participants across time points, stratified by group. In the DN/T group, the PPT in the right leg significantly improved from postFat to postTre (p < 0.001) and from postTre to 48hpost (p = 0.001). A similar trend was observed in the DN/shamT group (p < 0.001). In the shamDN/T group, significant differences were found between postFat to postTre (p < 0.05), but not from postTre to 48hpost (p = 0.088). For the left leg, the PPT progressively and significantly improved from postFat to postTre and from postTre to 48hpost (p < 0.05) in the DN/T and shamDN/T groups. In contrast, the DN/shamT group showed significant improvements only from postTre to 48hpost (p < 0.001).

Figure 6 illustrates the RSI in participants across time points, stratified by group. The RSI progressively and significantly increased from postFat to postTre and from postTre to 48hpost (p < 0.01) in the experimental groups (DN/T, DN/shamT, and shamDN/T).

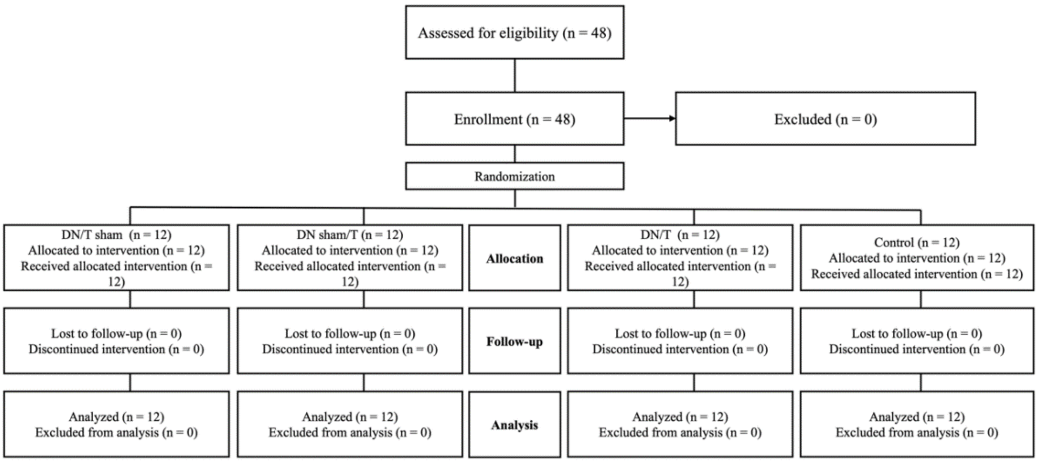

Figure 1. Participants flowchart.
DN/T Sham: Sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); DN Sham/T: Sham dry needling (superficial needle insertion) plus active Tecar therapy; DN/T: Active dry needling plus active Tecar therapy

Table 1. Demographic characteristics and anthropometric data of the participants.

	Men	Women	Age (years)	Training experience (years)	Body mass (kg)	Height (cm)	Body mass index (kg/m²)
DN/T sham (n = 12)	10	2	24.6 ± 3.4	6.4 ± 2.2	71.0 ± 12.9	178.4 ± 11.3	22.7 ± 1.5
DN sham/T (n = 12)	10	2	29.2 ± 3.4	11.1 ± 4.0	80.1 ± 13.3	178.0 ± 5.8	25.8 ± 2.0
DN/T (n = 12)	9	3	28.8 ± 3.7	10.8 ± 4.3	78.1 ± 16.0	176.8 ± 10.4	24.7 ± 2.1
Control (n = 12)	9	3	29.0 ± 5.4	11.8 ± 5.8	80.4 ± 17.9	176.8 ± 10.9	25.5 ± 2.7

DN/T Sham: Sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); DN Sham/T: Sham dry needling (superficial needle insertion) plus active Tecar therapy; DN/T: Active dry needling plus active Tecar therapy

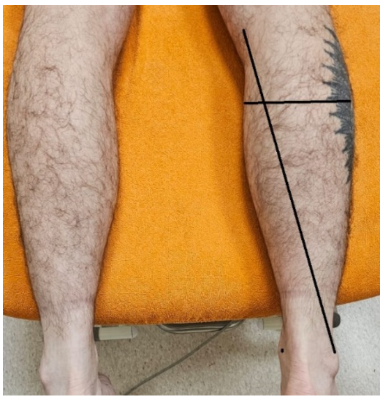

Figure 2. Measurement points for the gastrocnemius muscle. At a distance of approximately 15% (8–10 cm from the epicondyle) of the length of the line connecting the lateral malleolus with the epicondyle of the femur.

Table 2. Mean, standard deviation, and inferential statistics of blood perfusion and muscle elasticity across assessment time points for the four groups.

	DN/shamT (n = 12)	shamDN/T (n=12)	DN/T (n=12)	Control (n=12)	Between-group analysis	Significant pairwise comparisons
PU right (A.U.)						
Rest	16.6 ± 2.2	18.1 ± 1.9	17.7 ± 1.0	16.8 ± 1.5	p = 2.147; η_p^2 = 0.128	-
PostFat	25.4 ± 2.0	25.1 ± 1.4	25.1 ± 1.2	25.8 ± 1.4	p = 0.323; η_p^2 = 0.077	-
PostTre	16.4 ± 1.8	22.0 ± 1.6	23.6 ± 0.7	16.7 ± 1.6	$p < 0.001$; η_p^2 = 0.886	DN/T > DN/shamT ($p < 0.001$), shamDN/T ($p < 0.001$) and control ($p < 0.001$) shamDN/T > DN/shamT ($p < 0.001$) and control ($p < 0.001$)
48hPost	16.8 ± 1.9	18.2 ± 1.7	17.4 ± 0.8	16.9 ± 1.6	p = 0.417; η_p^2 = 0.063	-
PU left (A.U.)						
Rest	16.6 ± 1.3	18.0 ± 1.8	17.4 ± 1.4	18.0 ± 1.3	p = 0.076; η_p^2 = 0.143	-
PostFat	25.8 ± 1.2	24.9 ± 1.2	25.8 ± 0.7	25.7 ± 1.6	p = 0.180; η_p^2 = 0.106	-
PostTre	18.3 ± 1.8	21.1 ± 1.1	23.7 ± 0.6	18.0 ± 1.1	$p < 0.001$; η_p^2 = 0.853	DN/T > DN/shamT ($p < 0.001$), shamDN/T ($p < 0.001$) and control ($p < 0.001$) shamDN/T > DN/shamT ($p < 0.001$) and control ($p < 0.001$)
48hPost	16.6 ± 1.0	17.7 ± 2.0	17.7 ± 0.8	17.9 ± 1.2	p = 0.330; η_p^2 = 0.076	-
ME right (A.U.)						
Rest	1.6 ± 0.1	1.8 ± 0.2	1.8 ± 0.1	1.6 ± 0.1	p = 10.637; η_p^2 = 0.420	-
PostFat	1.9 ± 0.1	2.2 ± 0.1	2.0 ± 0.1	1.9 ± 0.1	p = 0.062; η_p^2 = 0.155	-
PostTre	1.9 ± 0.1	2.1 ± 0.1	1.8 ± 0.1	1.9 ± 0.1	$p < 0.001$; η_p^2 = 0.491	DN/T < DN/shamT ($p < 0.001$), shamDN/T ($p < 0.001$) and control ($p < 0.001$) shamDN/T > DN/shamT ($p < 0.001$) and control ($p < 0.001$)
48hPost	1.8 ± 0.1	1.9 ± 0.1	1.8 ± 0.1	1.8 ± 0.1	p = 0.001; η_p^2 = 0.307	DN/T < DN/shamT ($p < 0.001$), and control (p = 0.005)
ME left (A.U.)						
Rest	1.6 ± 0.1	1.9 ± 0.1	1.8 ± 0.1	1.7 ± 0.1	$p < 0.001$; η_p^2 = 0.595	-
PostFat	1.9 ± 0.1	2.1 ± 0.2	2.0 ± 0.1	1.9 ± 0.1	p = 0.215; η_p^2 = 0.098	-
PostTre	1.8 ± 0.1	2.1 ± 0.2	1.8 ± 0.1	1.9 ± 0.1	$p < 0.001$; η_p^2 = 0.434	DN/T < DN/shamT ($p < 0.001$), shamDN/T (p = 0.002) and control ($p < 0.001$)
48hPost	1.8 ± 0.1	1.9 ± 0.1	1.8 ± 0.1	1.8 ± 0.1	$p < 0.001$; η_p^2 = 0.462	DN/T < DN/shamT ($p < 0.001$), and control ($p < 0.001$) shamDN/T < DN/shamT (p = 0.011) and control ($p < 0.002$)

PU: perfusion unit; ME: muscle elasticity; DN/T Sham: Sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); DN Sham/T: Sham dry needling (superficial needle insertion) plus active Tecar therapy; DN/T: Active dry needling plus active Tecar therapy; PostFat: post fatigue protocol; PostTre: post treatment; 48hpost: 48 hours after the treatment

Table 3. Mean, standard deviation, and inferential statistics of blood perfusion and muscle elasticity across assessment time points for the four groups.

	DN/shamT (n = 12)	shamDN/T (n = 12)	DN/T (n = 12)	Control (n = 12)	Between-group analysis	Significant pairwise comparisons
PPT right (N/cm)						
Rest	89.1 ± 5.8	91.0 ± 4.0	90.2 ± 3.8	90.5 ± 4.4	$p = 0.771$; $\eta_p^2 = 0.025$	-
PostFat	77.7 ± 5.6	76.4 ± 2.7	75.3 ± 4.5	75.7 ± 2.7	$p = 0.421$; $\eta_p^2 = 0.063$	-
PostTre	80.0 ± 4.7	80.4 ± 4.2	81.0 ± 3.4	76.8 ± 2.4	$p = 0.035$; $\eta_p^2 = 0.180$	DN/T > control ($p = 0.046$)
48hPost	83.1 ± 3.0	81.9 ± 3.8	87.4 ± 3.3	77.7 ± 2.7	$p < 0.001$; $\eta_p^2 = 0.598$	DN/T > DN/shamT ($p = 0.014$), shamDN/T ($p < 0.001$) and control ($p < 0.001$) DN/shamT > control ($p < 0.001$) shamDN/T > control ($p = 0.015$)
PPT left (N/cm)						
Rest	89.2 ± 4.1	92.3 ± 4.2	89.4 ± 5.8	92.0 ± 3.4	$p = 0.189$; $\eta_p^2 = 0.102$	-
PostFat	79.1 ± 4.2	76.2 ± 3.1	74.2 ± 4.1	76.0 ± 2.1	$p < 0.001$; $\eta_p^2 = 0.385$	DN/shamT > shamDN/T ($p = 0.002$), DN/T ($p < 0.001$), control ($p = 0.001$)
PostTre	79.8 ± 4.3	78.1 ± 3.0	80.8 ± 4.2	76.6 ± 1.8	$p < 0.001$; $\eta_p^2 = 0.495$	DN/T > shamDN/T ($p < 0.001$) and control ($p < 0.001$) DN/shamT > shamDN/T ($p = 0.010$) and control ($p < 0.001$)
48hPost	83.7 ± 3.4	81.3 ± 3.0	85.4 ± 5.1	77.5 ± 1.5	$p < 0.001$; $\eta_p^2 = 0.716$	DN/T > shamDN/T ($p < 0.001$) and control ($p < 0.001$) DN/shamT > shamDN/T ($p < 0.001$) and control ($p < 0.001$) shamDN/T > control ($p < 0.001$)
RSI (m/s)						
Rest	2.3 ± 0.1	2.3 ± 0.1	2.4 ± 0.1	2.4 ± 0.1	$p = 0.121$; $\eta_p^2 = 0.123$	-
PostFat	1.9 ± 0.1	2.0 ± 0.1	2.0 ± 0.2	2.0 ± 0.1	$p = 0.089$; $\eta_p^2 = 0.139$	-
PostTre	2.0 ± 0.2	2.1 ± 0.1	2.2 ± 0.1	2.1 ± 0.1	$p = 0.004$; $\eta_p^2 = 0.267$	DN/T > DN/shamT ($p = 0.002$)
48hPost	2.1 ± 0.1	2.2 ± 0.1	2.3 ± 0.1	2.2 ± 0.1	$p < 0.001$; $\eta_p^2 = 0.505$	DN/T > DN/shamT ($p < 0.001$), shamDN/T ($p = 0.005$) and control ($p < 0.001$)

PPP: pressure pain threshold; RSI: reactive strength index; DN/T Sham: Sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); DN Sham/T: Sham dry needling (superficial needle insertion) plus active Tecar therapy; DN/T: Active dry needling plus active Tecar therapy; PostFat: post fatigue protocol; PostTre: post treatment; 48hpost: 48 hours after the treatment

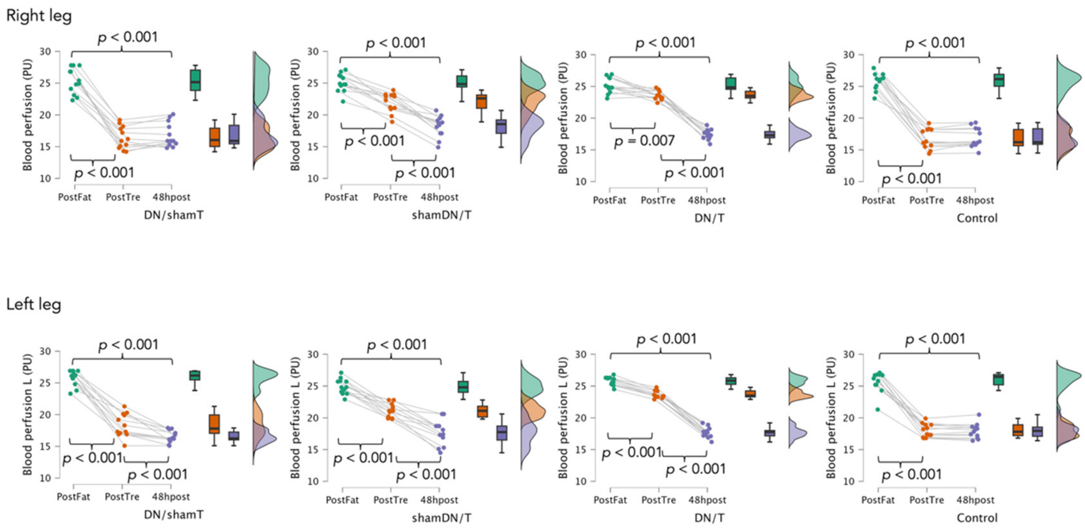

Figure 3. Blood perfusion of participants across time points, stratified by groups.
DN/T Sham: Sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); DN Sham/T: Sham dry needling (superficial needle insertion) plus active Tecar therapy; DN/T: Active dry needling plus active Tecar therapy; PostFat: post fatigue protocol; PostTre: post treatment; 48hpost: 48 hours after the treatment

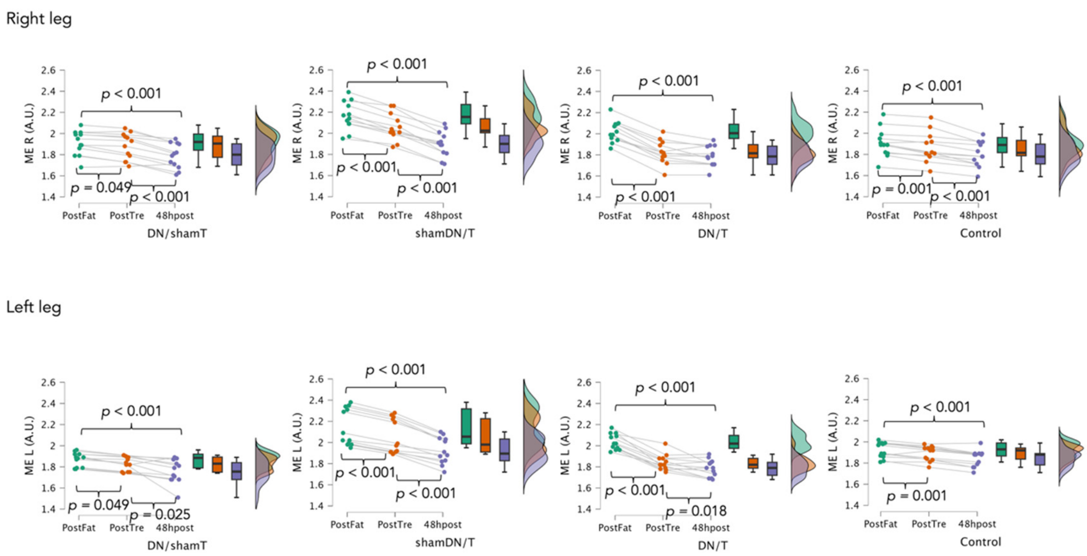

Figure 4. Muscle elasticity (ME) of participants across time points, stratified by groups.
DN/T Sham: Sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); DN Sham/T: Sham dry needling (superficial needle insertion) plus active Tecar therapy; DN/T: Active dry needling plus active Tecar therapy; PostFat: post fatigue protocol; PostTre: post treatment; 48hpost: 48 hours after the treatment

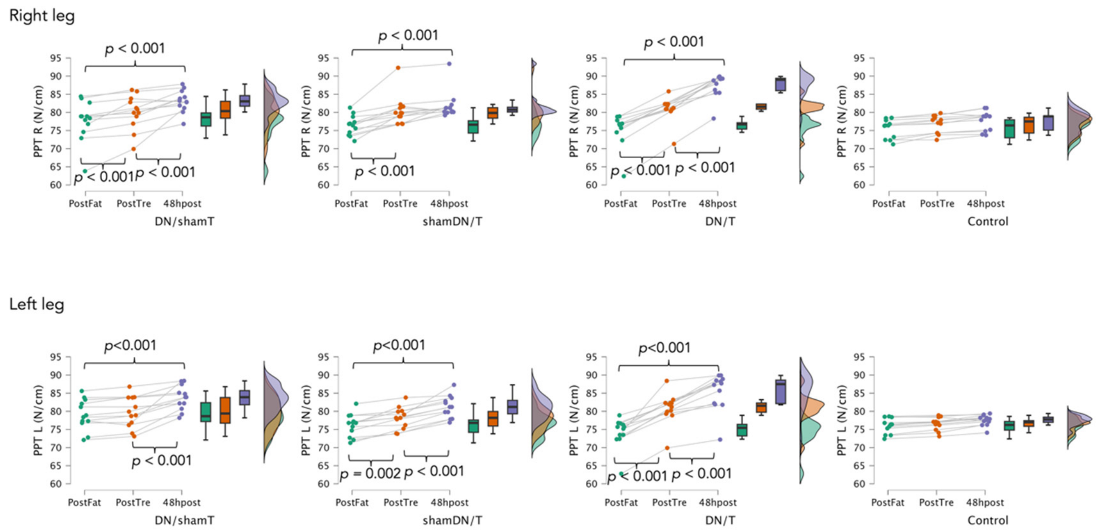

Figure 5. Pressure pain threshold (PPT) of participants across time points, stratified by groups.
DN/T Sham: Sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); DN Sham/T: Sham dry needling (superficial needle insertion) plus active Tecar therapy; DN/T: Active dry needling plus active Tecar therapy; PostFat: post fatigue protocol; PostTre: post treatment; 48hpost: 48 hours after the treatment

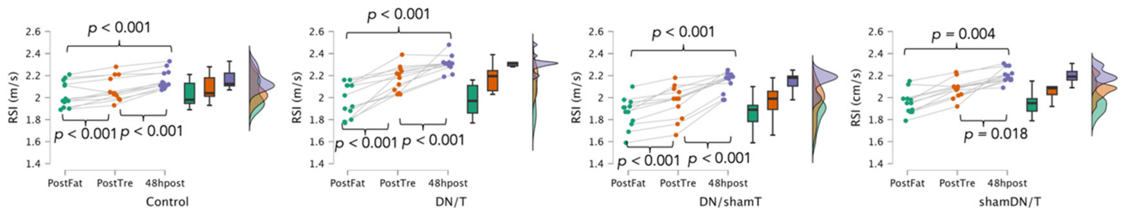

Figure 6. Reactive strength index (RSI) of participants across time points, stratified by groups.
DN/T Sham: Sham dry needling (superficial needle insertion) plus sham Tecar therapy (placebo device); DN Sham/T: Sham dry needling (superficial needle insertion) plus active Tecar therapy; DN/T: Active dry needling plus active Tecar therapy; PostFat: post fatigue protocol; PostTre: post treatment; 48hpost: 48 hours after the treatment

Discussion

DN/T produced the largest immediate post-treatment benefits in PU and the largest reductions in ME on both legs, with clinically mean differences (e.g., PU up to ~6.6 P.U. and ME down to –0.191 A.U.) and, in several comparisons, effects that persisted at 48 h. This superiority pattern was also mirrored in the PPT, with significant post-treatment increases and sustained 48 h improvements, and in the RSI, where the DN/T group outperformed other groups both immediately post-treatment and at the follow-up (48 hours into recovery). In contrast, single-modality and sham conditions tended to show smaller, less durable effects particularly considering PU and the PPT), reinforcing the interpretation that DN/T accelerates recovery and shifts the recovery curve upward rather than simply reflecting time-dependent normalization.

DN may provoke localized microtrauma and trigger-point modulation that promotes vasodilation and analgesia (e.g., nitric oxide-mediated changes and neuromodulation). Prior evidence indicates that DN can accelerate post-exercise perfusion recovery (Trybulski et al., 2024a, 2024b). DN can also affect vascular activity in muscle (Cagnie et al., 2012) and act as analgesic mediator release (Cagnie et al., 2013). Tecar therapy plausibly amplified these effects via radiofrequency-induced deep heating and vasodilation, improving oxygen/nutrient delivery and tissue repair kinetics (Szabo et al., 2022), while also supporting relaxation and pain modulation (Mousavi et al., 2024). The combined protocol likely optimized microcirculation (Guimaraes et al., 2018; Tang and Song, 2022), reduced stiffness through healing/collagen remodeling and tone reduction (Hsieh et al., 2012), and translated these physiological shifts into functional recovery (i.e., RSI), which is consistent with prior neuromuscular performance observations in athletes (Trybulski et al., 2024a) and Tecar-related recovery support (Szabo et al., 2020).

This study's conclusions should be interpreted in light of relevant limitations, especially the lack of the follow-up beyond 48 h, limited insight into why individuals may respond differently (e.g., baseline fitness or muscle fiber composition), and uncertainty about whether similar effects would be observed in other muscle groups or following different exercise. The results suggest meaningful clinical and practical value for athletes in high-intensity sports. Combining dry needling with Tecar therapy may represent an effective recovery strategy to accelerate restoration of muscle function, enhance repair efficiency, and potentially reduce post-exertional soreness, supporting faster, less uncomfortable return to training or competition, with benefits that appear to persist for at least 48 h.

Conclusions

In conclusion, this study suggests the superior effectiveness of DN with Tecar therapy for enhancing recovery across PU, ME, the PPT and the RSI in athletes subjected to a fatigue protocol. The DN/T combination proved consistently more efficient than individual treatments in improving blood perfusion, muscle elasticity, the pressure pain threshold, and reactive strength, both immediately post-treatment and at 48 hours into recovery. These findings suggest that the synergistic effects of DN and Tecar therapy not only support short-term recovery, but also promote sustained improvements in muscle function and performance. The results also highlight the potential of DN/T as an effective intervention for optimizing recovery in athletes engaged in high-intensity training and competition.

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ORCID iD:

Adrian Kużdżał: https://orcid.org/0000-0002-5685-3139

Gracjan Olaniszyn: https://orcid.org/0009-0003-1089-7632

Małgorzta Smoter: https://orcid.org/0000-0003-0894-6805

Adam Kawczyński: https://orcid.org/0000-0001-7840-3799

Filipe Manuel Clemente: https://orcid.org/0000-0001-9813-2842

Robert Trybulski: https://orcid.org/0000-0002-4276-4813

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