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Biomechanical Profile after Dry Needling in Mixed Martial Arts

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ABSTRACT

The purpose of this study was to compare the effects of dry needling (DN) intervention on the responses of muscle tone, stiffness, and elasticity, as well as power, pressure pain thresholds, and blood perfusion of the flexor carpi radialis muscle in mixed martial arts (MMA) athletes. Thirty-two trained/developmental men MMA fighters (25.5 ± 4.5 years; 24.5 ± 3 body mass index) participated in a randomized crossover study. Participants underwent a single intervention, receiving both DN and placebo. Laser Doppler flowmetry measured blood perfusion, while a myotonometer assessed the mechanical characteristics of muscle tone, stiffness, and elasticity of the flexor carpi radialis muscle. Pressure pain thresholds (PPT) were measured using an algometer, and maximal forearm muscle force was measured using a hand dynamometer. Outcomes were assessed at baseline, immediately after, and 24 hours and 48 hours post-intervention. A two-way repeated-measures ANOVA revealed significant *Intervention*Time* interaction for all outcomes: perfusion unit ($p < 0.001$), muscle tone ($p < 0.001$), stiffness ($p < 0.001$), elasticity ($p < 0.001$), PPT ($p < 0.001$) and maximal forearm muscle force ($p < 0.001$). The current study suggests that a single session of DN enhances muscle recovery, increases muscle strength, and improved PPT in MMA athletes. These positive adaptations appear to last up to 48 hours in some variables.

Introduction

Mixed Martial Arts (MMA) is a demanding sport combat combining striking and gripping, characterized by high-intensity efforts, requiring both high metabolic demands and neuromuscular readiness [1]. Although the physical demands of MMA are not yet well known, keeping the fists tight with small globes (globes are usually of 4 pounds) for several minutes requires tight and prolonged isometric muscle contraction of the forearm/hand musculature [2]. In addition, the combination of striking and gripping techniques involves alternate isometric contractions of this musculature [3]. The forearm muscles play a relevant role in MMA fight [4] by determining the strength of strikes and, above all, grips and submissions, particularly chokes [1].

Overload musculature tends to exhibit increased stiffness [5], which may have clinical consequences such as inhibition of muscle strength when compared to non-overload muscles [5]. Excessive strain on skeletal muscles can cause mechanical damage to cell membranes, activation of inflammatory processes, increased muscle soreness, as well as increased stiffness and muscle tone [6]. Despite limited research in this area, it is observed that immediately after MMA sparring matches, lactate levels significantly increase, exceeding 15 mmol/L [7]. Further, creatine kinase levels can vary from 250 U/L before the match to around 400 U/L 48 hours post-match [7]. Additionally, maximal handgrip strength can experience a significant decrease after the match, with impairment persisting for up to 48 hours, along with handgrip endurance [7].

As a consequence of combat or training, muscle fatigue or overload can contribute to the development of myofascial trigger points (MTrPs) in the most recruited musculature. MTrPs are defined as "hypersensitive areas located in a taut band of a skeletal muscle that refers to pain when they are stimulated" [8]. They are typically characterized as hyperirritable spots within skeletal muscle, often accompanied by palpable nodules in taut bands. They can be classified as active (a-MTrPs) or latent (l-MTrPs). An a-MTrP is characterized by both local and referred pain experienced during examination, while l-MTrPs produce referred pain symptoms solely upon stimulation and are not necessarily accompanied by pain recognition during examination [8]. The presence of MTrPs, either a-MTrPs or l-MTrPs, can lead to changes in biomechanical properties such as tone, stiffness, and elasticity, of the affected muscle [8]. Therefore, employing methods to reduce MTrPs can be pertinent in aiming to enhance the well-being of athletes and also promote their recovery.

Some examples of methods for mitigating MTrPs include manual therapy, trigger point injections, dry needling (DN), stretching exercises, and myofascial release techniques. DN, in particular, is one of the therapeutic methods used to alleviate MTrPs-related pain [9], although its actual mechanisms are not completely understood [10]. The American Physical Therapy Association defined DN as "skilled intervention using a thin filiform needle to penetrate the skin that stimulates myofascial MTrPs, muscles, and connective tissue for the management of neuromusculoskeletal disorders" [11]. The application of DN has potential effects on the biomechanical properties of the muscle, including reduction of muscle tone and stiffness, as well as increases in elasticity [12, 13].

The impact of DN on changes in the biomechanical properties of muscles is not fully understood; however, some authors suggest measurements of viscoelastic properties could be used to characterize the mechanical effect of DN [14]. One hypothesis is that MTrPs usually develop due to chronic muscle fatigue and acute or chronic damage to a muscle, tendon, ligament, joint, or nerve [15]. Consequently, MTrPs may have one or more hypersensitive locus/loci characterized by a higher concentration of muscle nociceptors. These loci usually occur mainly near the motor end of the muscle but can also be found in other areas of the muscle. Sensitive loci have a specific EMG pattern [15] consisting of spontaneous low-amplitude discharges superimposed on high-amplitude discharges. This phenomenon is called end-plate noise. DN can change the amplitude of discharges in the muscle motor end-plate and influence the sensitivity of receptors.

Although DN has been shown to be effective for improving pain sensitivity in sports athletes post-exercise, as demonstrated by Walsh et al. [16] who observed an increase of 13 % in pressure pain thresholds (PPT), e. g. decreases in pain sensitivity, compared to the control group, the efficacy in muscle strength after DN application is conflicting [17]. A single study found that the application of DN improved muscle performance by increasing vertical jump height in a sample of healthy subjects [18]. Furthermore, a study conducted on soccer players revealed that DN significantly benefited the improvement of muscular endurance and hip flexion range of motion [19]. Similarly, in handball players, DN was significantly effective in improving range of motion [20]. However, most published studies on athletes reveal no effect of DN on force production [21].

Scientific evidence suggests that the upper limbs of MMA athletes are particularly susceptible to musculoskeletal pathologies, including the formation of MTrPs. The repetitive stress endured by muscles and fascia during MMA training can lead to microtrauma, inflammation, and the subsequent development of MTrPs [8]. Additionally, the dynamic nature of MMA fights necessitates frequent engagement in explosive movements, intensifying muscle fatigue and tissue damage in the upper limbs [22]. These factors collectively contribute to the onset of MTrPs, which can impair muscle function, diminish range of motion, and predispose athletes to chronic pain and injury. Hence, prioritizing practices such as DN aimed at mitigating the impact of MTrPs on the well-being and functionality of these athletes is of paramount importance.

Since current research on the application of DN in sports athletes is limited [23] and the majority of studies concentrate on lower-extremity muscles, there is a prevailing tendency to primarily report on pain perception, thereby overlooking evidence concerning the biomechanical and muscle properties affected by DN. Additionally, there is a scarcity of integrative studies that incorporate a more comprehensive overview of outcomes, combining those associated with pain, muscle properties, muscular functionality, and force. A comprehensive analysis of the potential effects of DN on the functionality and biomechanical properties of athletes can be particularly relevant for understanding the mechanics influenced by the intervention. Moreover, it can establish a concrete understanding of how and for what purpose DN may be utilized in the context of sports recovery.

With the intention of addressing gaps in research on DN and introducing an innovative approach to MMA, an area still expanding within sports sciences (with over 280 results found on PubMed for the term "Mixed Martial Arts" between 2004–2023, 66 % of articles published in the last 5 years), particularly lacking in recovery strategies post-exercise [24, 25], we aimed to conduct a randomized crossover clinical trial. This study investigated the effect of DN on the biomechanical properties (muscle tone, stiffness, elasticity), maximum forearm muscle force, PPT, and blood perfusion of the flexor carpi radialis muscle in MMA athletes immediately after the intervention and at 24- and 48-hours post-intervention. We hypothesized that DN in an MTrPs area inducing local twitch response (LTRs) can beneficially affect the muscle tone, stiffness, elasticity of the flexor carpi radialis muscle, reduce the PPT, and increase maximum forearm muscle force in this population. This assumption is based on findings from studies conducted in other sports and body regions [26, 27]. Our study findings will contribute to a better understanding of the relationship between LTR and biomechanical properties of the muscle and local ischemia associated with l-MTrPs and their adverse effect on the athletic performance of MMA athletes.

Materials and Methods

Study design

This is a single-blind randomized, cross-over study with repeated-measures. All participants were randomly assigned (simple randomization 1:1 using randomizer.org) to either begin with the DN intervention (n = 16) or start with the placebo intervention (n = 16) prior to any assessment. Participants were unaware of their assigned intervention. Each subject received both interventions separated at least 14 days apart as a wash-up period. Study participants were asked to refrain from training for 48 hours before and after the intervention. Sub-groups were created based on the presence or absence of LTR during the intervention study. Allocation concealment was ensured by randomizing the participants to each of the interventions before commencing the first round of assessments.

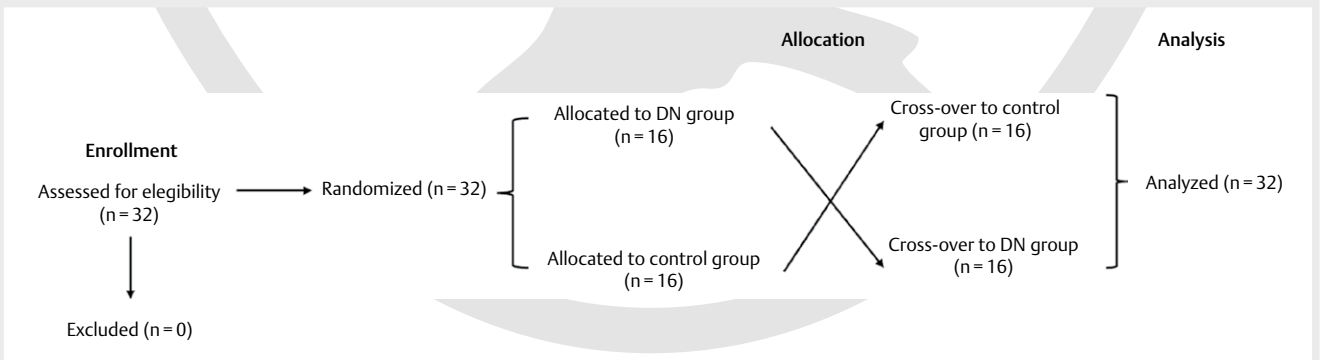
The following measurements were taken at baseline, immediately-post (measured 1–5 minutes after DN, at 24th and 48th hours post DN (Post 24 h/48 h): blood perfusion described in non-reference units, muscle tone Hz], stiffness [N/m], elasticity (E- [arb- relative arbitrary unit), PPT ([N/cm]), and maximum forearm muscle force (Fmax [N]). The measurements were taken by trained physiotherapists in the following order: (i) perfusion unit, (ii) tone, (iii) stiffness, (iv) elasticity, (v) PPT and (vi) Fmax. All participants were tested between 10 am – 12 pm at the Provita Medical Center in Poland.

Convenience sampling was utilized for participant recruitment. The recruitment process involved inviting MMA academies in the region through individual communication with the academy master and administration, followed by announcing the study to the fighters associated with those academies. The research study was approved by the ethics committee at the National Council of Physiotherapists (consent No. 26/2022 of January 12, 2023) and registered as a clinical trial (ISRCTN10378682). The study was carried out by the Declaration of Helsinki. After being informed about the risks and benefits associated with participation in the study, participants signed a voluntary informed consent form.

Participants

A priori power analysis was conducted using the G*Power 3 program. The analysis employed repeated measures ANOVA with an effect size of at least 0.25, $\alpha = 0.05$, and $1\text{-}\beta = 0.95$ gave a statistical power of 97.37 % and a sample size of a minimum of 16 subjects. Although only 16 athletes were required, we aimed to recruit more in order to prevent reductions in the sample size. Out of those available, we included 32 athletes, surpassing the necessary recommendation of 16 athletes. This exceeded level of acceptability also serves to mitigate the typical dropout rate observed in experimental studies.

After determining the required number of participants, the recruitment process began (▶ **Fig. 1**). Once participants expressed their interest in participating, they were assessed for eligibility criteria. The inclusion criteria included: (i) not having sustained musculoskeletal injuries or lesions or unspecified skin and myofascial lesions in the 4 weeks prior to the intervention; (ii) not being involved in competitions/tournaments during the experimental period, to prevent heterogeneous scenarios between athletes; (iii) abstaining from drugs, alcohol, or other illegal substances during the experimental period; (iv) being available for all assessment moments and interventions; (v) having at least five years of experience, with regular training occurring at least four times a week; (vi)



▶ **Fig. 1** Flowchart of the study.

showing a blood pressure (< 140/90 mm Hg) before examination; (vii) not having a tattoo in the test area. Exclusion also occurred in the case of needle phobia, extreme fatigue of the subject, fever, infection, nickel allergy, or refusal to participate in the study. Upon enrollment, participants exhibited neither active nor passive MTrPs that were recognized. Diagnosis was conducted via palpation, employing the methodology established in scientific literature, and focused on the dominant forearm.

Participants were required to avoid strenuous exercise for 48 hours before the study and refrain from training for 24 hours before. Additionally, to ensure accurate measurements of perfusion units, each participant was instructed to refrain from consuming ergogenic drinks 4 hours before the study.

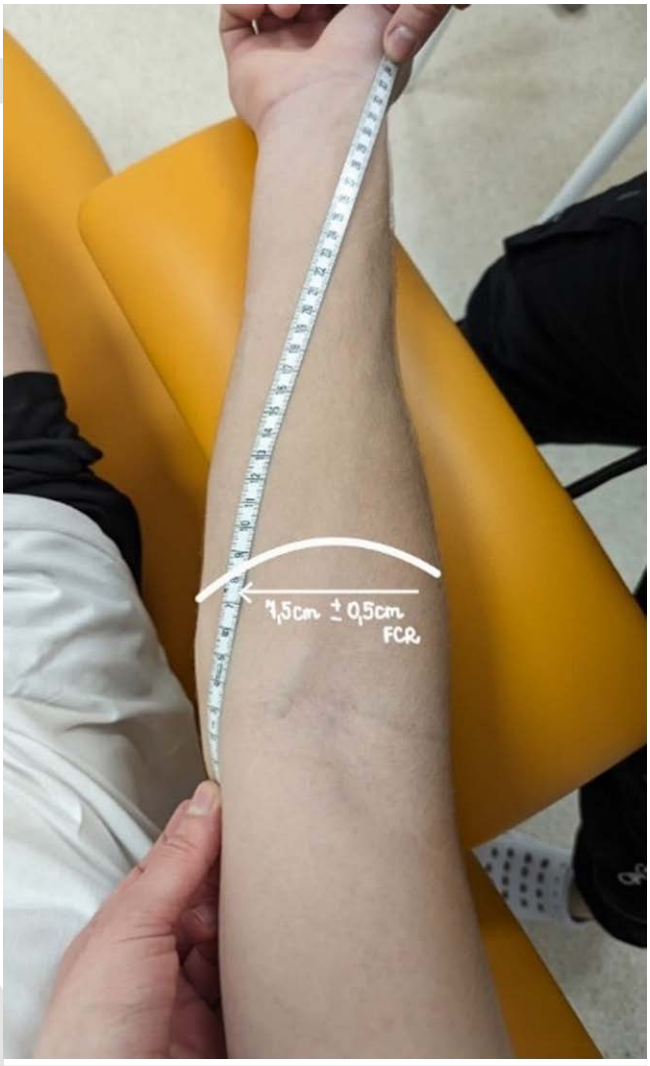
After recruitment and matching against the eligibility criteria, 32 trained/developmental men MMA fighters aged 18 to 40 were included in the study (mean age: 25.5 ± 4.5 years, BMI: 24.5 ± 3.0 kg/m^2, training experience: 10.3 ± 5.0 years). Participants engaged in three to four training sessions per week, focusing on preparing for competition. Their fight record (minimum 5) was publicly documented (mmapolska.org).

Interventions

The intervention included a familiarization phase that occurred 14 days before the study began. During this phase, participants were introduced to the dry needling DN protocol and its meaning, although they were not informed about which intervention they would be part of during the intervention stage. The familiarization session consisted of performing a single DN session in the FCR muscle of the dominant hand in a standard position. A maximum of three needle punctures were made without damaging the skin. The intervention was performed on Monday. Due to training plans, this is the most favorable day to conduct MMA research.

The most expanded DN approach used for the management of MTrPs is the "fast in, fast out" approach described by Hong [28]. An important topic of debate regarding this approach is the hypothesis that DN is more effective if a LTR is elicited during the procedure [28]. The LTR is characterized by an involuntary contraction of the taut band upon mechanical stimulation with a needle or palpation of the MTrPs area [28]. The technique was originally described as inserting the needle into the MTrPs area to provoke as much as LTR can elicit. The use of needle forcing to induce single or multiple LTRs until exhaustion has been questioned [29]. The only existing meta-analysis investigated the relevance of the LTR found low-level evidence, suggesting an immediate effect of DN interventions inducing LTRs on pain intensity without any effect on related-disability or sensitivity to pressure pain in MTrP-associated spinal pain disorders [30].

DN was carried out in a standardized supine position, with the feet hanging freely off the table. In the experimental intervention, sterile needles (0.30 × 30 mm; Soma; Japan) were used. Each puncture was made with one needle for one MTrPs, and elicited LTRs were monitored. TrP was defined as the presence of a palpable, painful spot in the taut band, approximately 7 cm below the cubital fossa, in the flexor carpi radialis muscle of the dominant hand. As per the scientific literature, the flexor carpi radialis was assessed and treated owing to its convenient direct accessibility and its crucial role in forearm exercises within MMA training [1]. The measuring part is marked with a marker. A line was drawn connecting the styloid process with the medial epicondyle of the humerus, defining a perpendicular line extending 7 cm from the epicondyle (7.5 ± 0.5 cm) (▶ **Fig. 2**). An experienced therapist (a DN instructor with more than 5 years of clinical practice) performed an average of five punctures in the area of the MTrPs without removing the needle from the skin. If an LTR was not observed after five punctures, insertions were stopped. The entire procedure lasted from 15 to 30 seconds for one MTrP. The scientific literature lacks consensus regarding the precise number of punctures during DN therapy, with the suggested needle insertions for locating latent trigger points ranging from 5 to 15. We opted to limit it to a maximum of five insertions because we did not track individual participant averages, as it was not within the scope of our research objectives. Moreover, we aimed to prevent excessive muscle trauma from an excessive number of needle insertions, which could potentially disrupt the accuracy of our measurements.



▶ **Fig. 2** FCR assessment point.

A register of side effects was maintained, with six participants reporting moderate pain and burning during the DN procedure. In the event of a burning sensation, the procedure was stopped, and

▶ **Fig. 3** Telescopic needle – sham therapy.

the puncture site was changed. After the DN, a 5-second ischemic compression was applied to reduce the unpleasant sensations.

The placebo intervention for the control group used a quasi-needle (qDN) that did not pierce the skin. This quasi-needle, equipped with a spring and used in a particular technique, could produce a similar sensation to the needle used in DN (▶ **Fig. 3**). It is important to note that the needle used in the placebo intervention was blunt [31]. During the intervention for both groups, participants were instructed to refrain from observing the intervention site, thus making it challenging to discern the insertion of the dry needle or quasi-needle stimulation.

Physical assessments

Athletes were evaluated after a 48-hour rest period from their last training session. The tests were conducted between 9:00 a.m. and 12:00 p.m. at the Provita Medical Center, where the temperature was maintained at 22 °C. Consistent conditions were maintained throughout the evaluation to prevent heterogeneity. Participants began by completing a questionnaire regarding study consent and health information. Measurements were performed at rest (Rest), 1–5 minutes after DN intervention (Post 1–5 min) and 24 and 48 hours after DN (Post 24 h/48 h) in the following order: blood perfusion described in non-reference units (PU), muscle tone (T-[Hz]), dynamic stiffness (S-[N/m]), elasticity (E-[arb]), PPT ([N/cm]) and isomeric muscle (Fmax [kgf]). According to the manufacturer's information (https://www.myoton.com/technology/), the values of the biomechanical properties of muscles are expressed in logarithmic units. Measurements were performed by trained physical therapists in the following order: (1) PU, (2) T, (3) S, (4) E, (5) PPT, and (6) Fmax. The primary outcomes considered were the perfusion unit and the tone, the stiffness, and the elasticity of the flexor carpi radialis muscle.

Perfusion unit (PU)

Laser Doppler flowmetry (LDF) was performed using a Perimed device (PeriFlux 6000 Combined System, Stockholm, Sweden). The measurement was made using a probe placed on the skin at the measurement site of the emitting probe laser light, and blood supply was recorded. The measurement depth was set at 2.5 mm and the volume at 1 mm^3. The entire measurement procedure lasted 2 minutes and followed standard recommendations [32]. The LDF method, thanks to its repeatability, high sensitivity, and non-invasiveness, allows for a precise assessment of microcirculation at rest and in response to a physical stimulus [33]. Laser Doppler flowmetry is a standard technology used to access microcirculatory function *in* vivo [34]. Better sensors and more effective wireless communication are generating major interest among scientists and clinicians in the use of LDF. Currently, LDF is the gold standard in the assessment of microcirculatory reaction, demonstrating great sensitivity and repeatability of measurements [34]. The outcome obtained was the perfusion unit.

Mechanical properties

Mechanical properties, i. e. tone, stiffness and elasticity of the flexor carpi radialis muscle was assessed using a hand hold myotonometer (MyotonPRO, AS, Myoton Ltd, Estonia 2021). The devices have undergone prior testing, confirming their validity and reliability in measuring the outcomes of the current study [35].

The pre-pressure (0.18 N) was first applied through the probe to the surface compressing the tissue underneath. A mechanical impulse (0.4 N, 15ms) is then released by the device, deforming the tissue for a short time period [36]. The device evaluates the state of the resting T based on the oscillation frequency of a muscle in a resting state (silent EMG signal) [37]. The term "silent EMG signal" refers to the frequency of oscillations that characterize the tension of superficial skeletal muscles at rest, occurring without voluntary contraction. The faster the tissue oscillation fades, the higher the dissipation of mechanical energy induced by the measurement impulse. The decrement of tissue natural oscillation inversely describes the tissue elasticity [37]. Elasticity, a biomechanical property of soft tissues, dictates their capacity to revert to their initial shape following deformation. It relies on various factors, including the properties of actin-myosin cross-bridges, pivotal in force generation processes. Muscle elasticity was quantified in NaN, tone in Na Hz, and stiffness in N/kg, serving as the extracted outcomes for subsequent data analysis. Muscle stiffness denotes the resistance of soft tissues to deformation. Reduced stiffness in the tendon reflects muscle characteristics. The scientific literature further acknowledges that low muscle stiffness can heighten the risk of injury and disrupt movement patterns [38].

Pressure pain threshold (PPT)

The PPT was measured using an algometer (FDIX, Wagner Instruments, Greenwich, CT, USA 2013). Pressure Pain Threshold (PPT) refers to the minimum amount of pressure applied to a specific body area that causes pain or discomfort. It is commonly used in clinical assessments to assess pressure sensitivity, which can objectify pain assessment and monitor changes in pain perception over time. Participants underwent three compression tests with a

▶ **Table 1** Comparison of results for variables recorded before intervention.

Variables	eDN	qDN	Δ (eDN − qDN)	*P*-value (±95 CI)
PU	10.44 ± 0.56	10.08 ± 0.61	0.35	0.059 (−001; 0.72)
T [Hz]	18.68 ± 1.01	17.82 ± 0.83	0.85	0.005 (0.27; 1.43)
S [N/m]	326.60 ± 46.27	319.19 ± 45.12	7.41	0.607 (−021.50; 36.28)
E [arb]	0.99 ± 0.06	1.00 ± 0.08	−0.01	0.627 (−005; 0.03)
PPT [N/cm]	91.17 ± 5.02	94.21 ± 3.64	−3.04	0.032 (−05.80; −2.23)
Fmax [kgf]	35.33 ± 2.15	35.28 ± 2.68	0.05	0.944 (−01.49; 1.59)

Note: PU – perfusion unit; T, S and E – tone, stiffness and elasticity of the flexor carpi radialis muscle (respectively); PPT – pressure pain threshold; Fmax – maximal forearm muscle force.

▶ **Table 2** Intra-class correlation test, standard error of the mean and minimal detectable change for all studied variables.

Variables	$ICC_{(1,k)}$ [95 CI]	SEM	MDC_{95}
PU	0.86 [0.72 – 0.94]	0.262	0.726
T [Hz]	0.88 [0.77 – 0.95]	0.305	0.845
S [N/m]	0.99 [0.99 – 1.00]	4.169	11.555
E [arb]	0.75 [0.53 – 0.89]	0.034	0.094
PPT [N/cm]	0.89 [0.78 – 0.95]	1.494	4.140
Fmax [kgf]	0.98 [0.96 – 0.99]	0.365	1.011

Note: ICC – intraclass correlation coefficient; SEM – standard error of measurement; MDC – minimal detectable change; PU – perfusion unit; T, S and E – tone, stiffness and elasticity of the flexor carpi radialis muscle (respectively); PPT – pressure pain threshold; Fmax – maximal forearm muscle force.

probe (parameters: r = 4 mm) applied to a specific tissue area (mm). The force value (in kg or N/cm^2) was calculated as the average of the three measurements and digitally displayed. If a significant deviation in the measured value occurred, the device signaled the need to repeat the test. Pressure was increased until the stimulus became unpleasant for the participant. This instrument is widely used to assess myofascial pain and various musculoskeletal diseases, demonstrating high repeat measurement reliability [39].

Maximal forearm muscle force (Fmax)

The maximal forearm muscle force (Fmax) was measured using a Digital Hand Dynamometer Grip Strength Tester (EH106, China). The measurement was performed in a standing position with the arms hanging freely. The maximum forearm muscle force expressed in kg was calculated. The grip strength test consisted of a 5-second contraction of the forearm muscles on the dynamometer. Before the test, each participant performed a warm-up consisting of 10 times the maximum pressure of a small ball, followed by 10 seconds of the forearm muscles [40]. Grip dynamometry is a reliable and repeatable measure of hand strength. It is a general indicator of combined external and internal hand strength that does not respond directly to changes in the strength of isolated internal hand components**.** The best trial, identified from the attempts, was selected for further data analysis.

Statistical analysis

The statistical procedures were selected to calculate the means and standard deviations (SD). The normality of all datasets was checked and confirmed using the Shapiro-Wilk test ($p > 0.05$). A two-way repeated-measures ANOVA with the *Intervention* (experimental, placebo) and *Time* (baseline, immediately-post Post 24 h, Post 48 h) was used to assess differences in perfusion unit, muscle mechanical properties, PPT, and Fmax. Results corrected by the Greenhouse-Geisser procedure were used if Mauchly's sphericity assumption was violated. To determine the intra- and inter-intervention differences, post hoc Bonferroni tests were used. The level of significance was set at $p \leq 0.05$. Partial eta squared (ηp^2) for ANOVA was used to estimate an effect size with the following classification: small (0.01), medium (0.06), and large (0.14) [41].

To determine the between-interventions differences separated by the presence or absence of the LTR, the t-test for independent samples was used, and solute and percentage differences were also calculated. The magnitudes of all effects were assessed using the standardized effect sizes (ES), where thresholds representing trivial (< 0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), and very large (> 2.0) [41]. Furthermore, the Minimal Detectable Change (MDC) was calculated to determine whether the observed effects are clinically significant. All statistical computations were performed using STATISTICA software version 13 PL (TIBCO Software Inc., Palo Alto, CA, USA, 2017) for a $p < 0.05$.

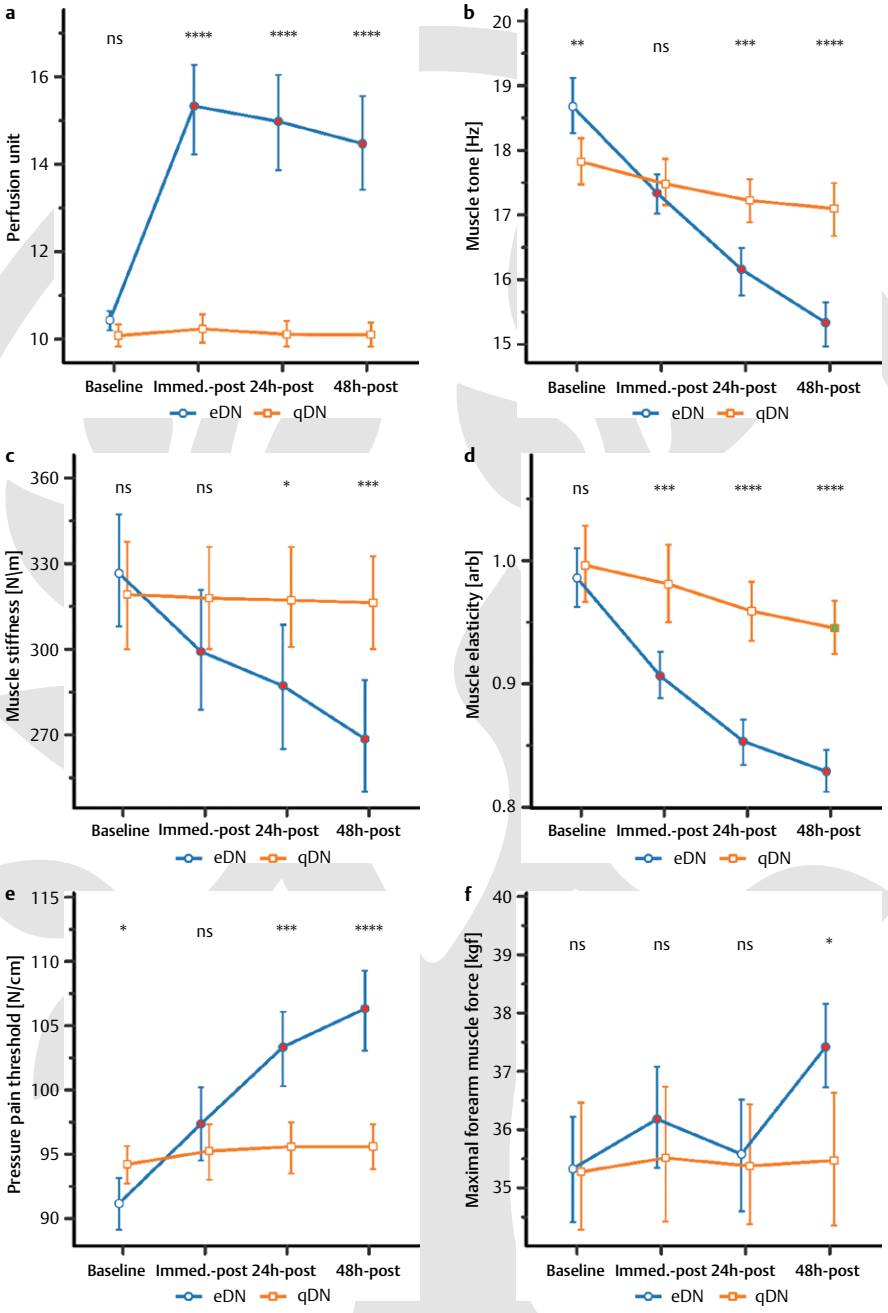
Results

▶ **Table 1** presents comparative characteristics the perfusion unit, mechanical properties and PPT of the flexor carpi radialis muscle as well as maximal forearm muscle force registered before intervention in the eDN and qDN groups.

▶ **Table 2** presents the calculated MDC values and the statistics on which they are based (ICC, SEM) for the perfusion unit, mechanical properties and PPT of the flexor carpi radialis muscle as well as maximal forearm muscle force.

▶ **Fig. 4** shows mean ± standard deviation of the perfusion unit, mechanical properties, and PPT of the flexor carpi radialis muscle, as well as maximal forearm muscle force at baseline, immediately after, and at 24 and 48 hours post-DN.

The repeated-measures ANOVA revealed a significant *Intervention* × *Time* ($F_{1.68; 65.52} = 52.54$, $p < 0.001$, $\eta p^2 = 0.57$) interaction for the perfusion unit: the perfusion unit significantly increased immediately after, at 24 and 48 hours post DN in experimental intervention compared to the placebo intervention ($p < 0.001$, ▶ **Fig. 4a**). The highest PU value in the eDN group was recorded immediately after intervention (15.33 ± 2.48), and the difference, compared to



▶ **Fig. 4** Descriptive statistics of the outcomes were analyzed both before and after the interventions. Perfusion unit (**a**), muscle tone (**b**), stiffness (**c**), elasticity (**d**), pressure pain threshold (**e**), and maximal force (**f**) for dry needling (eDN) and control (qDN). ns: no significant; between-condition differences; points on the graphs filled with red color represent significant differences at the $p < 0.001$ compared to the Baseline.

the pre-intervention value ($\Delta = -4.90$ [95 CI: −5.97; −3.82], $p < 0.001$) in relation to MDC, can be considered clinically significant.

Similarly, the ANOVA revealed significant *Intervention* × *Time* interactions for muscle tone ($F_{(1.77; 68.97)} = 52.5$, $p < 0.001$, $\eta p^2 = 0.57$), muscle stiffness ($F_{(1.61; 62.84)} = 27.49$, $p < 0.001$, $\eta p^2 = 0.41$) and muscle elasticity ($F_{2.19; 85.47} = 15.01$, $p < 0.001$, $\eta p^2 = 0.28$): muscle tone decreased from baseline to 48 hours after within the DN intervention ($p < 0.001$) (▶ **Fig. 4b**), whereas muscle stiffness (▶ **Fig. 4c**) and muscle elasticity (▶ **Fig. 4d**) decreased immediately-, 24- and 48-hours post DN in experimental intervention compared to the placebo intervention (all, $p < 0.001$). In the eDN group, the most significant differences were observed 48 hours after the intervention compared to pre-intervention measurements for muscle tone, muscle stiffness, and muscle elasticity. These differences were: $\Delta = 3.34$ Hz (95 % CI: 2.77; 3.91, $p < 0.001$), $\Delta = 58.00$ N/m (95 % CI: 41.89; 74.11, $p < 0.001$), and $\Delta = 0.16$ arb (95 % CI: 0.12; 0.20,

▶ **Table 3** Results of comparison of subjects with the LTR effect (Yes) and without the effect (No).

Variable	LTR : Yes	LTR : No	Difference (%)	*P*-value	Effect size (rating)
PU : Rest	10.55 ± 0.56	10.3 ± 0.55	0.25 (2.3 %)	0.339	0.44 (Small)
PU : Post 1–5	17.12 ± 1.65	13.14 ± 1.21	3.97 (23.2 %)	**< 0.001**	2.70 (Very large)
PU : Post 24	16.43 ± 1.73	13.21 ± 2.1	3.22 (19.6 %)	**0.001**	1.69 (Large)
PU : Post 48	15.98 ± 1.76	12.62 ± 2.29	3.36 (21.0 %)	**0.002**	1.67 (Large)
T : [NaHz] Rest	19.07 ± 1.02	18.19 ± 0.79	0.88 (4.63 %)	**0.048**	0.96 (Moderate)
T : Post 1–5	17.28 ± 0.89	17.41 ± 0.46	− 0.13 (− 0.8 %)	0.700	0.18 (Trivial)
T : Post 24	16.28 ± 0.83	16.01 ± 0.93	0.27 (1.7 %)	0.499	0.31 (Small)
T : Post 48	15.5 ± 0.73	15.13 ± 0.89	0.37 (2.4 %)	0.325	0.45 (Small)
S : [NaHz] Rest	340.5 ± 49.32	309.7 ± 38.17	30.79 (9.0 %)	0.143	0.69 (Moderate)
S : Post 1–5	310.5 ± 58.42	285.4 ± 33.41	25.01 (8.1 %)	0.270	0.51 (Small)
S : Post 24	298.6 ± 57.97	273.2 ± 33.13	25.41 (8.5 %)	0.259	0.52 (Small)
S : Post 48	277.7 ± 53.25	257.4 ± 33.69	20.28 (7.3 %)	0.336	0.44 (Small)
E : [NaN] Rest	0.99 ± 0.06	0.98 ± 0.05	0.01 (1.1 %)	0.672	0.19 (Trivial)
E : Post 1–5	0.91 ± 0.06	0.9 ± 0.02	0.01 (0.9 %)	0.700	0.18 (Trivial)
E : Post 24	0.86 ± 0.05	0.84 ± 0.03	0.02 (2.4 %)	0.299	0.48 (Small)
E : Post 48	0.84 ± 0.05	0.82 ± 0.03	0.02 (2.2 %)	0.336	0.44 (Small)
PPT : [N/cm^2] Rest	91.8 ± 6.05	90.4 ± 3.59	1.4 (1.5 %)	0.550	0.27 (Small)
PPT : Post 1–5	97.7 ± 8.79	97.0 ± 3.98	0.73 (0.7 %)	0.822	0.1 (Trivial)
PPT : Post 24	103.2 ± 8.43	103.5 ± 4.2	− 0.34 (− 0.3 %)	0.913	0.05 (Trivial)
PPT : Post 48	106.3 ± 8.88	106.4 ± 4.44	− 0.08 (− 0.1 %)	0.982	0.01 (Trivial)
Fmax : [N/cm] Rest	36.25 ± 2.01	34.21 ± 1.84	2.03 (5.6 %)	**0.031**	1.05 (Moderate)
Fmax : Post 1–5	37.02 ± 1.97	35.16 ± 1.73	1.86 (5,0 %)	**0.039**	1.00 (Moderate)
Fmax : Post 24	36.37 ± 2.2	34.61 ± 1.63	1.76 (4,8 %)	0.062	0.90 (Moderate)
Fmax : Post 48	37.99 ± 1.86	36.72 ± 1.38	1.27 (3,3 %)	0.106	0.76 (Moderate)

Note: LTR – local twitch response; PU – perfusion unit; T, S and E – tone, stiffness and elasticity of the flexor carpi radialis muscle (respectively); PPT – pressure pain threshold; Fmax – maximal forearm muscle force.

p < 0.001), respectively. Based on the MDC, these results can be considered clinically significant.

The ANOVA also revealed a significant interaction *Intervention × Time* for PPT ($F_{(2.05;\ 79.77)} = 51.85$, $p < 0.001$, $\eta p^2 = 0.57$) and maximal forearm muscle force ($F_{(2.05;\ 79.77)} = 51.85$, $p < 0.001$, $\eta p^2 = 0.57$): PPT increased from baseline to 24 hours after intervention just within the DN intervention (p < 0.001, ▶ **Fig. 4e**), whereas maximal forearm muscle force increased immediately after just in the experimental intervention (p < 0.01, ▶ **Fig. 4f**). In the eDN group, the most significant differences were observed 48 hours after the intervention compared to pre-intervention measurements for PPT and maximal forearm muscle force, with Δ = − 15.16 N/cm (95 % CI: − 18.05; − 12.26, p < 0.001) and Δ = − 2.09 kgf (95 % CI: − 2.80; − 1.38, p < 0.001), respectively. Relative to the Minimal Detectable Change (MDC), these results can be considered clinically significant.

▶ **Table 3** shows mean ± standard deviation of the perfusion unit, mechanical properties and PPT of the flexor carpi radialis muscle, as well as maximal forearm muscle force according to the presence or absence of LTR. The t-test for independent samples showed significantly greater perfusion unit immediately- (23.7 %; p < 0.001; ES = 2.7, very large), 24 hours (19.6 %; p = 0.001; ES = 1.69, large), and 48 hours post (21.0 %; p = 0.002; ES = 1.67, large) when LTRs were obtained. Moreover, we observed significantly greater differences in muscle tone range at baseline in the intervention with LTR (4.6 %; p = .048; ES = 0.96, moderate). Furthermore, significantly greater maximal forearm muscle force was observed at baseline and immediately-post DN in LTR (5.6 %; p = 0.03; ES = 1.05, moderate and 5.0 %; p = 0.039; ES = 1.0, moderate, respectively).

During the interventions, three reports of pain were recorded: one during, one of headache, and one of tingling afterward. No instances of bleeding were registered.

Discussion

Our study revealed that DN significantly surpassed the control intervention in the perfusion unit, mechanical properties, e. g. muscle tone, stiffness and elasticity, and PPT over the flexor carpi radialis muscle, as well as maximal forearm muscle force, thereby enhancing conditions and exhibiting superiority over non-intervention. We observed that DN was able to enhance blood perfusion, increase isometric strength, and raise pain threshold (mechanical hypoalgesia) as well as to improve the biomechanical properties of the radial wrist flexor muscle by decreasing muscle tension and stiffness and increasing flexibility as compared to the placebo intervention. The positive changes induced by DN persisted from 24 to 48 hours, depending on the outcome.

Notably, we can also highlight the effect of LTR, which remains somewhat questionable in the scientific literature. In our study, LTR demonstrated a specific impact on tissue perfusion at all time periods after DN. Isometric muscle strength also exhibited significant results in those participants where LTR was elicited during DN, with the most significant changes observed immediately after DN (1–5 min). However, the effects of LTR on other variables such as pressure pain sensitivity, tension, stiffness, and flexibility, were not significant.

Perfusion unit

The effect of DN on blood perfusion is not commonly investigated [22]. We observed significant changes in PU, which indicated that DN increases blood perfusion in the treated area. These results align with a previous experimental study conducted on the gastrocnemius muscle [22]. Various mechanisms including release of vasoactive substances such as calcitonin gene-related peptide and substance P following activation of A-δ and C-fibers via the axonal reflex have been suggested for DN-induced blood flow [42]. In fact, the release of vasoactive substances causes small vessels to dilate and improves blood flow. Reflex vasodilation can also be triggered by the activation of nociceptors [43], which can be stimulated by DN.

Cagnie et al. also showed that a single session of DN increased blood flow and oxygen saturation in the quadriceps muscle of healthy participants, and DN-induced changes persisted throughout the 15-minute recovery period [42]. No changes in blood perfusion were observed in areas distant from the DN site [42]. Similarly, Ohkubo et al. found an increase in oxygenation of the DN-treated area of the quadriceps muscle [44], and therefore no change was seen in blood perfusion in the area 3 cm away from the DN site.

On the contrary, a previous study [45] found a transient, significant increase in blood perfusion in the opposite area of the DN-stimulated quadriceps muscle. However, the increase was much smaller than in DN-stimulated muscles and was observed only during the initial post-DN phase. The authors suggested that this short-term improvement in blood perfusion in the contralateral area may have been a consequence of the sympathetic stress response, which is consistent with the previously observed short-term increase in sympathetic nerve activity during needle manipulation (acupuncture) in healthy individuals [46]. Jiang et al. analyzed the phenomenon of local muscle hypoxia and microcirculation disruption in MTrPs, which, on the one hand, interferes with the excretion of metabolic products (e. g. CO2, hydrogen ions, lactate) and, on the other hand, impedes the supply of substances necessary for muscle work [47].

It has been hypothesized that sensory nerve endings act as metabolic receptors, and their stimulation by-products of cellular metabolism can lead to excessive stimulation of the sympathetic nervous system [48] – the phenomenon of sensitization of the MTrPs area [46]. Blood circulation in the MTrPs area is impaired, leading to hypoxia and reduced transport of metabolic products (e. g. CO_2, H^+, lactate), which consequently leads to muscle fatigue [49]. Therefore, our finding of improved PU in a latent MTrPs appears to have important implications for MMA trainees, where facilitated recovery and reduced likelihood of injury will be crucial for optimal athletic performance. It should be noted that the most significant changes of all measured variables occurred precisely in perfusion, at the site of needling, and in elicitation of the LTR response [28].

Biomechanical properties

We observed a positive effect of DN on muscle in terms of biomechanical properties such as tone, stiffness, and elasticity, between the placebo and experimental interventions. Others have also shown similar results [9, 50]. There is evidence in the scientific literature that excessive muscle tension and impaired muscle elasticity can cause injury or worsen sports performance [51, 52]. For this reason, studies evaluating the effects of DN, a rapid method for leveling these changes, are clinically relevant.

However, it should be noted that when comparing the sub-intervention with and without LTR on tone, stiffness and elasticity, the lack of twitch response did not significantly affect the magnitude of the change. The stiffness score produced a moderate/small effect, the others were small and insignificant. Baraja-Vegas et al. even observed an increase in stiffness (measured by tensiomyography) with the presence of intramuscular edema in latent MTrPs in the medial gastrocnemius muscle [53]. Our results suggest that reducing the stiffness of the test muscle in response to DN could explain to the improvement observed in maximal muscle strength. Gervasi et al. showed that the higher the stiffness (as assessed using MyotonPro as in the current study) of the patella and Achilles tendons, as well as the quadriceps, gastrocnemius calf muscles, and rectus femoris muscle at rest, the lower the relative strength index and fall jump performance in young male basketball players [54]. The authors also observed that tendon and muscle stiffness increased with age in adolescents and suggested that the players' extensive training experience may have influenced stiffness levels. However, due to the lack of an untrained control group, the separate effect of physical training and maturation could not be assessed [54].

Muscle strength

Our results indicated that DN had a significant positive effect on maximal forearm muscle force. Bandy et al. evaluated the effect of a single DN therapy session on vertical jumping ability on both legs in healthy asymptomatic (no muscle pain) college students [18]. Similarly, DN led to a significant increase in vertical jump height in DN compared to the sham intervention. Other studies have observed improved athletic performance in response to DN. Haser et al. found that DN increased maximum knee extensor strength in soccer players [19]. Further, DN increased muscular endurance and hip flexion range of motion, which was maintained for 4 weeks after treatment [19]. Schneider et al. observed that the application of DN to latent MTrPs in the gluteus medius muscle significantly increased gluteal muscle strength immediately after the intervention in asymptomatic individuals [55]. DN also reduced electromyographic muscle activation required during force generation tests. The authors concluded that latent MTrPs hurts the strength of the gluteus medius muscle and the effectiveness of its contraction [55].

Pressure pain sensitivity

Our findings suggest a mechanical hypoalgesic effect, as indicated by the increase in PPT following DN. These results are consistent

with previous studies highlighting the potential benefits of DN in modulating pain sensitivity [22, 56].

The physiological mechanism underlying this effect remains vague, with various hypotheses proposed. Current speculation regarding the mechanisms of DN encompasses both segmental and central processes [57]. One plausible explanation lies in the ability of DN to stimulate the release of endogenous opioids, such as enkephalins and endorphins [58]. These compounds bind to opioid receptors within the central nervous system, exerting an inhibitory effect on pain transmission and perception [59].

The insertion of needles may activate descending pain modulation pathways, including the periaqueductal gray and rostral ventromedial medulla [42]. These pathways release neurotransmitters such as serotonin and norepinephrine, which act to attenuate pain signals at the level of the spinal cord [60]. Collectively, these neurophysiological responses may contribute to an increase in PPT, thereby reducing sensitivity to pressure-induced pain.

Local twitch response

In a systematic review of the literature, Perreault et al. included RCTs providing insights in the neurophysiological mechanisms of MTrPs-DN and assessing the clinical significance of LTR [29]. They identified studies whose results suggested a beneficial pain effect in groups with LTR and where eliciting LTR provided very little benefit [29]. This hypothesis has been confirmed by a meta-analysis showing low-quality evidence in favor of eliciting LTRs [30]. In addition, it appears that the number of needle insertions during puncture at a single insertion site positively correlates with the level of post-needling soreness, increased levels of inflammation within the muscle fibers, and mechanical trauma at or near the neuromuscular junction [61]. It should be noted that studies on an animal model seem to contradict this hypothesis of damage and inflammation through excessive insertions [62]. In addition, the DN technique using needle rotation (i. e. unidirectional or bidirectional winding) has been shown to elicit similar neurophysiological responses that can positively alter MTrP status and reduce pain without the need for LTR. Many athletes and their coaches are concerned about potential DN-induced microdamage to skeletal muscles and nerve fibers. As a result, DN therapy is often avoided, especially between sporting events. Our results suggest that there is no basis for this, and DN therapy can be used successfully in the period between workouts.

Limitations and future research

Although the measurement tools used in our study objectify the assessment of changes induced by DN, they also have some limitations. First, the measurement methods did not have reference values, which made it difficult to interpret the observed changes induced by DN. Furthermore, there were statistical differences in T[Hz] and PPT [N/cm] at baseline, which should be disclosed, as they can potentially contribute to bias in interpreting the trends of evolution after intervention or exposure to the control condition. Additionally, the use of only a single session does not provide us with a long-term perspective on how repeated sessions can impact players' adaptations concerning the observed measures. Another limitation is that we measured changes in only one muscle. In subsequent tests, the number of muscles measured should be increased. The participants were young, without current muscle pain, and with latent MTrPs. So the study results cannot be directly generalized to other groups, including the elderly or individuals with pain. Ultimately, our sample consisted of 32 MMA fighters and the observation period was limited to 48 hours. Future studies should explore extending the duration of analyzing the effects of DN, as well as investigating the impact of multiple DN sessions over the long-term and under various interventions (e. g. during combat, post-recovery).

Practical implications

DN significantly enhanced blood perfusion, muscle biomechanical properties, and maximal muscle force, thereby promoting faster recovery, reducing the risk of injury, and improving athletic performance. This highlights DN's potential as a highly effective intervention in sports recovery and performance enhancement programs. Additionally, DN reveals a mechanical hypoalgesic effect, elevating pressure pain threshold and providing relief from muscle soreness and discomfort. Consequently, athletes and coaches can positively opt for DN, as our results suggest its safe and effective integration into recovery protocols, fostering quicker recovery and potentially enhancing athletic performance readiness. Importantly, considering DN up to 48 hours prior to the desired performance period may be crucial, as it effectively alleviates symptoms of MTrPs, thus optimizing athletes' physical condition for training or competition.

Conclusions

In our study, DN emerged as a superior intervention, outperforming the control intervention across several key parameters. as in perfusion unit, muscle tone, stiffness, elasticity, PPT, and maximal forearm muscle force over the flexor carpi radialis muscle. These findings highlight DN's effectiveness in enhancing physiological conditions and surpassing outcomes observed in the placebo intervention. Furthermore, DN demonstrated its ability to improve blood perfusion, increase isometric strength, elevate pain threshold, and enhance biomechanical properties of the radial wrist flexor muscle, including reduced muscle tension and stiffness alongside increased flexibility compared to placebo. Importantly, these benefits persisted for up to 48 hours post-intervention, indicating sustained effectiveness over time. Therefore, integrating DN into treatment plans for MMA athletes with MTrPs holds promise for mitigating negative effects and enhancing athlete functionality. Further research is crucial to establish optimal protocols and understand long-term effects, paving the way for wider adoption in clinical settings.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Andrade A, Flores MA, Andreato LV et al. Physical and Training Characteristics of Mixed Martial Arts Athletes: Systematic Review. Strength Cond J 2019; 41: 51–63

[2] Kirk C, Clark DR, Langan-Evans C et al. The physical demands of mixed martial arts: A narrative review using the ARMSS model to provide a hierarchy of evidence. J Sports Sci 2020; 38: 2819–2841

[3] Alm P. Physiological Characters in Mixed Martial Arts. Am J Sports Sci 2013; 1: 12

[4] Slimani M, Davis P, Franchini E et al. Rating of Perceived Exertion for Quantification of Training and Combat Loads During Combat Sport-Specific Activities. J Strength Cond Res 2017; 31: 2889–2902

[5] Ballyns JJ, Turo D, Otto P et al. Office-Based Elastographic Technique for Quantifying Mechanical Properties of Skeletal Muscle. J Med Ultrasound 2012; 31: 1209–1219

[6] Kelly JP, Koppenhaver SL, Michener LA et al. Characterization of tissue stiffness of the infraspinatus, erector spinae, and gastrocnemius muscle using ultrasound shear wave elastography and superficial mechanical deformation. J Electromyogr Kinesiol 2018; 38: 73–80

[7] Coswig VS, Ramos S, de P, Del Vecchio FB. Time-Motion and Biological Responses in Simulated Mixed Martial Arts Sparring Matches. J Strength Cond Res 2016; 30: 2156–2163

[8] Fricton J. Myofascial Pain. Oral Maxillofac Surg Clin North Am 2016; 28: 289–311

[9] Gattie E, Cleland JA, Snodgrass S. The Effectiveness of Trigger Point Dry Needling for Musculoskeletal Conditions by Physical Therapists: A Systematic Review and Meta-analysis. J Orthop Sports Phys Ther 2017; 47: 133–149

[10] Fernández-de-Las-Peñas C, Nijs J. Trigger point dry needling for the treatment of myofascial pain syndrome: Current perspectives within a pain neuroscience paradigm. J Pain Res 2019; 12: 1899–1911

[11] APTA. Physical therapists & the performance of dry needling: An educational resource paper. Alexandria, VA, USA: APTA Department of Practice and APTA State Government Affairs; 2012

[12] Roch M, Morin M, Gaudreault N. Immediate Effect of Dry Needling on the Viscoelastic Properties of a Trigger Point on the Infraspinatus Muscle Measured with MyotonPRO. Physiotherapy Canada 2022; 74: 232–239

[13] Sánchez-Infante J, Bravo-Sánchez A, Jiménez F et al. Effects of dry needling on mechanical and contractile properties of the upper trapezius with latent myofascial trigger points: A randomized controlled trial. Musculoskelet Sci Pract 2021; 56: 102456

[14] Roch M, Morin M, Gaudreault N. Immediate Effect of Dry Needling on the Viscoelastic Properties of a Trigger Point on the Infraspinatus Muscle Measured with MyotonPRO. Physiother Can 2022; 74: 232–239

[15] Ding CL, Ma YT, Huang QM et al. Effect of Dry Needling Stimulation of Myofascial Trigger Point on Sample Entropy of Electromyography of Gastrocnemius Injured Site in Rats. Zhen Ci Yan Jiu 2018; 43: 127–132

[16] Walsh R, Kinsella S, McEvoy J. The effects of dry needling and radial extracorporeal shockwave therapy on latent trigger point sensitivity in the quadriceps: A randomised control pilot study. J Bodyw Mov Ther 2019; 23: 82–88

[17] Pérez-Bellmunt A, Casasayas-Cos O, López-de-Celis C et al. Effects of Dry Needling of Latent Trigger Points on Viscoelastic and Muscular Contractile Properties: Preliminary Results of a Randomized Within-Participant Clinical Trial. J Clin Med 2021; 10: 3848

[18] Bandy WD, Nelson R, Beamer L. Comparison of dry needling vs. sham on the performance of vertical jump. Int J Sports Phys Ther 2017; 12: 747–751

[19] Haser C, Stoggl T, Kriner M et al. Effect of Dry Needling on Thigh Muscle Strength and Hip Flexion in Elite Soccer Players. Med Sci Sports Exerc 2017; 49: 378–383

[20] Ceballos-Laita L, Medrano-de-la-Fuente R, Estébanez-De-Miguel E et al. Effects of Dry Needling in Teres Major Muscle in Elite Handball Athletes. A Randomised Controlled Trial. J Clin Med 2021; 10: 4260

[21] Mansfield CJ, Vanetten L, Willy R et al. The Effects of Needling Therapies on Muscle Force Production: A Systematic Review and Meta-analysis. J Orthop Sports Phys Ther 2019; 49: 154–170

[22] Trybulski R, Stanula A, Żebrowska A et al. Acute Effects of the Dry Needling Session on Gastrocnemius Muscle Biomechanical Properties, and Perfusion with Latent Trigger Points – A Single-Blind Randomized Controlled Trial in Mixed Martial Arts Athletes. J Sports Sci Med 2024; 136–146

[23] Tang C-T, Song B. Acupuncture and Dry Needling for Sports Performance and Recovery. Curr Sports Med Rep 2022; 21: 213–218

[24] Ghoul N, Tabben M, Miarka B et al. Mixed Martial Arts Induces Significant Fatigue and Muscle Damage Up to 24 Hours Post-combat. J Strength Cond Res 2019; 33: 1570–1579

[25] Tabben M, Ihsan M, Ghoul N et al. Cold Water Immersion Enhanced Athletes' Wellness and 10-m Short Sprint Performance 24-h After a Simulated Mixed Martial Arts Combat. Front Physiol 2018; 9: 1542

[26] Cushman DM, Cummings K, Skinner L et al. Postrace Dry Needling Does Not Reduce Subsequent Soreness and Cramping—A Randomized Controlled Trial. Clin J Sport Med 2021; 31: 225–231

[27] Janowski JA, Phelan-Smith DML, Kroat Brady MN et al. Acute Effects of Dry Needling on Myofascial Trigger Points in the Triceps Surae of Ballet Dancers: A Pilot Randomized Controlled Trial. Int J Sports Phys Ther 2021; 16: 418–430

[28] Hong C-Z. Lidocaine injection versus dry needling to myofascial trigger point. The importance of the local twitch response. Am J Phys Med Rehabil 1994; 73: 256–263

[29] Perreault T, Dunning J, Butts R. The local twitch response during trigger point dry needling: Is it necessary for successful outcomes? J Bodyw Mov Ther 2017; 21: 940–947

[30] Fernández-de-las-Peñas C, Plaza-Manzano G, Sanchez-Infante J et al. The importance of the local twitch response during needling interventions in spinal pain associated with myofascial trigger points: A systematic review and meta-analysis. Acupuncture Med 2022; 40: 299–311

[31] Braithwaite FA, Walters JL, Li LSK et al. Blinding Strategies in Dry Needling Trials: Systematic Review and Meta-Analysis. Phys Ther 2019; 99: 1461–1480

[32] Liana R, Chudański M, Ponikowska I. Standardisation of laser Doppler flowmetry-own standards. Clin Diabetology 2009; 10: 58–64

[33] Wright CI, Kroner CI, Draijer R. Non-invasive methods and stimuli for evaluating the skin's microcirculation. J Pharmacol Toxicol Methods 2006; 54: 1–25

[34] Rodrigues LM, Rocha C, Ferreira H et al. Different lasers reveal different skin microcirculatory flowmotion – data from the wavelet transform analysis of human hindlimb perfusion. Sci Rep 2019; 9: 16951. DOI: 10.1038/s41598-019-53213-2

[35] Davidson MJ, Bryant AL, Bower WF et al. Myotonometry Reliably Measures Muscle Stiffness in the Thenar and Perineal Muscles. Physiotherapy Canada 2017; 69: 104–112

[36] Melo ASC, Cruz EB, Vilas-Boas JP et al. Scapular Dynamic Muscular Stiffness Assessed through Myotonometry: A Narrative Review. Sensors 2022; 22: 2565

[37] Bartsch K, Brandl A, Weber P et al. Assessing reliability and validity of different stiffness measurement tools on a multi-layered phantom tissue model. Sci Rep 2023; 13: 815

[38] Butler RJ, Crowell HP, Davis IM. Lower extremity stiffness: Implications for performance and injury. Clin Biomech 2003; 18: 511–517

[39] Fernández-Lao C, Cantarero-Villanueva I, Fernández-De-Las-Peñas C et al. Myofascial trigger points in neck and shoulder muscles and widespread pressure pain hypersensitivity in patients with postmastectomy pain: Evidence of peripheral and central sensitization. Clin J Pain 2010; 26: 798–806

[40] Zebrowska A, Trybulski R, Roczniok R et al. Effect of Physical Methods of Lymphatic Drainage on Postexercise Recovery of Mixed Martial Arts Athletes. Clin J Sport Med 2019; 29: 49–56

[41] Hopkins WG, Marshall SW, Batterham AM et al. Progressive Statistics for Studies in Sports Medicine and Exercise Science. Med Sci Sports Exerc 2009; 41: 3–13

[42] Cagnie B, Dewitte V, Barbe T et al. Physiologic Effects of Dry Needling. Curr Pain Headache Rep 2013; 17: 348

[43] Simon AM, McWhorter AR. Vascular Abnormalities in Mice Lacking the Endothelial Gap Junction Proteins connexin37 and connexin40. Dev Biol 2002; 251: 206–220

[44] Ohkubo M, Hamaoka T, Niwayama M et al. Local increase in trapezius muscle oxygenation during and after acupuncture. Dynamic Med 2009; 8: 2. DOI: 10.1186/1476-5918-8-2

[45] Sandberg M, Larsson B, Lindberg L et al. Different patterns of blood flow response in the trapezius muscle following needle stimulation (acupuncture) between healthy subjects and patients with fibromyalgia and work-related trapezius myalgia. Euro J Pain 2005; 9: 497–497

[46] Liu L, Huang Q-M, Liu Q-G et al. Effectiveness of Dry Needling for Myofascial Trigger Points Associated With Neck and Shoulder Pain: A Systematic Review and Meta-Analysis. Arch Phys Med Rehabil 2015; 96: 944–955

[47] Jiang F, Yu S, Su H et al. Assessment of the effects of ischaemia/hypoxia on angiogenesis in rat myofascial trigger points using colour Doppler flow imaging. PeerJ 2020; 8: e10481

[48] Simons DG, Hong C-Z, Simons LS. Endplate Potentials Are Common to Midfiber Myofacial Trigger Points. Am J Phys Med Rehabil 2002; 81: 212–222

[49] Bueno JCA, Faro H, Lenetsky S et al. Exploratory Systematic Review of Mixed Martial Arts: An Overview of Performance of Importance Factors with over 20,000 Athletes. Sports 2022; 10: 80

[50] Kietrys DM, Palombaro KM, Azzaretto E et al. Effectiveness of Dry Needling for Upper-Quarter Myofascial Pain: A Systematic Review and Meta-analysis. J Orthop Sports Phys Ther 2013; 43: 620–634

[51] Meerits T, Bacchieri S, Pääsuke M et al. Acute effect of static and dynamic stretching on tone and elasticity of hamstring muscle and on vertical jump performance in track-and-field athletes. Acta Kinesiol Univ Tartu 2014; 20: 48

[52] Feng YN, Li YP, Liu CL et al. Assessing the elastic properties of skeletal muscle and tendon using shearwave ultrasound elastography and MyotonPRO. Sci Rep 2018; 8: 17064

[53] Baraja-Vegas L, Martín-Rodríguez S, Piqueras-Sanchiz F et al. Localization of Muscle Edema and Changes on Muscle Contractility After Dry Needling of Latent Trigger Points in the Gastrocnemius Muscle. Pain Med 2019; 20: 1387–1394

[54] Gervasi M, Benelli P, Venerandi R et al. Relationship between Muscle-Tendon Stiffness and Drop Jump Performance in Young Male Basketball Players during Developmental Stages. Int J Environ Res Public Health 2022; 19: 17017

[55] Schneider E, Moore ES, Stanborough R et al. Effects of Trigger Point Dry Needling on Strength Measurements and Activation Levels of the Gluteus Medius: A Quasi-Experimental Randomized Control Study. Int J Sports Phys Ther 2022; 17: 1404–1416

[56] Castro Sánchez AM, García López H, Fernández Sánchez M et al. Improvement in clinical outcomes after dry needling versus myofascial release on pain pressure thresholds, quality of life, fatigue, pain intensity, quality of sleep, anxiety, and depression in patients with fibromyalgia syndrome. Disabil Rehabil 2019; 41: 2235–2246

[57] Unverzagt C, Berglund K, Thomas JJ. Dry needling for myofascial trigger point pain: A clinical commentary. Int J Sports Phys Ther 2015; 10: 402–418

[58] Hsieh Y-L, Hong C-Z, Liu S-Y et al. Acupuncture at Distant Myofascial Trigger Spots Enhances Endogenous Opioids in Rabbits: A Possible Mechanism for Managing Myofascial Pain. Acupuncture Med 2016; 34: 302–309

[59] Zhang Q, Zhou M, Huo M et al. Mechanisms of acupuncture-electroacupuncture on inflammatory pain. Mol Pain 2023; 19. DOI: 10.1177/17448069231202882

[60] Ma X, Chen W, Yang N-N et al. Potential mechanisms of acupuncture for neuropathic pain based on somatosensory system. Front Neurosci 2022; 16. DOI: 10.3389/fnins.2022.940343

[61] Hsieh M-C, Wang S-H, Chuah S-K et al. A Prognostic Model Using Inflammation- and Nutrition-Based Scores in Patients With Metastatic Gastric Adenocarcinoma Treated With Chemotherapy. Medicine 2016; 95: e3504. DOI: 10.1097/MD.0000000000003504

[62] Domingo A, Mayoral O, Monterde S et al. Neuromuscular Damage and Repair after Dry Needling in Mice. Evidence-Based Complementary Alter Med 2013; 2013: 1–10