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Stimulation of myofascial trigger points with ultrasound induces segmental antinociceptive effects: A randomized controlled study

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Abstract

Musculoskeletal pain affects a significant proportion of the general population. The myofascial trigger point is recognized as a key factor in the pathophysiology of musculoskeletal pain. Ultrasound is commonly employed in the treatment and management of soft tissue pain and, in this study, we set out to investigate the segmental antinociceptive effect of ultrasound. Subjects ($n = 50$) with identifiable myofascial trigger points in the supraspinatus, infraspinatus and gluteus medius muscles were selected from an outpatient rehabilitation clinic and randomly assigned to test or control groups. Test subjects received a therapeutic dose of ultrasound to the right supraspinatus trigger point while control groups received a sham (null) exposure. Baseline pain pressure threshold (PPT) readings were recorded at the ipsilateral infraspinatus and gluteus medius trigger-point sites prior to ultrasound exposure. The infraspinatus point was chosen due to its segmental neurologic link with the supraspinatus point; the gluteus medius acted as a segmental control point. Following the ultrasound intervention, PPT readings were recorded at 1, 3, 5, 10 and 15 min intervals at both infraspinatus and gluteus medius trigger points; the difference between infraspinatus and gluteus medius PPT values, PPT_{seg}, represents the segmental influence on the PPT. The ultrasound test group demonstrated statistically significant increases in PPT_{seg} (decreased infraspinatus sensitivity) at 1, 3 and 5 min, when compared with PPT_{seg} in the sham ultrasound group. These results establish that low-dose ultrasound evokes short-term segmental antinociceptive effects on trigger points which may have applications in the management of musculoskeletal pain.

Keywords: Trigger point; Ultrasound; Myofascial pain; Segmental pain; Antinociception; Musculoskeletal pain

1. Introduction

Musculoskeletal pain affects up to 85% of the general population [55]. It is a primary cause of health-care visits, absenteeism and early pensions [33,56] and represents the second leading cause of illness in Canada [25]. An accumulating body of evidence suggests that myofascial trigger points may play a central role in the pathophysiology of common musculoskeletal pain syndromes [52].

Myofascial trigger points are defined as localized hyperirritable nodules found within palpable taut bands of skeletal muscle fibers [51]. They have been identified in both humans [52] and animals [26]. Trigger points are typically tender to touch and often

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elicit referred pain with prolonged pressure stimulation [53].

The association between trigger points and pain of musculoskeletal origin was first introduced by Travell and Rinzler [60]. Subsequent publications have since highlighted relationships between trigger points and joint dysfunction [37], mechanical headache [61], mechanical low-back pain [54] and disc lesions [31]. There also appears to be a strong evidential link between trigger points and certain types of pathologies such as migraine [8], fibromyalgia [27] and psychological stress [42].

Experimental evidence demonstrates that stimulation of trigger points elicits systematic physiologic effects. For example, lidocaine injected into periarticular trigger points has been shown to dramatically decrease osteoarthritic knee pain and improve joint range of motion [67]. Similarly, injections into gluteal trigger points provided total pain relief and immediate restoration of normal ambulation in cases of acute sacroiliitis [62]. Other studies have reported relief from intercostal post-herpetic neuralgia [9] and renal colic [32] after anaesthetizing injections of lidocaine into intercostal and psoas trigger points, respectively.

Therapeutic ultrasound is commonly employed in the management of various forms of musculoskeletal pain and has the ability to decrease short-term local trigger-point sensitivity [57]. It is an inexpensive, non-ionizing form of radiation that is easily integrated into a clinical setting. In light of its ability to penetrate biologic tissues [15], and because it is less invasive than traditional needle therapy, ultrasound may be a viable alternative to dry-needle trigger-point therapy, injections or acupuncture.

The purpose of this study was to assess the hypothesis that exposure of a trigger point to one, low-dose application of therapeutic ultrasound will decrease the sensitivity of trigger points found in other segmentally linked, but distinct, muscles. Previous animal experiments have demonstrated that ultrasound applied to peripheral tissues evokes cellular changes in the dorsal horn of the spinal cord [29] suggesting that ultrasound may induce its antinociceptive effect segmentally through central neuromodulatory mechanisms. This phenomenon has not been previously studied in humans and, if substantiated, may offer insight into novel treatment strategies for musculoskeletal pain syndromes.

2. Methods

This study was approved by the University of Guelph Ethics Committee. The primary outcome measure used to quantify trigger-point sensitivity was the pain pressure threshold (PPT) value. The force applied to the trigger point was measured in units of Newtons (N), which is defined as the force required to accelerate a mass of 1 kg at a rate of 1 m/s^2. A Chatillon DFE Series Digital Force Gauge was used to record the pressure readings at each trigger-point location. Contact area of the gauge tip was 285 mm^2 (19 mm × 15 mm).

The list of diagnostic criteria used to identify trigger points has been previously reported [2]. The chief physical features include a localized tender nodule that is palpable within a tight band of skeletal muscle. Prolonged pressure on the nodule (10–20 s) elicits a diffuse, achy and poorly localized or radiating discomfort. To enhance reliability, only trigger-point loci with baseline PPT values less than 35 N were used in the study [50]. A jump sign and/or local muscular twitch response to pressure stimulation were also observed in some cases but were not compulsory for the diagnosis, as they are not considered reliable signs of the trigger-point phenomenon [24].

Two clinicians participated in this study. A recruiting clinician with 20 years of experience in manual therapy was primarily responsible for identifying potential subjects. The principal inclusion criterion was the presence of myofascial trigger-point loci in each of the supraspinatus, infraspinatus and gluteus medius muscle groups. A second clinician with 14 years of experience was in charge of performing the physical examinations on each subject as well as collecting all PPT readings. A diagram of patient flow through each stage of the study is illustrated in Fig. 1.

To determine sample size, a power analysis was performed using previously reported data [57]. Based on an estimated 45% increase in PPT after ultrasound exposure, we calculated that a sample size of 25 subjects per group was required to pro-

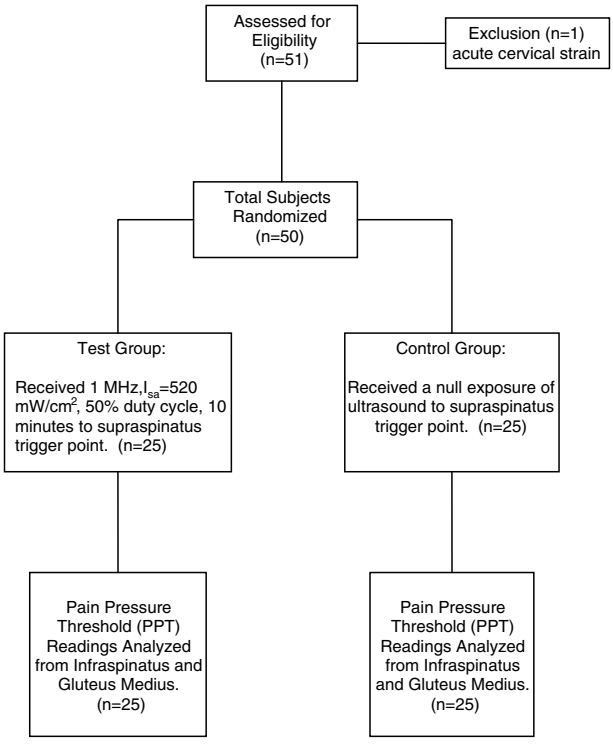

Fig. 1. Diagram of patient flow through each stage of the study. Eligible subjects were randomly divided into test (ultrasound) and control (sham ultrasound) groups and tested for pain sensitivity over identified infraspinatus and gluteus trigger points at baseline, 1, 3, 5, 10 and 15 min intervals.

Table 1
A summary of the demographic profile of test and control groups used for this study

	Test	Control
Subjects (*n*)	25	25
Age (years)	42.9 (19.7)	48.6 (18.1)
Sex (% males)	40.0	52.0
Height (inches)	65.9 (4.9)	67.1 (4.4)
Weight (lbs)	158.4 (33.4)	168.9 (36)

Values are expressed as means (SD).

vide 95% power. Subjects ($n = 50$; 26 males, 24 females) were identified from a daily pool of patients within a rehabilitation outpatient clinic facility in Guelph, Ontario, Canada (Table 1). Each participant provided informed consent prior to commencement of the study. Subjects were required to complete a brief health questionnaire to rule out any medical conditions that could affect normal somatosensory function; recent acute injury to the cervicothoracic region, pre-existing peripheral/central neuromuscular disease or current medication use were the primary exclusion criteria of the study. Qualified subjects were assigned into either test or control groups using a random-draw technique performed by a research assistant. The technique involved blindly drawing labeled slips of paper from a bin. Brief history and physical examinations were then performed on each subject by the data clinician. None of the participants withdrew from the study.

Patients were placed in a prone position for the data collection. Trigger-point locations in the right supraspinatus, infraspinatus and gluteus medius muscles were identified by the data clinician and marked with a non-toxic marker. All trigger points used in the study were taken from the right side to ensure consistency. The pain pressure threshold was measured by applying increasing pressure over the identified trigger-point locus perpendicular to the skin surface at the rate of approximately 5 N/s [10] using the pressure algometer. Subjects were instructed to identify the onset of a deep dull achy or sharp stabbing sensation at the trigger-point site; the corresponding pressure reading of the algometer was recorded as the PPT value. Prior to the application of either therapeutic or sham ultrasound, each subject was trained to identify the PPT using the left infraspinatus trigger-point site. Training continued until the subject identified two consecutive PPT readings within a 2 N difference.

Baseline (pre-ultrasound) PPT readings were first recorded from the right infraspinatus and right gluteus medius trigger-point sites. Ultrasound was then applied to the area on the right trapezius muscle, directly over the identified supraspinatus trigger point, by the research assistant according to the following protocol: the test group received a 10-min session of ultrasound (1 MHz, $I_{sa} = 520$ mW/cm^2, 12% duty cycle, treatment area = 2 times the Effective Radiation Area) while the control group received a 10-min sham ultrasound treatment with null output. The ultrasound application techniques were identical for both the test and control groups with the only difference being that the ultrasound unit was shut off for the sham procedure. Immediately after the 10-min ultrasound application, PPT readings were recorded by the data clinician from both the infraspinatus and gluteus medius sites at 1, 3, 5, 10 and 15 min post-ultrasound. Subjects and data clinician were both blinded to treatment group; the research assistant was not blinded, but was not directly involved in the collection of the PPT measures.

Three PPT readings were recorded at the infraspinatus and gluteus medius sites at each time point under either ultrasound or sham ultrasound-treatment conditions; the average of the closest two readings was used as the raw PPT value. All PPT values were normalized to the pre-ultrasound baseline scores to standardize for variations between subjects and the effects of spatial summation [12].

Since both the infraspinatus and supraspinatus muscles are commonly innervated by $C_{5,6}$ spinal segments, the PPT readings at the infraspinatus muscle are influenced by a combination of segmental and non-segmental physiologic effects (PPT_{comb}). The PPT changes at the gluteus medius trigger point, however, are exclusively impacted by non-segmental influences (PPT_{nseg}) due to the absence of a direct segmental link to the insonated supraspinatus muscle; thus, the gluteus medius trigger point acts as a segmental control point in our study design. The difference between the infraspinatus and gluteus medius PPT values ($PPT_{comb} - PPT_{nseg}$), therefore, reflects the net segmental contribution (PPT_{seg}) to the observed antinociceptive effects at the infraspinatus trigger point.

Our primary interest was to compare PPT_{seg} values between the ultrasound and sham ultrasound-treatment conditions to determine if ultrasound evokes segmental antinociceptive effects. For this analysis, we were not specifically interested in the overall effect of time on PPT. Accordingly, for statistical analysis, we performed a univariate ANOVA at each time point using treatment as our independent variable and PPT_{seg} as our dependent variable.

Our secondary interest was in quantifying the peak antinociceptive effect at the infraspinatus muscle due to the ultrasound treatment. To test for significance, we performed a univariate ANOVA individually at each time point using PPT_{comb} as our dependent variable and treatment as the independent variable. Once again, the overall effect of time was not of interest and, accordingly, we did not include time in our analysis.

Data were tested for normality using the Kolmogorov–Smirnov (K–S) test and homogeneity of variance was tested using the Brown and Forsythe test. The data analyst was not blinded to treatment group.

3. Results

The ultrasound test group demonstrated statistically significant increases in PPT_{seg} values (decreased sensitivity at the infraspinatus) at 1 ($p = 0.002$), 3 ($p = 0.004$), and 5 ($p = 0.002$) min, when compared with PPT_{seg} changes after sham ultrasound; no significant differences in PPT_{seg} were observed between treatment conditions at 10 ($p = 0.288$) and 15 ($p = 0.155$) min (Fig. 2).

In addition, the comparison of ultrasound versus sham ultrasound at the infraspinatus muscle demonstrated significant increases in PPT_{comb} in the ultrasound test group at all time points, including 1 ($p < 0.001$), 3 ($p < 0.001$), 5 ($p < 0.001$), 10 ($p = 0.020$) and 15 ($p = 0.012$) min (Fig. 3). The peak normalized

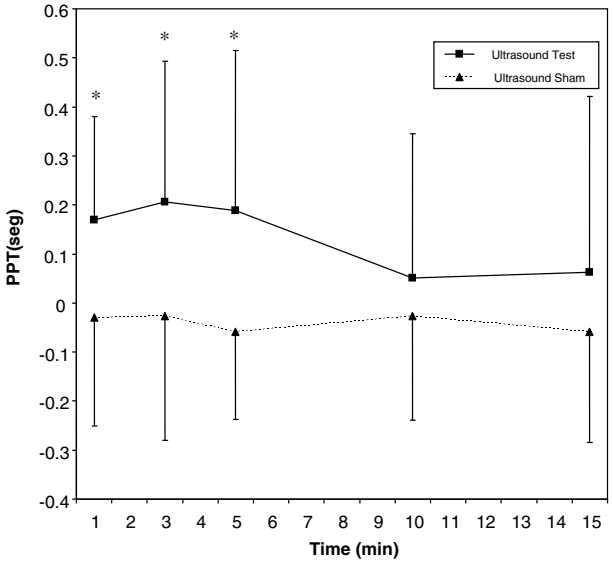

Fig. 2. A comparison of the pain pressure threshold difference (PPT_{seg}) between infraspinatus and gluteus medius trigger points over time for ultrasound versus sham ultrasound groups. The raw PPT values recorded at each muscle were normalized to pre-ultrasound baseline (time zero) values. The test group received low-dose therapeutic ultrasound while controls received a sham (null) dose. A significant short-term increase in PPT_{seg} (decrease in pressure sensitivity at the infraspinatus) is observed in the ultrasound group, but not in sham controls. Significant differences are denoted with an asterisk.

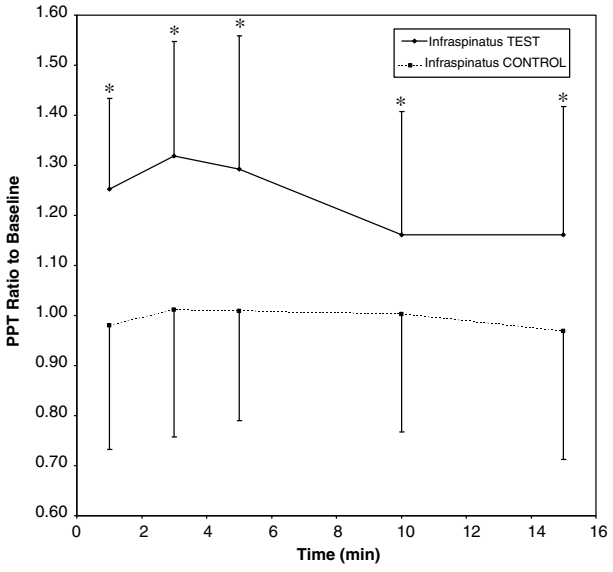

Fig. 3. A comparison of the pain pressure threshold (PPT_{comb}) changes over time for ultrasound versus sham ultrasound groups at the infraspinatus trigger point. PPT values are normalized to pre-ultrasound baseline (time zero) readings. The test group received low-dose therapeutic ultrasound while controls received a sham (null) dose. A significant decrease in pressure sensitivity (increased PPT_{comb}) was observed at all times in the ultrasound group as compared to controls. The greatest difference in PPT_{comb} values was observed at 3 min post-ultrasound, representing a peak 31% decrease in pain sensitivity after ultrasound treatment. Significant differences are denoted by an asterisk.

PPT_{comb} value at the infraspinatus trigger point was 1.32(0.23) at 3 min post-ultrasound as compared to 1.01(0.25) with sham ultrasound after 3 min, representing a peak 31% decrease in pain sensitivity with ultrasound treatment (Fig. 3).

4. Discussion

Our results demonstrate that ultrasound treatment of the supraspinatus trigger point evoked a significantly greater short-term decrease in pain sensitivity at the infraspinatus trigger point as compared to the gluteus medius. The insonated supraspinatus trigger point and the infraspinatus trigger point share a common innervation at the $C_{5,6}$ spinal levels, which is not shared by the gluteus medius muscle. Accordingly, the infraspinatus PPT is impacted by both segmental and non-segmental antinociceptive effects, whereas the gluteus medius trigger point is impacted by only non-segmental effects. Thus, the difference in pain pressure sensitivity (PPT_{seg}) between the infraspinatus (PPT_{comb}) and gluteus medius (PPT_{nseg}) points represents a measure of the segmental antinociceptive effects at the infraspinatus trigger-point site. We observed significantly greater PPT_{seg} values at 1, 3 and 5 min post-ultrasound, when compared to sham ultrasound (Fig. 2). Consequently, the unique antinociceptive effects observed at the infraspinatus muscle appear to be mediated through segmental spinal pathways. These findings support our hypothesis that a low-dose exposure of ultrasound to a myofascial trigger point evokes systematic segmental antinociceptive effects (segmental antinociception).

In addition, we observed significant decreases in trigger-point sensitivity (increased PPT_{comb}) at the infraspinatus muscle at all time intervals after ultrasound exposure, when compared to sham controls (Fig. 3). This finding suggests that the ultrasound exposure was, in fact, responsible for the observed segmental effects at the infraspinatus muscle. Moreover, our data demonstrate that a noteworthy 31% decrease in short-term pain sensitivity was evoked by using a low-dose ultrasound exposure.

Previous studies have investigated the effects of ultrasound on trigger-point sensitivity but none has adequately characterized these antinociceptive effects. For instance, decreased subjective pain scores have been reported after employing a unique high-power ultrasound technique that stimulated trigger points to their pain threshold [17]. Similarly, trigger point pain sensitivity has been reduced by ultrasound in combination with massage and exercise [40]. Both studies used supra-therapeutic output parameters; our aim was to investigate whether low-dose therapeutic levels of ultrasound could evoke similar effects on pain.

Our study uniquely employed the PPT measure to quantify the antinociceptive effects of ultrasound.

Pressure algometry is an inexpensive and reliable method of assessing trigger-point sensitivity [13,28] and pain perception [21,22,36]. Pressure algometry has demonstrated high inter- and intra-examiner reliability when used as an index of trigger-point sensitivity [48] and a strong correlation exists between the clinical intensity of trigger point pain and the absolute PPT value [21]. Indeed, repeated pressure algometry trials (7 trains of 2 repeated measurements over a 1 h test period) do not modulate PPT values over time [10]. The PPT reading, therefore, provides a reliable gauge for the activation state of the trigger point; any change in this value suggests an underlying change in the subject's pain experience, which may include influence(s) from spinal (segmental), supraspinal or other physiologic (biochemical, electrochemical, and hormonal) mechanisms.

Striking comparisons can be made between trigger points and acupuncture points (acupoints). A 71% correlation exists between trigger points and acupoints with respect to spatial distribution and pain referral patterns [43]. These authors conclude that trigger points and acupoints, although discovered independently and characterized differently, are identical phenomena and can be explained using similar neurophysiologic paradigms. This correlation has recently been further validated using electrophysiologic comparisons of acupoint and trigger-point loci [34]. Thus, many of the laws governing the biophysical effects of trigger points can be applied to acupoints, and vice-versa.

Accordingly, a large body of evidence demonstrates that site-specific acupoint stimulation can initiate a wide spectrum of systematic physiologic effects, not limited to antinociception. Acupoint-specific stimulation is reported to modulate the amplitude and latency of somatosensory cortical-evoked potentials in humans [1] and animals [49] as well as evoking viscero-somatic responses in animals [41] and humans [16,38,59]. Postoperative analgesic requirements have also been reduced by up to 39% after transcutaneous electrical stimulation (TENS) of acupoints, as compared to non-acupoint stimulation and sham TENS [9]. In a study using pain pressure threshold measures as outcomes, a significant decrease in pressure sensitivity over the temporalis muscle has been recorded after acupoint treatment for headaches [35]. Additionally, needle stimulation of the LI_4 acupoint (in the belly of the 1st dorsal interosseous muscle of hand) resulted in increased pain thresholds at associated LI_5, LI_{11} and LI_{20} acupoints as compared with adjacent control points located 15 mm from the trigger-point locus [20]. These studies collectively illustrate the profound and unique site-specific physiologic effects evoked by acupoint (trigger-point) stimulation, providing a convincing rationale for ongoing research in trigger-point physiology.

The primary limitation of this study is that only short-term (less than 15 min) effects of ultrasound were evaluated. While it appears that the segmental antinociceptive effects of ultrasound were short-lived, it must be acknowledged that one low-dose of ultrasound evoked this effect. The documented non-linear dose–response relationship of ultrasound bioeffects [58] and ultrasound-induced cavitation [3,4,14], one of the purported mechanisms of ultrasound, highlights the possibility for higher outputs to induce substantially greater and longer-lasting antinociceptive effects, which may be clinically important in pain management.

The research assistant administering the ultrasound treatment was not blinded to subject grouping. Furthermore, after data collection, subjects were not queried about which treatment group they believed they were placed in. This exposes the potential for subject group bias, though the impact of this limitation is likely negligible based on the study design. Employment of the gluteus medius ($L_{4,5}S_1$) segmental control point mitigates potential subject group bias effect(s) since the impact of such bias would be comparable at both the infraspinatus and gluteus medius sites. Furthermore, the impact of excluding non-trigger point control points, another potential limitation, is overcome by the explicit aim of this study, which was to test the segmental nature of trigger-point stimulation. The existing basic science characterizing the unique anatomic [39], physiologic [34] and systematic clinical bioeffects [7] of site-specific acupoint stimulation provides sufficient basis to attribute the observed changes in this study to the stimulation of the supraspinatus trigger point.

Musculoskeletal pain manifests in segmental patterns throughout the nervous system [30] and, in this study, we have observed that these segmental pathways can be modulated with therapeutic levels of ultrasound. While these observations may add potential insight into novel strategies in pain management, they have not yet been adequately studied. Future research needs to investigate both the dose–response relationship and bioeffect(s) (duration and intensity) of single and cumulative ultrasound exposures on trigger-point sensitivity. Additionally, in order to determine optimal treatment protocols, biologic responses to different waveform parameters, such as peak pulse intensity or pulse frequency, need to be established.

The current literature on ultrasound use in rehabilitation medicine is equivocal. Two literature reviews report positive outcomes with acute inflammatory conditions, such as periarticular inflammation [18] and calcific tendonitis [46]. Two others report no evidence to support ultrasound use in the treatment of osteoarthritis [47,66]. The challenge in translating the current research lies primarily in the inconsistency and poor reporting of ultrasound output parameters, inconsistent application techniques and poor study designs and/or methodologies [66]. These discrepancies significantly influence the absolute dose delivered to the tissues and preclude

meaningful inter-study comparisons. Moreover, some of these studies evaluated ultrasound in combination with other therapeutic modalities such as exercise [19] and massage [23]. Nevertheless, numerous experimental and animal studies have shown a broad spectrum of beneficial effects of ultrasound including facilitation of protein synthesis [65], improved collagen repair [5,6], enhanced cartilage repair [11,44], modulation of inflammation [68], enhanced fracture repair [63,64] and increased transdermal drug delivery (phonophoresis) [45,68].

There is accumulating scientific and clinical evidence to justify significant interest in therapeutic ultrasound and its potential applications in musculoskeletal pain management. Much of our current awareness in trigger-point physiology is not derived from studies using trigger point outcomes but relies largely on corresponding data from acupoint research. It is, therefore, appropriate to continue expanding our knowledge of the potential applications of ultrasound through well-designed protocols specifically targeting trigger point outcomes and employing strict methodologies, meticulous reporting of output parameters and standardized application techniques. Furthermore, these study designs must focus on isolating the effects of ultrasound by excluding, where possible, adjunctive modalities; only under these conditions can reliable conclusions be made on its efficacy and application. In light of its potential antinociceptive effects, ultrasound may offer clinicians a novel, non-invasive option for treating pain of musculoskeletal origin.

Conflict of interest

The authors declare no conflict of interest.

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