REVIEW PAPER

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# Efficacy of diadynamic currents in the treatment of musculoskeletal pain: a systematic review

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**Abstract**

**Introduction.** Musculoskeletal pain (MSP) is one of the main causes of chronic pain in adults and the main reason for disability. Diadynamic currents (DDC) are described as classic electrotherapy modalities for the management of MSP, however, the available information and studies that support their use are limited. The aim of this report is therefore to describe the efficacy of DDC in the treatment of MSP.

**Methods.** Randomised clinical trials (RCTs) were identified in the PubMed, Scopus, Web of Science, Cinahl, and Science Direct databases as of August 1, 2021. Three independent investigators reviewed the articles' titles and abstracts to determine their eligibility, risk of bias, and quality using the Cochrane Rob2 tool and the PEDro scale. Pain reduction was considered as the main outcome and changes in the range of motion, strength, or disability/functionality as secondary outcomes.

**Results.** Thirteen RCTs were obtained after eliminating duplicates, reviewing the titles and abstracts and applying the selection criteria. The MSP conditions included joint ($n$ = 9) and soft tissue ($n$ = 5) disorders. The studies had a low risk of bias and good quality, with average scores of 7 for the PEDro scale. Pain reduction was observed for DDC treatments, as well as an improvement in functionality in favour of the experimental groups ($p < 0.05$).

**Conclusions.** DDC are effective in reducing MSP and improving functionality compared to other electrotherapy modalities. This review made it possible to generate dosage recommendations and establish that the best therapeutic results are achieved with combined diadynamic applications.

**Key words:** electric stimulation therapy, electric stimulation, diadynamic current, musculoskeletal diseases

## Introduction

Musculoskeletal pain (MSP) has become a major concern for health systems, constituting one of the main causes of chronic pain in adults, with a high emotional burden and being an important reason for occupational disability [1–4]. Beyond its symptoms, it has been associated with high financial costs, including medical expenses, lost working days, decreased productivity, and quality of life repercussions [5]. It has been estimated that the prevalence of MSP is between 11 and 40%, affecting mostly females, having a direct relationship with age, presence of comorbidities and sociocultural level [3–6]. The most common regions of MSP include the lumbar and cervical spine, shoulders, and knees [7].

MSP is classified as primary when it occurs due to a direct injury to the musculoskeletal system, and secondary when it is the result of autoimmune diseases, crystal arthropathy, infections, or degenerative processes. Other classifications have divided it into acute or chronic, according to whether its duration exceeds three months [5, 7, 8].

MSP pathogenic mechanisms are associated with each musculoskeletal structure innervation, through individual neuronal circuits between tissues and the central nervous system (CNS), making differentiating its origin and diagnosis a challenge [9–11]. The persistence of MSP has been associated with progressive central sensitisation processes characterised by morphological changes, greater excitability, and the facilitation of neurons' synaptic transmission in the spinal cord (dorsal horn), subcortical and cortical areas such as the thalamus, somatosensory cortex and/or primary motor cortex, to which are added the emotional and psychosocial factors that contribute to its maintenance [7, 9–11].

The International Association for the Study of Pain (IASP) has highlighted the importance and challenges involved in the management of MSP, given its high prevalence, inappropriate treatment, and difficult relationship between pathophysiological changes and actual pain in the patient, in addition to the fact that it is generally given a lower priority compared to other acute illnesses with more critical symptoms [2–4, 12, 13].

There are various therapeutic options for the management of MSP, including medications (anti-inflammatory drugs, analgesics, or opiates), injections (corticosteroids), and surgeries, although these treatments are sometimes associated with adverse effects or high economic costs [14–16]. On the other hand, physical therapy has been supported as a treatment in various MSP conditions through interventions such as therapeutic exercise, manual therapy, and transcutaneous electrical nerve stimulation (TENS), with the objective of reducing pain and regaining functionality [17–23]. Among these treatments, electrotherapy stands out as a resource supported by the literature for managing MSP, reducing inflammation, controlling oedema and strengthening the muscles [24–30].

Diadynamic currents (DDC), or Bernard currents, constitute one of the classic electrotherapy modalities (described in 1945), which stand out for their biophysical properties when combining galvanic effects with sensitive stimulation (such

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as TENS), for which they have been proposed as an alternative for the management of MSP [31–44]. DDC consist of low-frequency sinusoidal unidirectional currents (50 and 100 Hz) obtained by rectifying an alternating current, and unlike other currents, because their parameters only consider intensity (milliamps, mA) and treatment time (minutes). These currents include two basic modes, the fixed monophasic current (MF) and fixed diphasic current (DF), which are combined and modulated in their delivery time, generating other DDC such as short-periods currents (CP), long-periods currents (LP) and syncopated rhythm (RS), which offers clinicians five common modalities of choice. In addition, a lot of equipment also adds 10 or 20% galvanic to each type, which strengthens its electrochemical effects (DDC combined with a galvanic current base). The diversity of DDC provides different biological effects, which can be summarised as galvanic effects (DF and LP, whose galvanic component is 66% and 50%, respectively), sensory effects (CP and LP), and motor effects (RS and MF) [30, 34, 35, 40–44].

Although the analgesic effects of DDC are not entirely clear, they would be supported by activation of the gate control theory (Melzack-Wall theory) through low-threshold mechanoreceptor stimulation (Aβ fibres), the release of endogenous opioid peptides and electrochemical changes achieved through galvanism effects (polar effects) [30, 44–49].

Although DDC are available in most new-generation electrical stimulators, most clinicians use TENS or Kilohertz-modulated medium-frequency alternating currents in their practice for analgesic or neuromuscular stimulation purposes (NMES) [50–52], which may be due to the insufficient information available and knowledge of this electrical modalities. The need for safe and effective treatments for the management of MSP offers other electrotherapy modalities the opportunity to assess their efficacy.

Thus, the objective of this systematic review (SR) was to investigate the available scientific evidence regarding the efficacy of DDC in the treatment MSP.

## Subjects and methods

### Study design

This SR adheres to the PRISMA statement on reporting preference items for SR and meta-analysis (MT-A) (available at http://www.prisma-statement.org) [53]. The research was electronically registered in the International RS Prospective Registry (PROSPERO) of the National Institute for Health Research (NIHR) obtaining the identification code CRD42021 227382 (https://www.crd.york.ac.uk/prospero).

The SR used the acronym PICO (participants, intervention, comparison, and outcome) to structure the research question and search algorithm based on the following elements: patients with MSP, treated with DDC (any of its modalities), compared with a control, sham application, or placebo, and evaluating pain reduction as the main outcome and changes in function/disability, range of motion (ROM), muscular strength or others as secondary outcomes.

### Search strategy

A SR was carried out via the PubMed, Scopus, Web of Science, Cinahl, and Science Direct electronic databases as of August 1, 2021. Keywords were chosen from the MeSH dictionary (Medical Subject Headings, https://www.ncbi.nlm.nih.gov/mesh/) used for indexing scientific articles to the PubMed database. Search terms included “Electric stimulation therapy”, “Electric stimulation”, “Transcutaneous electric nerve stimulation”, “Bernard’s diadynamic currents”, “Diadynamic currents”, “Musculoskeletal pain”, “Musculoskeletal diseases”, “Myofascial pain syndromes”, “Arthralgia” and “Tendinopathy” connected through the Boolean terms “OR” and “AND”, obtaining the following search algorithm: (((((“Electric stimulation therapy”) OR (“Electric stimulation”)) OR (“Transcutaneous electric nerve stimulation”)) OR (“Bernard’s diadynamic currents”)) OR (“Diadynamic current”)) AND (((((“Musculoskeletal pain”) OR (“Musculoskeletal Diseases”)) OR (“Myofascial pain syndromes”)) OR (“Arthralgia”)) OR (“Tendinopathy”)).

The searches were downloaded for each database (nbib, ris or ciw formats) and these files were analysed with the Rayyan tool developed for the preliminary selection of articles’ abstracts and titles (https://rayyan.qcri.org) [54]. Three independent researchers (NB, IL and CV) analysed the article titles and abstracts based on the selection criteria, classifying them into the categories ‘included’, ‘maybe’, and ‘excluded’. The references of these studies were also examined, extracting and reviewing their country, author, affiliated institutions, and enrolment periods to identify and exclude duplicate publications. Articles in the ‘maybe’ category were reviewed by the research team to be included in or excluded from the final count. Articles with incomplete abstracts were discarded from the analysis and each investigator recorded their exclusion reasons.

The main outcome result was pain reduction in patients with musculoskeletal disorders treated with DDC, while ROM, muscle strength and/or disability/functionality changes were considered as secondary outcomes. For the included articles, the study objective, internal validity (PEDro score), participants’ demographic data, follow-up sessions, treatment protocol, DDC type/dose and results of the variables of interest were analysed [55, 56].

### Selection criteria

Inclusion criteria considered: (1) randomised clinical trials (RCTs) or controlled trials (RCT), (2) studies in humans, (3) participants older than 18 years, (4) articles in the English or Spanish language, (5) studies that used DDC alone or with another intervention for the treatment of MSP, and (6) comparison with another treatment, sham application, or placebo. The following were excluded: (i) case report studies, systematic reviews (SR), meta-analyses (MT) and literature reviews, (ii) animals or in vitro studies, (iii) use of DDC in non-musculoskeletal conditions, and (iv) studies with incomplete abstracts or texts.

### Article quality and risk of bias

Each article’s quality was evaluated with the PEDro scale (Cohen kappa coefficient between 0.5 and 0.79 for groups of 2 or 3 evaluators) [55–57]. Each researcher performed an independent assessment, and any disagreement was subsequently discussed to establish consensus. RCTs that achieved a score of 9 or 10 on the PEDro scale are considered to have excellent methodological quality. Studies with a score between 6 and 8 have good methodological quality, those between 4 and 5 have fair quality, and those below 4 have poor methodological quality.

Each article’s risk of bias was assessed with the RoB.2 tool proposed by the Cochrane Collaboration for the analysis of RCTs in SRs for the following domains [58, 59]; (1) bias arising from randomisation process, (2) bias due to deviations

from planned interventions, (3) bias due to missing outcome data, (4) outcome measurements bias, (5) bias in reported outcome selection, and (6) overall article bias. The investigators rated the risk of bias for each criterion as high, low, unclear, or no information where the data provided was insufficient to make this determination [58–60]. Box and summary plots were constructed with the Robvis tool (https://www.riskofbias.info/welcome/robvis-visualisation-tool) (Figure 2) [61]. Studies with two or more high risks of bias were considered low quality [62].

## Ethical approval

The conducted research is not related to either human or animal use.

## Results

### Search results

The preliminary search strategy yielded a total of 770 articles for the selected databases (PubMed, *n* = 293; Scopus, *n* = 6; WoS, *n* = 20; Cinahl, *n* = 184, and Science Direct, *n* = 274). Subsequently, duplicates were eliminated using the Rayyan tool [54], obtaining 519 articles.

The main reasons for exclusion included other electrotherapy modalities, another main outcome, other types of studies, articles not in the English or Spanish languages, and studies that dealt with non-musculoskeletal conditions. After reviewing the titles and abstracts, 23 articles were obtained between 'possible' and 'included' when applying the selection criteria. The researchers adopted consensus for these articles, discarding 10 studies, and finally obtaining 13 for analysis. The reasons for these exclusions included interventions with other electrical currents (*n* = 2), non-musculoskeletal pain management (*n* = 1), and articles with incomplete or unavailable abstracts (*n* = 7). Figure 1 shows the PRISMA flow chart with a summary of the screening results [53, 61, 62].

### Risk of bias and quality

This SR rated 15.38% of the articles (*n* = 2) as high risk of bias [32, 35], especially in domains 1 and 2 for the RoB.2 Cochrane tool [61, 62]. Moreover, 30.76% (*n* = 4) did not present risks of bias for any of the domains [33, 40–42]. Figure 2 summarises the risk of bias of the selected articles.

Table 1 shows the PEDro score for the 13 articles of this SR, while Table 2 summarises the characteristics of study groups, treatment sessions, and outcome measures. Internal validity shows a high quality for 92.30% of the articles (*n* = 12) (score greater than or equal to 6 on the PEDro scale) [31–35, 37–43] with an average of 7 points for all studies [55, 56].

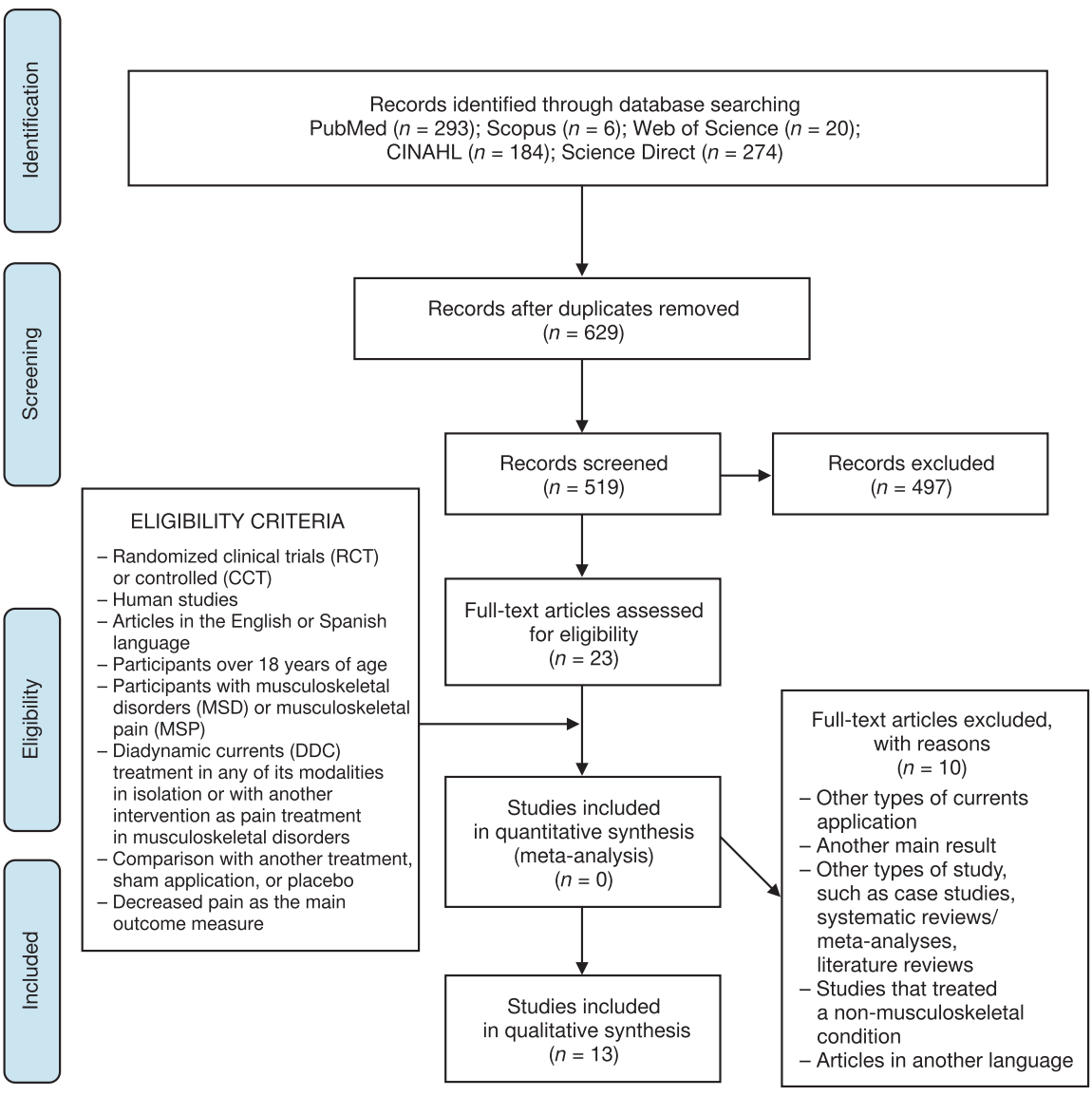
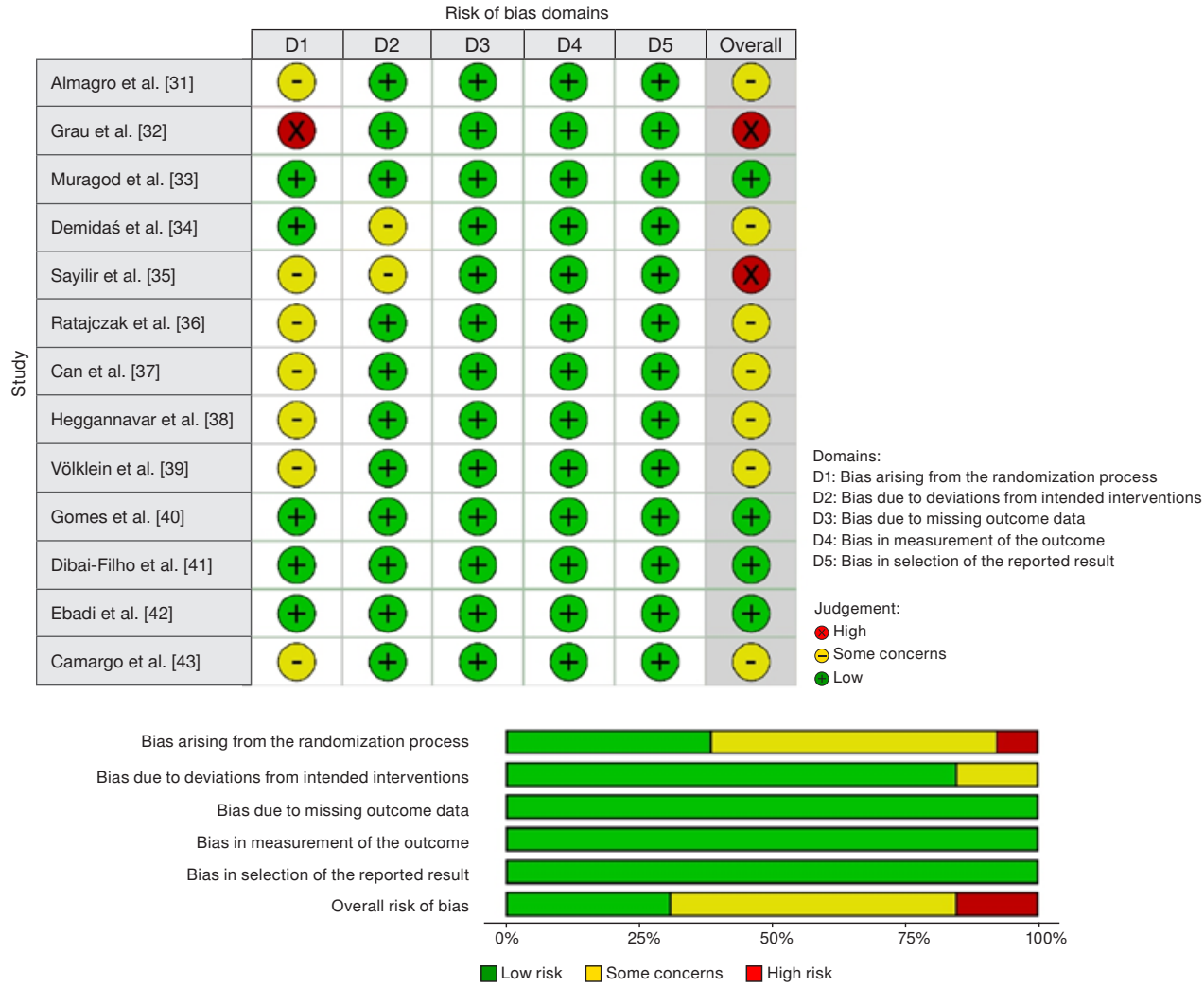



Figure 1. Flowchart of the included studies in the review in accordance with the PRISMA 2009 guidelines




Trials involving two or more high risks of bias were considered of poor methodological quality [58, 61, 62].

Figure 2. Studies included in the review assessed with the Cochrane risk of bias tool, RoB.2, and graphed with the Robvis tool [58, 61, 62]

## Study characteristics

Table 2 (see end of paper) summarises the characteristics of the selected RCT, as well as the primary and secondary outcomes of interest. It is observed that six articles (46.15%) report the DDC application for joint conditions, highlighting temporomandibular joint pain (TMJ) ($n$ = 2) [31, 32], lumbar discopathy (LD) ($n$ = 1) [36], patellofemoral pain syndrome (PFPS) ($n$ = 1) [37], shoulder impingement syndrome (SIS) ($n$ = 1) [40], and knee osteoarthritis (OA) and low back pain syndrome (LBPS) in the same article ($n$ = 1) [39]. On the other hand, six studies (46.15%) describe applying DDC in soft tissue conditions such as dysmenorrhoea ($n$ = 1) [33], nonspecific chronic low back pain ($n$ = 3) [35, 39, 42], heel pain ($n$ = 1) [38] and cervical myofascial trigger points (MTrPs) ($n$ = 1) [41], while two studies (15.38%) reported using DDC in experimentally induced MSP (EIMSP) in the hand and forearm [34, 43].

It is observed that seven studies (53.84%) used DDC in experimental groups (EG) without another added treatment [31, 33, 34, 36, 40, 42, 43], while seven articles applied DDC combined with another intervention [32, 35, 37–41]. The most used DDC included DF ($n$ = 11, 84.61%) [31–37, 39–41, 43] and LP ($n$ = 11, 84.61%) [31, 32, 34–40, 42, 43], followed by CP ($n$ = 10, 76.91%) [31, 32, 34–36, 39–43]. On the other hand, MF reported the lowest use ($n$ = 5, 38.46%) [34, 36, 37, 3, 43], while one study applied the combination of different modalities of DDC (MF, DF, LP and CP) combined with a galvanic current base ($n$ = 1, 7.69%) [39]. Furthermore, it should be noted that RS current was not used in any article.

Complementary treatments for EG included the use of therapeutic ultrasound (US) ($n$ = 3, 23.07%) [32, 35, 38], manual therapy (positional release, ischemic pressure technique and joint distractions) ($n$ = 2, 15.38%) [40, 41], flexibility and therapeutic exercises ($n$ = 2, 15.38%) [37, 38], and hot packs ($n$ = 1, 7.69%) [35]. In contrast, for the control groups (CG), treatments with physical resources are mostly reported ($n$ = 9, 69.23%), highlighting the use of TENS [33–37, 42], US [35, 38, 41], direct current (DC) [31], HCC [35] and transcutaneous electrical stimulation with microcurrents (MENS) [38]. In a few studies, the use of therapeutic and relaxation exercises ($n$ = 2, 15.28%) [37, 38], and manual therapy ($n$ = 2, 15.28%) [40, 41] stand out for controls. Furthermore, it is noteworthy that none of the articles report the use of medications for the groups.

Regarding the treatment sessions, an average of 10 sessions is observed, with at least one session in the studies by Ebadi et al. [42] and Camargo et al. [43], and a maximum of 30 for Can et al. [37]. It should be noted that in most of the studies ($n$ = 10, 76.92%), the sessions were on continuous days and carried out over a period of two weeks [31–33,

Table 1. PEDro scale score of the analysed studies [55, 57]

| Clinical trial number | Author, year of publication | PEDro scale criteria | | | | | | | | | | | Total score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1* | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
| 1 | Almagro et al. [31] | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 6/10 |
| 2 | Grau et al. [32] | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 5/10 |
| 3 | Muragod et al. [33] | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 9/10 |
| 4 | Demidaś and Zarzycki [34] | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 7/10 |
| 5 | Sayilir and Yildizgoren [35] | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 5/10 |
| 6 | Ratajczak et al. [36] | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4/10 |
| 7 | Can et al. [37] | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 6/10 |
| 8 | Heggannavar et al. [38] | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 6/10 |
| 9 | Völklein and Callies [39] | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 5/10 |
| 10 | Gomes et al. [40] | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 7/10 |
| 11 | Dibai-Filho et al. [41] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 8/10 |
| 12 | Ebadi et al. [42] | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 9/10 |
| 13 | Camargo et al. [43] | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 9/10 |

PEDro (Physiotherapy Evidence Database) scale criteria:
(1) The selection criteria were specified.
(2) Subjects were randomised into groups (in a crossover study, subjects were randomised as they received treatments).
(3) The assignment was hidden.
(4) The groups were similar at the beginning in relation to the most important prognostic indicators.
(5) All subjects were blinded.
(6) All therapists who administered the therapy were blinded.
(7) All assessors who measured at least one key outcome were blinded.
(8) Measures of at least one of the key outcomes were obtained from more than 85% of the subjects initially assigned to the groups.
(9) Results were presented for all subjects who received treatment or were assigned to the control group, or, when this could not be the case, data for at least one key outcome were analysed by 'intention to treat'.
(10) Results of statistical comparisons between groups were reported for at least one key outcome.
(11) The study provides point and variability measures for at least one key outcome.

* Criterion 1 does not go into the final score because it only affects the clinical trial's external validity, not its internal validity.

35–39, 42,43], while Demidaś and Zarzycki [34], Gomes et al. [40] and Dibai-Filho et al. [41] used interval treatments 2–3 times a week for 3–5 weeks.

This review shows that most of the studies carried out two evaluation sessions, that is, before and after treatment (T0 and T1) ($n$ = 6, 46.15%) [33, 35, 36–38, 40], while three studies reported three evaluative instances (T0–T2) ($n$ = 3, 23.07%) [31, 32, 34] and another three reported four (T0–T3) ($n$ = 3, 23.07%) [39, 41, 42]. On the other hand, the study by Camargo et al. [43] stands out, which carried out a total of five evaluation sessions (T0–T4), although all of them were on the same day, recording changes before application, during and post-treatment [43]. It is observed that the first evaluation was more frequent in session five [31–33, 39], while the second evaluation was carried out in session 10 [31–32, 39].

## Main outcome

Pain intensity was assessed in all articles in this SR. It is observed that the visual analog scale (VAS) was the most used instrument ($n$ = 8, 61.53%) [31–33, 35–38, 42] followed by the painful pressure threshold (PPT) assessed through algometry ($n$ = 3.23.07%) [34, 42, 43]. Additionally, Demidaś and Zarzycki [34] used algometry to assess pressure pain tolerance in participants with EIMSP. On the other hand, Gomes et al. [40] and Dibai-Filho et al. [41] used the numeric pain rating scale (NRS) to assess pain at rest and movement in SIS and cervical MTrPs, respectively [40, 41]. In addition, two articles are highlighted that report the assessment of pain through the present pain index (PPI; part IV of the McGill questionnaire, MPQ) to assess TMJ pain [31, 32], and one study documents the full use of MPQ in patients with dysmenorrhoea [33]. On the other hand, Gomes et al. [40] reported the use of the first section of the Shoulder Pain and Disability Index (SPADI) to assess pain intensity in patients with SIS. Only Völklein and Callies [39] carried out the pain assessment through a verbal consultation with the participants regarding the decrease of pain during and at the end of the treatment period (dichotomous verbal response). Six of the studies show a decrease in pain at rest for VAS for both groups in relation to the initial evaluation (T0) and the follow-up sessions (T1, T2 and T3), with the change being greater in favour of EG with statistically significant differences ($p < 0.05$) [31–33, 36–38]. On the other hand, the studies by Sayilir and Yildizgoren [35] and Camargo et al. [43] reported analgesia for VAS in both groups, although without significant differences between them, while Ebadi et al. [42] documented a decrease in pain, but with statistical significance in favour of CG. On the other hand, Demidaś and Zarzycki [34] and Camargo et al. [43] use algometry to assess pain intensity, showing an increase in the response to PPT in both groups, although without statistical differences between them. Furthermore, in the study by Ebadi et al. [42], the PPT shows a significant increase in favour of the CG that received only the application of TENS. Studies that used NRS show a decrease in pain intensity in favour of EG with statistically significant differences [40, 41], although

Gomes et al. [40] reported that the greatest reduction was achieved using DDC in conjunction with manual therapy.

Regarding PPI, Almagro et al. [31], and Grau et al. [32] report a statistically significant reduction in pain in favour of EG for evaluation sessions (T1 and T2). On the other hand, Muragod et al. [33] report a pain decrease for MPQ for EG with statistical significance ($p < 0.05$) [33], while Gomes et al. [40] obtained pain reduction with statistical significance for the first section of SPADI.

### Secondary outcomes

Secondary outcomes for this review included measurement of functionality/disability [35–37, 40, 41], range of motion (ROM) [35, 36, 41], touch sensitivity [34], stress and anxiety [42], discomfort to electrical current during stimulation [43], skin temperature, and electromyographic activity [41]. The assessment of functionality/disability in participants with LBPS was carried out using the Lequesne algofunctional index [36], the Roland-Morris questionnaire (RDQ) and the Oswestry Disability Index (ODI) [35], while for knee conditions, the standardised Lysholm scale (LKS) and the four levels activity test were used [37]. The results show a disability reduction via the RDQ and ODI for participants of both groups, although without statistical significance between them ($p > 0.05$) [35]. On the other hand, the Lequesne algofunctional index reports a statistically significant improvement in functionality in the EG compared with CG that did not receive treatment ($p < 0.05$), but not with the CG that was treated with TENS [36]. The results show an improvement in functionality for the LKS and the four-level activity test in participants with PFPS treated with DDC, although only with statistical significance for the four-level test ($p < 0.05$) [37].

On the other hand, in participants with heel pain, the pain disability index (PDI) and foot disability index (FDI) were used [38], while in participants with SIS, the SPADI was used to assess functionality [40]. In addition, the cervical disability index (NDI) was used in trapezius MTrPs [41]. The results show a disability reduction for both PDI and FDI in the EG, although only with statistical significance for FDI ($p < 0.007$) [38]. On the other hand, the SPADI shows a decrease in disability in the groups treated with DDC, although only with statistical significance when the currents are combined with manual therapy ($p < 0.05$) [40]. For NDI, a reduction in disability is observed for all study groups without statistically significant differences between them ($p > 0.05$) [41].

ROM assessment was performed in participants with SDL through the Schober test and finger-to-ground distance test (FFD) [35]. In addition, fleximetry (inclinometer) was used in participants with cervical MTrPs [41]. On the other hand, Ratajczak et al. [36] describe the spinal ROM assessment without detailing the instrumentation used [36]. The results show an improvement in ROM for the Schober and FFD tests when the groups were analysed independently and compared, although without significant differences ($p = 0.323$; $p = 0.805$) [35]. Fleximetry shows an improvement in both groups, although only with statistically significant changes in favour of EG for the second evaluation (T2 = 5 weeks) ($p < 0.05$) [41].

The secondary outcomes of stress and anxiety in patients with LPS [42], and skin temperature and electromyographic activity (EMG) in participants with MTrPs [41] were assessed using the depression stress and anxiety scale (DAAS) [42], and thermography and electromyography, respectively [41]. For thermography, a greater increase in temperature at the MTrPs level was registered for participants treated with CDD and manual therapy, although without statistical significance ($p > 0.05$), while for EMG, no differences are reported between the groups after the evaluation sessions. On the other hand, it should be noted that the results for changes in stress and anxiety were not reported [42]. Finally, the study by Demidaś and Zarzycki [34] is highlighted, which incorporates the assessment of skin sensitivity through esthesiometry in participants with EIMSP, showing a statistically significant increase in sensitivity for both groups ($p < 0.0001$).

Despite not having been considered a secondary outcome for this SR, the study by Camargo et al. [43] assessed the discomfort to the DDC during stimulation with VAS. The results show that the most uncomfortable current was the MF, while the DF, CP and LP were better tolerated by participants, although with statistical significance only for the CP current ($p = 0.021$).

### Characteristics and dosage of DDC

Table 3 (see end of paper) summarises the DDC characteristics used in the studies. It is observed that all studies report the current intensity at a sensory level (electrical paresthaesia), although two studies also applied DDC at the motor stimulation level (muscle contraction induced electrically) as a treatment for myofascial pain [40, 41]. Intensity was only reported by Ratajczak et al. [36] and Völklein and Callies [39], highlighting an average value of 19.6 milliamps (mA), while in those studies that applied DDC at the motor level, intensity was not documented. On the other hand, studies report varied treatment times that fluctuate between 3 and 20 minutes [33, 39], with an average of 10 minutes, with 6 to 10 minutes being the most frequent [31, 32, 34, 36, 37, 39, 41, 42]. Table 3 shows the current dose (mA.min) determined only for those studies in which the intensity was reported, obtaining an average value of 75.9 mA.min [36, 39].

Table 3 indicates mostly DDC applications with carbon rubber electrodes ($n = 6$, 46.15%) [34–37, 39, 42], followed by self-adhesive electrodes ($n = 2$, 15.38%) [31, 31] and aluminium electrodes ($n = 1$, 7.69%) [42]. Four studies did not report the type of electrodes used [33, 38, 40, 41]. Furthermore, most studies applied DDC in a bipolar modality (2 electrodes locally) ($n = 9$, 69.23%) [33–39, 42, 43], while 4 studies applied currents in a monopolar application in participants with TMJ pain ($n = 2$) [31, 32], shoulder impingement ($n = 1$) [40], and cervical MTrPs [41].

## Discussion

The purpose of this SR was to investigate the scientific evidence on the effectiveness of DDC as a treatment for MSP. The results suggest that DDC may be a therapeutic option to reduce pain and improve functionality for different musculoskeletal disorders (MSD).

The low risk of bias obtained in 11 studies (84.61%) is highlighted [61, 62], as well as the good internal validity for 12 articles (92.30%) after analysis with the PEDro scale [55, 56], thereby supporting the methodology and results of the studies analysed. The review shows treatments for joint pain conditions (TMJ pain, LBPS, PFPS, SPSA, OA and gonarthrosis) and soft tissues (dysmenorrhoea, heel pain and cervical MTrPs) that affect the spine, extremities, and head/neck, showing various therapeutic applications for DDC. The review shows that DDC are effective for TMJ pain management, dysmenorrhoea pain, LBPS, knee OA and EIMSP when used without the combination of another intervention, demonstrating greater effectiveness than DC, MENS and TENS in pain reduction [31, 32, 34, 38, 39, 42]. Considering these re-

sults, the combined use of LP and DF currents, or LP, DF and MF, is suggestive. These combinations may be more efficient due to the mixture of galvanic and sensitive effects (modulated to a greater or lesser extent) for each type of current and that are not achieved with DC, MENS or TENS [30, 44–49].

Despite exhibiting good analgesic results in the treatment of LBPS, the effectiveness of DDC was lower compared to TENS [36]. This may be explained by the unidirectionality and greater galvanic component of DDC, which limits their depth due to the greater capacitance exhibited by the tissues, unlike TENS (bidirectional and pulsed current). Given the above, it is likely that TENS generates a more profound analgesic effect when applied to the lumbar spine [44, 49, 63, 64]. It should be considered that the biological effects of currents with a galvanic component greater than 50% reach maximum depths of 4 or 5 cm, which is dependent on the application time and current density under the electrode ($mA/cm^2$). This could affect the depth of DF and LP currents, whose modulated galvanic components are in the order of 66% [44, 63, 64].

Studies that describe pure DDC applications in EG preferably document bipolar installations at a sensitive intensity, except for that reported by Urrutia (1998), who treated TMJ pain with a monopolar application [31]. The analgesic efficacy in favour of bipolar applications supports the premise of central analgesic mechanisms such as endogenous opioid peptides and/or activation of Melzack's gate control theory by stimulation of low-threshold mechanoreceptors (Aβ fibres) [45–48, 65, 66]. On the other hand, a monopolar application is reported by Urrutia, using the anode on the TMJ supporting the galvanic analgesic effects given by the hyperpolarisation of nociceptive neurons through the positive pole [36, 44, 49, 63]. Even though Völklein and Callies [39] report a bipolar application in participants with gonarthrosis, it should be noted that this study used all DDC modalities with galvanic basis, placing the anode at the site of pain, which reinforces a reduction in pain mediated by polar effects. This review shows a greater analgesic effect in favour of CG when LP and CP currents were compared with TENS in the management of LBPS in only one study. Likewise, it should be noted that it was a single session of 10 minutes, which suggests that more sessions and a longer treatment time may be necessary, especially if it is considered that the average number of sessions for the articles was on the order of 10 [42].

This review further supports the analgesic efficacy of DDC in TMJ pain, LBPS, heel pain, PFPS, and SIS when these currents are applied in conjunction with other treatments [32, 35, 37, 38, 40]. The studies mostly report the combination with US, which supports the joint application of both treatments for the reduction of TMJ pain, heel pain and LBP. The LP current was the most used, so it is suggestive that the combination of it with US is determined to be the most effective [32, 35, 38]. US was used in all the studies in pulsed modality at 1 MHz and a treatment time of 5 minutes, with an intensity of 1 $W/cm^2$ as the maximum, and without detailing the effective radiation areas (ERA). Although the analgesic mechanisms of US are not entirely clear, its use for muscle spasm and pain reduction in MTrPs has been supported, which, combined with the galvanic effects of LP currents, would favour vasodilation by inducing relaxation of the masticatory, paravertebral and plantar muscles in the treated conditions [32, 35, 38, 67–69]. Furthermore, the depth of US is favoured by skin electroporation and blood flow increase produced by the galvanic effects of LP [44, 63, 70].

It is observed that the combination of DDC (sensory threshold of stimulation) with therapeutic exercises is effective for heel pain and PFPS management, showing a greater analgesic effect than TENS and MENS combined with the same exercises. This makes CDD a good therapeutic adjunct to perform knee and foot exercises with less pain [37, 38]. Both studies coincide in the application of LP, so this modality is suggestive if it is intended to combine DDC with exercises. The galvanic effects of DF and sensitive effects of MF give LP currents the properties to promote flexibility and analgesia through galvanism and activation of A-beta fibres [37, 38, 44, 63, 65]. On the other hand, Gomes et al. [40] and Dibai-Filho et al. [41] report that the combination of DDC at the sensory level (DF and LP) and motor (CP) plus manual therapy (ischemic pressure and joint distraction) is effective in reducing MTrPs pain [40], as well as neck pain on movement [41]. Analgesia in these cases could be based on circulatory changes induced by the polar effects of DF and LP, or by muscle activation with CP. Likewise, a monopolar application is suggested when treating MTrPs, considering that both studies support this installation [40, 41]. It is highlighted that the interventions in CG (CD, TENS, US, HCC, therapeutic exercises, MENS and manual therapy) also showed a reduction in pain, which also makes it possible to consider these resources as a therapeutic alternative when not using DDC to treat MSP conditions [31, 33–42]. This further upholds the ethical principle of beneficence for the studies because the authors provided effective treatments to all participants regardless of the results obtained with the DDC [71].

This review highlights VAS and algometry as the main instruments to assess pain [31–38, 42, 43]. This improves the quality of the results obtained, given the evidence that validates both instruments (algometry: test-retest reliability of 0.81 to 0.99; VAS: test-retest reliability of 0.97) [72–75]. In addition, the versatility of the Camargo et al. [43] study in adapting VAS to assess current discomfort during stimulation is highlighted [43], which is interesting as it broadens the possibilities of the instrument to measure pain during treatment. Given the evidence that supports both instruments, the use of any of these is supported in new studies to objectify changes in pain.

Secondly, there is the NRS used to assess pain at rest and movement in patients with SIS and neck pain [40, 41], which is also validated (test-retest reliability of 0.95) [72, 76]. The movement pain assessment is interesting because it has a more functional nature.

Two studies stand out for their use of MPQ [31–33], an instrument to assess pain in other dimensions that are not always considered due to their qualitative nature and more difficult objectivation (sensory, affective/motivational, and cognitive dimensions). Likewise, the literature validates the MPQ questionnaire in both its long and abbreviated versions as an instrument to assess pain in MSP conditions (test-retest reliability 0.81) [77, 78]. On the other hand, only one study reports pain assessment through verbal questioning during and after treatment, an assessment that could be questioned due to its subjectivity [39]. However, the review shows a reduction in pain in participants treated with CDD for all reported measurement instruments, regardless of their nature.

This review shows that most of the articles report secondary outcomes ($n$ = 9, 69.23%), which adds significant value given the other therapeutic effects (direct or indirect) for DDC [33–38, 40–41]. The main secondary outcome reported was functionality/disability, assessed with the RDQ [35], ODI [35], Lequense functional index [36], LKS [37], FADI [38], SPADI [40] and NDI [41]. After reviewing the validation of these instruments, their psychometric properties stand out (RDQ, test-retest reliability of 0.81 [79]; ODI, test-retest reli-

ability of 0.83 to 0.99 and internal consistency $\alpha$ = 0.71 to 0.87 [80]; index of Lequense, test-retest reliability of 0.94 and internal consistency $\alpha$ = 0.84 [81, 82]; LKS, test-retest reliability of 0.91 and internal consistency $\alpha$ = 0.65 [83]; SPADI, test-retest reliability > 0.89 and internal consistency $\alpha$ = 0.90 [84, 85]; NDI, test-retest reliability from 0.50 to 0.98 and internal consistency $\alpha$ = 0.85 [86, 87]; FADI, test-retest reliability from 0.84 to 0.89 [88]) which supports stable, safe and congruent results for the assessment of functionality/disability. The studies show an improvement in functionality (decrease in disability) for EG, which supports the effectiveness of DDC in MSP such as LBP, PFPS, heel pain, SIS and neck pain [35, 36, 38, 40, 41]. Although it is complex to explain a direct effect of DDC on the improvement of functionality, its positive effects would be indirect and could be supported by the interruption of the 'pain-fear-disability' circle, demonstrating the close relationship between MSP and different psychological factors that affect the person's functionality [89, 90]. The interruption of this circuit could be due to local analgesic mechanisms, such as the activation of gate theory and the galvanic effects, as well as the release of endogenous opioids, which would play an analgesic role and positive regulation of stress, emotions, and cognition to combat pain (neuromatrix theory of pain) [45, 46, 48, 91–92]. It is suggested for future studies to maintain the evaluation of functionality through these questionnaires or tests, taking advantage of the evidence that validates them for different body regions [35, 36, 38, 40, 41].

Other secondary outcomes included ROM, dysmenorrhoea distress, stress, and anxiety, measured through goniometry and questionnaires (MDQ and DAAS) [33, 35, 36, 42]. The literature reports good reliability for both questionnaires (MDQ, test-retest reliability 0.62 to 0.76 and internal consistency r = 0.93 for the Split-Half method [79]; DAAS, internal consistency $\alpha$ = 0.7 to 0.88 [93]), which validates the results in these studies. The study by Muragod et al. [33] is interesting when considering the management of menstrual pain with different electrotherapy alternatives, showing positive analgesic effects for both DDC and TENS. Although dysmenorrhoea could not be considered as an MSD, it was decided to include it in the review because this condition is a source of referred pain at the pelvic and lumbar level. This broadens the therapeutic possibilities of electrotherapy in other clinical conditions [94]. On the other hand, the study by Ebadi et al. [42] measured changes in stress and anxiety (with DAAS) in participants with LBP treated with electroanalgesia. It is interesting when considering the emotional factors that accompany MSP and that affect functionality [89, 90]. However, the authors did not report changes in DAAS after treatment or the reasons for not reporting their findings [42]. On the other hand, the ROM is examined and reported through the Schober test and fleximetry in patients with lumbar and cervical pain, respectively [35, 41]. The Schober test is highlighted as an alternative to assess the spinal ROM, given its psychometric properties (concurrent validity *r* = 0.9 when compared with radiographs, and test-retest reliability 0.86 to 0.90), so its use is suggested for other studies that include the assessment of lumbar mobility [95].

The review shows an average of 10 sessions for most studies, developed between 3 and 5 weeks, achieving analgesia and improvements in secondary outcomes. This supports the idea that a minimum number of sessions is necessary if changes are to be achieved through DDC.

Although the results support the efficacy and effectiveness of DDC, one of the main limitations lies in the diversity of dosages used and not clearly reporting the current densities to establish suggestive doses. However, from the analysis of the methodologies and parameters, the following recommendation can be established; combined DDC applications (LP and DF, or LP, DF and MF) or preferably choosing the LP current, intensity at a sensory level, 10 minutes of treatment and bipolar applications. For bipolar applications, using the anode for analgesic purposes and the cathode in the treated region should be considered for the purposes of hyperaemia. It is suggested to consider these parameters in clinical practice and in the development of new trials.

## Conclusions

Electrotherapy currently offers different analgesic modalities for the management of various MSD. Among these modalities, DDC stands out, with currents characterised by their analgesic effects by combining the properties of galvanism with the sensitive electrical stimulation effects, which gives them analgesic properties that differentiate them from the rest of the electrical currents.

This SR indicates that DDC are effective in reducing pain and improving the functionality of various MSP conditions both in the short and long term, showing comparative advantages over other physical agents such as TENS, MENS, DC and US. However, despite the good results, its application is suggested in conjunction with exercises or other physical therapy strategies that tend to restore functionality as a general objective. Similarly, new challenges may include evaluating the efficacy of DDC in other MSD not reported by this review and comparing their effectiveness with other modalities of physical agents.

It should be noted that this review allowed the researchers to establish dosage recommendations based on those reported in the articles, which can be reviewed and used for new research or clinical practice.

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Table 2. Characteristics of the included studies

| Clinical trial number | Author, year, country | Study | Musculoskeletal condition | Type of study | Sample size (*n*) males females age (years) | EG and CG | Intervention | Treatment time | DDC sessions | Evaluation time | Outcomes (measuring instrument) | Conclusions |
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| 1 | Almagro et al. 1998 [31] Cuba | Diadynamic and galvanic currents in the treatment of temporomandibular dysfunction | TMJ pain | RCT | *n* = 30 (NS by sex) age: 16–70 | EG = 15<br>CG = 15 | EG: DDC (DF, CP and LP)<br>CG: DC | DF: 1 minutes<br>CP: 2 minutes<br>LP: 3 minutes<br>All modalities are applied in the same session for all sessions<br>Total treatment time: 6 minutes | 10 sessions (daily sessions in 10 days) | T0: baseline (before treatment)<br>T1: session 5<br>T2: session 10 | Primary outcome: pain intensity (VAS) pain intensity (PPI) | Pain intensity (VAS):<br>EG: T2* < T1* < T0<br>CG: T2* < T1* < T0<br>EG < CG at T1*<br>EG = CG at T2<br>Pain intensity (PPI):<br>EG: T2* < T1* < T0<br>CG: T2* < T1* < T0<br>EG < GC at T1*<br>GE = GC at T2 |
| 2 | Grau et al. 1998 [32] Cuba | Diadynamic currents and ultrasound in the treatment of temporomandibular dysfunction | TMJ pain | RCT | *n* = 20 (NS by sex) age: 23–54 | EG = 20 | EG: US (0.5 W/cm$^2$ – 1 W/cm$^2$ – 5 minutes) + DDC (DF, CP and LP) | DF: 1 minutes<br>CP: 2 minutes<br>LP: 3 minutes<br>All modalities are applied in the same session for all sessions<br>Total treatment time: 6 minutes | 10 sessions (daily sessions in 10 days) | T0: baseline (before treatment)<br>T1: session 5<br>T2: session 10 | Primary outcome: pain intensity (VAS) pain intensity (PPI) | Pain intensity (VAS):<br>EG: T2* < T1* < T0<br>Pain intensity (PID):<br>EG: T2* < T1* < T0 |
| 3 | Muragod et al. 2007 [33] India | Effectiveness of transcutaneous electrical nerve stimulation and diadynamic current on primary dysmenorrhoea: a randomised clinical trial | Dysmenorrhoea | RCT | *n* = 32<br>males = 0 (0%)<br>females = 32 (100%)<br>age: 18–25 | EG = 16 (16 females)<br>CG = 16 (16 females) | EG: DDC (DF)<br>CG: TENS | DF: 20 minutes | 5 sessions (1 session daily)<br>Total treatment 1 week | T0: baseline (before treatment)<br>T1: session 5 | Primary outcome: pain intensity (VAS) pain intensity (MPQ)<br>Secondary outcome: dysmenorrhoea distress (MDQ) | Pain intensity (VAS):<br>EG: T1* < T0<br>CG: T1* < T0<br>EG < CG at T1*<br>Pain intensity (MPQ):<br>EG: T1* < T0<br>CG: T1* < T0<br>EG < CG at T1*<br>Dysmenorrhoea distress (MDQ):<br>GE: T1* < T0<br>GC: T1 < T0<br>GE < GC at T1* |
| 4 | Demidaś and Zarzycki 2019 [34] Poland | Touch and pain sensations in diadynamic current (DD) and transcutaneous electrical nerve stimulation (TENS): a randomised study | Experimentally induced musculoskeletal pain (EIMSP) | RCT | *n* = 40<br>males = 3 (7.5%)<br>females = 37 (92.5%)<br>age: 20–25 | EG = 20 (19 females, 1 male)<br>CG = 20 (18 females, 2 males) | EG: DDC (DF, MF, LP and CP)<br>CG: TENS | DF: 2 minutes<br>MF: 3 minutes<br>LP: 3 minutes<br>CP: 2 minutes<br>All modalities are applied in the same session for all sessions<br>Total treatment time: 10 minutes | 3 sessions (once a week)<br>Total treatment 3 weeks | T0: baseline (before treatment)<br>T1: immediately after each session<br>T2: 30 minutes after each session<br>T0, T1 and T2 were evaluated for each week (weeks 1, 2 and 3) | Primary result: PPT (AL) PPTL (AL)<br>Secondary results: touch sensitivity (ES) | PPT (AL):<br>EG: T2* < T1 < T0<br>CG: T2* < T1 < T0<br>EG = CG in T1 and T2, for week 1, 2 and 3<br>PPTL (AL):<br>EG: T2* < T1 < T0<br>CG: T2* < T1 < T0<br>EG = CG in T1 and T2, for week 1, 2 and 3<br>Touch sensitivity (ES):<br>EG: T2* > T1 > T0<br>CG: T2* > T1 > T0<br>EG = CG at T1 and T2 for weeks 1 and 2 |

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| 5 | Sayilir and Yildizgoren 2017 [35] Turkey | The medium-term effects of diadynamic currents in chronic low back pain<br>TENS versus diadynamic currents: a randomised, follow-up study | Low back pain (LBP) | RCT | *n* = 44<br>males = 12 (27.3%)<br>females = 32 (72.7%)<br>age:<br>29–63 | EG = 24<br>(15 females, 9 males)<br>CG = 20<br>(17 females, 3 males) | EG: DDC (DF, CP and LP) + hot packs +<br>US CG: TENS + hot packs + US | DF: 2 minutes<br>CP: 3 minutes<br>LP: 3 minutes<br>All modalities are applied in the same session for all sessions<br>Total treatment time: 8 minutes | 10 sessions (5 sessions per week)<br>Total treatment 2 weeks | T0: baseline (before treatment)<br>T1: 4 weeks (at end of treatment) | Primary outcome:<br>Pain intensity at rest (VAS).<br>Pain intensity in activity (VAS).<br>Secondary outcomes:<br>Trunk flexion (Schober test, FFD)<br>Physical disability (RDQ, ODI) | Pain intensity at rest (VAS):<br>EG: T1* < T0<br>CG: T1* < T0<br>EG = GC at T1 < T0<br>Pain intensity on activity (VAS):<br>EG: T1* < T0<br>CG: T1* < T0<br>EG = GC at T1 < T0<br>Trunk flexion (Schober test):<br>EG: T1 > T0<br>CG: T1 > T0<br>EG = GC at T1<br>Trunk flexion (FFD):<br>EG: T1 < T0<br>CG: T1 < T0<br>EG = GC at T1<br>Disability (RDQ):<br>EG: T1* < T0<br>CG: T1* < T0<br>EG = CG at T1<br>Disability (ODI):<br>EG: T1* < T0<br>CG: T1* < T0<br>EG = CG at T1 |
| 6 | Ratajczak et al. 2011 [36] Poland | Effectiveness of diadynamic currents and transcutaneous electrical nerve stimulation in disc disease lumbar part of spine | Lumbar nucleus pulposus hernia | RCT | *n* = 120<br>males = 39 (32.5%)<br>females = 81 (67.5%)<br>age: 40–60 | EG = 40<br>(30 females, 10 males)<br>CG 1 = 40<br>(27 females, 13 males)<br>CG 2 = 40<br>(24 females, 16 males) | EG: DDC (DF, MF, LP and CP)<br>CG 1: TENS<br>CG 2: non-intervention | DF: 2 minutes<br>MF: 3 minutes<br>LP: 3 minutes<br>CP: 2 minutes<br>All modalities are applied in the same session for all sessions<br>Total treatment time: 10 minutes | 11 sessions (5 sessions per week)<br>Total treatment 2 weeks | T0: baseline (before treatment)<br>T1: 2 weeks (at end of treatment) | Primary outcome:<br>Pain intensity (VAS)<br>Secondary outcomes:<br>lumbar spine ROM (does not report measurement instrument)<br>functional fitness (Lequesne functional index) | Pain intensity (VAS):<br>EG: T1* < T0<br>CG 1: T1* < T0<br>CG 2: T1 = T0<br>EG = CG 1 at T1<br>EG < CG 2 at T1*<br>Range of motion:<br>not reported<br>Functional fitness (Lequesne index):<br>EG: T1* < T0<br>CG 1: T1* < T0<br>CG 2: T1 = T0<br>EG = CG 1 at T1<br>EG < CG 2 at T1* |

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| 7 | Can et al. 2003 [37]<br>Turkey | Rehabilitation of patellofemoral pain syndrome: TENS versus diadynamic current therapy for pain relief | Patellofemoral pain syndrome (PFPS) | RCT | *n* = 30<br>males = 8 (26.7%)<br>females = 22 (73.3%)<br>age: 18–56 | EG = 14 (11 females, 3 males)<br>CG = 16 (11 females, 5 males) | EG: DDC (MF, DF and LP) + therapeutic exercises (isometric exercises, isotonic CCE and OCE exercises, and stretching exercises)<br>CG: TENS + therapeutic exercises (isometric exercises, isotonic CCE and OCE exercises, and stretching exercises) | MF: 1 minute<br>DF: 2 minutes<br>LP: 3 to 4 minutes<br>All modalities are applied in the same session for all sessions<br>Total treatment time: 7 minutes | 24 to 30 sessions (4 to 5 weekly sessions)<br>Total treatment 6 weeks | T0: baseline (before treatment)<br>T1: 6 weeks (at end of treatment) | Primary outcome: Pain intensity (VAS)<br>Secondary outcomes: knee function (LKS) activity level (4-level activity test) | Pain intensity (VAS):<br>EG: T1* < T0<br>CG: T1 < T0<br>GE < GC at T1*<br>Knee function (LKS):<br>EG: T1* < T0<br>CG: T1 < T0<br>EG > CG at T1<br>Activity level (four-level activity test):<br>EG: T1* < T0<br>CG: T1 < T0<br>EG > CG at T1* |
| 8 | Heggannavar et al. 2015 [38]<br>India | Effectiveness of diadynamic current and MENS in heel pain: a randomised clinical trial | Heel pain | RCT | *n* = 30<br>males = 4 (13.4%)<br>females = 26 (86.6%)<br>age: 18–45 | EG = 15 (13 females, 2 males)<br>CG = 15 (13 females, 2 males) | EG: DDC (LP) + US + stretching + therapeutic<br>GC: MENS + US + stretching + therapeutic | LP: 12 minutes<br>Total treatment time: 12 minutes | 7 sessions<br>Total treatment 1 week | T0: baseline (before treatment)<br>T1: 1 week (at end of treatment) | Primary outcome: Pain intensity (VAS)<br>Secondary outcomes: disability (PDI) foot disability (FADI) | Pain intensity (VAS):<br>EG: T1* < T0<br>CG: T1 < T0<br>EG < CG at T1*<br>Disability (PDI):<br>EG: T1 < T0<br>CG: T1 < T0<br>EG < CG at T1<br>Foot Disability (FDI):<br>EG: T1* < T0<br>CG: T1 < T0<br>EG < CG at T1* |
| 9 | Völklein and Callies 1990 [39]<br>Germany | Change in pain due to different current forms of diadynamic currents in gonarthrosis and lumbar syndrome | Gonarthrosis and lumbar pain syndrome | RCT | *n* = 200<br>(NS by sex)<br>age: NS | EG 1 = 25<br>EG 2 = 25<br>EG 3 = 25<br>EG 4 = 25<br>EG 5 = 25<br>EG 6 = 25<br>EG 7 = 25<br>EG 8 = 25<br>G1-G4 participants with knee OA<br>G5–G8 participants with LBPS | EG 1: DDC (MF + galvanic base)<br>EG 2: DDC (DF + galvanic base)<br>EG 3: DDC (CP + galvanic base)<br>EG 4: DDC (LP + galvanic base)<br>EG 5: DDC (MF + galvanic base)<br>EG 6: DDC (DF + galvanic base)<br>EG 7: DDC (CP + galvanic base)<br>EG 8: DDC (LP + galvanic base) | MF + galvanic base: 3, 6 or 9 minutes (depending on baseline pain)<br>DF + galvanic base: 3, 6 or 9 minutes (depending on baseline pain)<br>CP: 3, 6 or 9 minutes (according to baseline pain)<br>LP: 3, 6 or 9 minutes (according to baseline pain)<br>Treatment time depended on the participant's baseline pain (subjective assessment; minimum, medium, or maximum) | 15 sessions (5 sessions per week)<br>Total treatment 3 weeks | T0: baseline (before treatment)<br>T1: week 1 (session 5)<br>T2: week 2 (session 10)<br>T3: week 3 (session 15) (at end of treatment) | Primary outcome: pain intensity (subjective assessment by questioning) | Pain intensity<br>EG 1 = EG 2 = EG 3 = EG 4 at T3* < T2* < T1* < T0<br>EG 5 = EG 6 = EG 7 = EG 8 at T3* < T2* < T1* < T0 |

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| 10 | Gomes et al. 2018 [40]<br>Brazil | Combined use of diadynamic currents and manual therapy on myofascial trigger points in patients with shoulder impingement syndrome | Shoulder impingement | RCT | *n* = 60<br>males = 14 (23.4%)<br>females = 46 (76.6%)<br>age: 18–59 | EG 1 = 20 (16 females and 4 males)<br>EG 2 = 20 (14 females and 6 males)<br>CG = 20 (16 females and 4 males) | EG 1 = DDC (DF, LP and CP) + manual therapy (positional release, ischemic pressure technique)<br>EG 2 = DDC (DF, LP, CP)<br>CG = manual therapy (positional release, ischemic pressure technique) | DF: 4 minutes (sensory stimulation threshold)<br>LP: 4 minutes (sensory stimulation threshold)<br>CP: 4 minutes (motor stimulation threshold)<br>DDC all sessions were applied in that order<br>Total treatment time: 12 minutes | 16 sessions in total (2 sessions per week)<br>Total treatment 8 weeks | T0: baseline (before treatment)<br>T1: 8 weeks (at end of treatment) | Primary outcome: pain intensity (SPADI) pain intensity (NPRS)<br>Secondary outcome: disability (SPADI) | Pain intensity (SPADI)<br>EG 1: T1* < T0<br>EG 2: T1* < T0<br>CG: T1 < T0<br>EG 1 < EG 2 at T1*<br>EG 1 < CG at T1*<br>EG 2 < CG at T1<br>Pain intensity (NRPS)<br>EG 1: T1* < T0<br>EG 2: T1* < T0<br>CG: T1 < T0<br>EG 1 < EG 2 at T1*<br>EG 1 < CG at T1*<br>EG 2 < CG at T1<br>Disability (SPADI)<br>EG 1: T1* < T0<br>EG 2: T1* < T0<br>CG: T1 < T0<br>EG 1 < EG 2 at T1*<br>EG 1 < CG at T1*<br>EG 2 < CG at T1 |
| 11 | Dibai-Filho et al. 2017 [41]<br>Brazil | Additional effect of static ultrasound and diadynamic currents on myofascial trigger points in a manual therapy program for patients with chronic neck pain | Neck pain and MTrPs in the upper trapezius muscle | RCT | *n* = 60<br>males = 6 (10%)<br>females = 54 (90%)<br>age: 18–45 | EG = 20 (18 females and 2 males)<br>CG 1 = 20 (18 females and 2 males)<br>CG 2 = 20 (18 females and 2 males) | EG = DDC (DF and CP) + manual therapy (3 series of 1-minute grade -3 cervical distraction)<br>CG 1 = manual therapy (3 sets of 1 minute of upper trapezius myofascial release, 3 sets of 30 seconds of static stretching, and 3 sets of 1-minute grade -3 cervical distraction) + US (1 MHz -duty cycle 100% – 1.5 W/cm$^2$ – 90 seconds)<br>CG 2 = manual therapy (3 sets of 1 minute of upper trapezius myofascial release, 3 sets of 30 seconds of static stretching, and 3 sets of 1-minute grade -3 cervical distraction) + US (1 MHz –duty cycle 100% – 1.5 W/cm$^2$ – 90 seconds) | DF: 4 minutes (sensory stimulation threshold)<br>CP: 6 minutes (motor stimulation threshold)<br>Both modalities were applied combined all sessions<br>Total treatment time: 10 minutes | 10 sessions in total (2 sessions per week)<br>Total treatment 5 weeks | T0: baseline (before treatment)<br>T1: 1 session<br>T2: 5 weeks (at end of treatment)<br>T3: 9 weeks (4 weeks after treatment) | Primary outcome:<br>Pain intensity at rest (NPRS)<br>Pain intensity on movement (NPRS)<br>Pain intensity (PRSS) PPT(AL)<br>Secondary result:<br>Disability (NDI)<br>Cervical joint range (fleximetry)<br>Skin temperature (thermography)<br>Electromyographic activity (EMG) | Pain intensity at rest (NPRS):<br>EG < CG 1 at T1, T2 and T3<br>EG < CG 2 at T1, T2 and T3<br>Pain intensity on movement (NPRS):<br>EG < GC1 at T1, T2 and T3*<br>EG < CG2 at T1, T2 and T3<br>Pain intensity (PRSS):<br>EG = CG 1 at T1, T2 and T3<br>EG = CG 2 at T1, T2 and T3<br>Painful pressure threshold (pressure algometry):<br>EG > CG 1 at T1, T2 and T3<br>EG > CG 2 at T1, T2 and T3<br>Disability (NDI):<br>EG < CG 1 at T1, T2 and T3<br>EG = CG 2 at T1 and T2, and EG < CG 2 at T3<br>Cervical joint range (fleximetry)<br>EG > CG 1 for T1, T2 and T3<br>EG > CG 2 for T1, T2* and T3<br>Skin temperature (thermography):<br>EG > GC 1 at T1, T2 and T3<br>EG < GC 2 at T1, T2and T3<br>Electromyographic activity (EMG):<br>EG = CG 1 at T0, T1, T2 and T3<br>EG = CG 2 at T0, T1, T2 and T3 |

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| 12 | Ebadi et al. 2018 [42] Iran | No immediate analgesic effect of diadynamic current in patients with nonspecific low back pain in comparison to TENS | Nonspecific chronic low back pain | RCT | *n* = 30<br>males = 15 (50%)<br>females = 15 (50%)<br>age: 18–60 | EG = 15<br>(5 females, 10 males)<br>CG = 15<br>(10 females and 5 males) | EG = DDC<br>(LP and CP)<br>CG = TENS | LP: 5 minutes<br>CP: 5 minutes<br>Both modalities were applied combined all sessions<br>Total treatment time: 10 minutes | 1 session | T0: baseline (before treatment)<br>T1: immediately after treatment<br>T2: 20 minutes after treatment<br>T3: 48 hours after treatment | Primary result:<br>Pain intensity (VAS)<br>PPT (AL)<br>Secondary result:<br>Depression Stress and Anxiety (DASS) | Pain intensity (VAS):<br>EG: T2* < T1* < T0<br>CG: T2* < T1* < T0<br>CG < EG at T1 and T2*<br>EG = CG at T3<br>PPT (AL):<br>EG: T2 > T1* > T0<br>CG: T2* < T1* < T0<br>CG > EG at T1*, T2* and T3*<br>Depression Anxiety and Stress Scale (DASS):<br>no changes are reported after treatment |
| 13 | Camargo et al. 2012 [43] Brazil | Hypoalgesic effect of Bernard's diadynamic currents on healthy individuals | Hand and forearm experimentally induced musculoskeletal pain (EIMSP) | RCT | *n* = 75<br>males = 35 (47%)<br>females = 40 (53%)<br>age: 18–60 | EG 1 = 15<br>(8 females, 7 males)<br>EG 2 = 15<br>(8 females, 7 males)<br>EG 3 = 15<br>(8 females, 7 males)<br>EG 4 = 15<br>(8 females, 7 males)<br>CG = 15<br>(8 females, 7 males) | EG 1 = DDC (DF)<br>EG 2 = DDC (MF)<br>EG 3 = DDC (CP)<br>EG 4 = DDC (LP)<br>CG = non intervention | DF: 15 minutes<br>MF: 15 minutes<br>CP: 15 minutes<br>LP: 15 minutes<br>Total treatment time: 15 minutes for each group | 1 session | T0: baseline (before treatment)<br>T1: during treatment (at 5 minutes)<br>T2: during treatment (at 10 minutes)<br>T3: at end of treatment<br>T4: 15 minutes after DDC application | Primary result:<br>PPT (AL)<br>Discomfort to electrical current (VAS) | PPT (AL):<br>EG 1, EG 3 and EG 4:<br>T4 > T3 > T2 > T1 > T0<br>EG 2: T4 < T3 < T2 < T1 < T0<br>EG 1 = GC at T1–T4<br>EG 2 = GC at T1–T4<br>EG 3 = GC at T1–T4<br>EG 4 = GC at T1–T4<br>Discomfort to electrical current during stimulation (VAS):<br>EG 1: T3 < T2 < T1<br>EG 2: T3 > T2 > T1<br>EG 3: T3* < T2* < T1<br>EG 4: T3* < T2 < T1 |

Own elaboration.

AL – algometry, CCE – closed kinematic chain exercises, CG – control group, CP – short periods diadynamic current, DASS – depression stress and anxiety scale, DC – direct current (Galvanic current), DDC – diadynamic currents, DF – diphasic fixed diadynamic current, EMG – surface electromyography, EIMSP – experimental induced musculoskeletal pain, EG – experimental group, ES – esthesiometer, FADI – Foot and Ankle, FFD – finger-ground distance test disability Index, LBPS – low back pain syndrome, LP – long periods diadynamic currents, LKS – Lysholm Standardised Knee Scale, MDQ – Moos menstrual distress questionnaire, MENS – microcurrents transcutaneous electrical stimulation, MF – monophasic fixed diadynamic current, MPQ – McGill–Melzack questionnaire, MTrPs – myofascial trigger points; NDI – neck disability index; NS – not specified; NSCLBP – nonspecific chronic back pain, NPRS – numeric pain rating scale, OCE – open kinematic chain exercises, ODI – Oswestry Disability Index, OA – osteoarthritis, PDI – Present disability index, PPI – present pain index, PPTL – pressure pain tolerance, PPT – pain pressure threshold, PRSS – pain-related self-declaration scale, RDQ – Roland Morris Low Back Pain Questionnaire, RCT – randomised clinical trial, SPADI – shoulder pain and disability index, TENS – transcutaneous electrical nerve stimulation, TMJ – temporomandibular joint, US – therapeutic ultrasound, VAS – visual analog scale

* $p$-value < 0.05

Table 3. Characteristics of DDC used in the studies

| Clinical trial number | Author | Musculoskeletal condition | Type of DDC | Level of stimulation Current intensity (mA) | Treatment time | Dose (mA.min) | Types of electrodes | Electrode size | Electrode location |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Almagro et al. [31] | TMJ pain | DF-CP-LP | Sensitive level stimulation I = NS | Total: 6 minutes DF: 1 minute CP: 2 minutes LP: 3 minutes | NS | Adhesive electrodes | NS | Anode in TMJ Cathode in the mandibular angle (monopolar application) |
| 2 | Grau et al. [32] | TMJ pain | DF-CP-LP | Sensitive level stimulation I = NS | Total: 6 minutes DF: 1 minute CP: 2 minutes LP: 3 minutes | NS | Adhesive electrodes | NS | Anode in ATM Cathode in the mandibular angle (monopolar application) |
| 3 | Muragod et al. [33] | Dysmenorrhoea | DF | Sensitive level stimulation I = NS | Total: 20 minutes | NS | NS | NS | Bipolar application in lower abdominal area (hypogastrium) (coplanar bipolar application) |
| 4 | Demidaś and Zarzycki [34] | Experimentally induced musculoskeletal pain (EIMSP) | DF-MF-LP-CP | Sensitive level stimulation I = NS | Total: 10 minutes DF: 2 minutes MF: 3 minutes LP: 3 minutes CP: 2 minutes | NS | Carbon rubber | 36 $cm^2$ | Cathode on palmar surface and anode on dorsal side of the hand (bipolar contraplanar application) |
| 5 | Sayilir and Yildizgoren [35] | LBP | DF-CP-LP | Sensitive level stimulation I = NS | Total: 8 minutes DF: 2 minutes CP: 3 minutes LP: 3 minutes | NS | Carbon rubber | 35 $cm^2$ | Bipolar transverse application in the lumbar spine (paravertebral) (coplanar bipolar application) |
| 6 | Ratajczak et al. [36] | Lumbar nucleus pulposus hernia | MF-DF-LP-CP | Sensitive level stimulation I = 15 mA | Total: 10 minutes | 150 mA.min | Carbon rubber | 36 $cm^2$ | Bipolar application in lumbar region (coplanar bipolar application) |
| 7 | Can et al. [37] | PFPS | MF-DF-LP | Sensitive level stimulation I = NS | Total: 5–6 minutes | NS | Carbon rubber | NS | Medial and lateral aspects of the knee (bipolar contraplanar application) |
| 8 | Heggannavar et al. [38] | Heel pain | LP | Sensitive level stimulation I = NS | Total: 12 minutes | NS | NS | NS | Plantar application (coplanar bipolar application) |
| 9 | Völklein and Callies [39] | Gonarthrosis and lumbar pain syndrome | DF-MF-LP-CP | Sensitive level stimulation DF – minimum: 10.5 mA; mean 11.7 mA; maximum: 12.5 mA CP: minimum 5.9 mA; mean 7.2 mA; 8.6 mA maximum MF: 4.4 mA minimum; mean 5.3 mA; max 6.1 mA LP: NS | Total: 3–9 minutes | DF: 31.5–112.5 mA.min CP: 17.7–77.4 mA.min MF: 13.2–54.9 mA.min LP: NS | Carbon rubber | 48 $cm^2$ | Anode always placed above the location of the pain (bipolar contraplanar application) |

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|---|---|---|---|---|---|---|---|---|---|
| 10 | Gomes et al. [40] | Shoulder impingement | DF-LP-CP | DF and LP: sensitive level stimulation<br>CP: motor level stimulation<br>I: NS | Total: 12 minutes<br>DF: 4 minutes<br>LP: 4 minutes<br>CP: 4 minutes | NS | NS | 49 $cm^2$ | Anode placed between the scapulae and the cathode on the MTrP (monopolar application) |
| 11 | Dibai-Filho et al. [41] | Neck pain and MTrPs in the upper trapezius muscle | DF-CP | DF: sensitive level stimulation<br>CP: motor level stimulation<br>I: NS | Total: 10 minutes<br>DF: 4 minutes<br>CP: 6 minutes | NS | NS | 49 $cm^2$ | Anode placed between the scapulae and the cathode on the MTrP (monopolar application) |
| 12 | Ebadi et al. [42] | NSCLBP | LP-CP | Sensitive level stimulation<br>I = NS | Total: 10 minutes<br>LP: 5 minutes<br>CP: 5 minutes | NS | Carbon rubber | 24 $cm^2$ | In the lumbar area. NS position of cathode and anode (bipolar application) |
| 13 | Camargo et al. [43] | Hand and forearm EIMSP | MF-DF-LP-CP | Sensitive level stimulation<br>I = NS | 15 minutes<br>DF: 15 minutes<br>MF: 15 minutes<br>LP: 15 minutes<br>CP: 15 minutes | NS | Aluminium | 48.5 $cm^2$ | Application on lateral aspect of the forearm and dorsal surface of the hand (bipolar contraplanar application) |

Own elaboration.
CP – short periods diadynamic current, DDC – diadynamic currents, DF – diphasic fixed diadynamic current, EIMSP – experimental induced musculoskeletal pain, I – current intensity, LBP – low back pain, LP – long periods diadynamic currents, MF – monophasic fixed diadynamic current, MTrPs – myofascial trigger points, NS – not specified, NSCLBP – nonspecific chronic back pain, PFPS – patellofemoral pain syndrome, TMJ – temporomandibular joint