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Systematic Review

# Effect of Percutaneous Electrical Stimulation on Active Muscle Functionality. A Systematic Review

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## ABSTRACT

**Background and Objectives:** Percutaneous Electrical Stimulation (PES) interventions, particularly percutaneous neuromodulation (PNM) and electroacupuncture (EA) techniques, have shown potential in targeting neuromusculoskeletal tissues, primarily for improving pain and functionality. Regarding functionality, this study specifically aims to analyze the impact of PES interventions on active muscle functionality in both healthy individuals and those with neuromuscular pathologies.

**Methods:** A systematic review was registered in PROSPERO (CRD42024605747) following PRISMA guidelines. A literature search was conducted in July 2024 across PubMed, Cochrane, BVS, Science Direct, Web of Science, and Scopus. Included studies were randomized controlled trials in which a group received an isolated PES intervention and variables related to active muscle functionality were addressed (e.g., strength, endurance, contractile properties). Methodological quality was assessed using the PEDro scale, and the risk of bias was evaluated with the RoB2 tool.

**Results:** A total of 359 participants from 8 studies were included. Regarding active muscle functionality variables, 5 studies targeted strength, 1 study assessed endurance, 1 study evaluated contraction time, and 1 study examined nerve excitability. PES demonstrated positive effects on all variables except contraction time, where PES was no more effective than non-percutaneous interventions.

**Discussion:** PES interventions are suggested to be effective for enhancing active muscle functionality, particularly in individuals with neuromusculoskeletal conditions who are more likely to present muscle impairments. However, these findings should be interpreted with caution due to significant heterogeneity in PES protocols, comparators, and study populations, making direct comparisons between studies challenging.

**Conclusions:** PES, including EA and PNM interventions, is an effective approach for enhancing active muscle functionality, specifically in terms of maximum isometric strength, endurance, and nerve excitability, in both healthy individuals and populations with musculoskeletal pathologies. Further research is needed to establish standardized PES application protocols in rehabilitation settings.

**Keywords:** Percutaneous Electrical Stimulation; Percutaneous Neuromodulation; Electroacupuncture; Active Muscle Functionality; Strength; Endurance; Nerve Excitability.

# 1. Introduction

Skeletal muscles, classified as striated musculature, are characterized by the precise organization of their fibers which are large multinucleated cells that are arranged in fascicles covered by connective tissue<sup>(1)</sup>. This structural arrangement is essential for optimal functionality<sup>(2,3)</sup>. The primary functions of skeletal muscles is to maintain body posture, to generate force and, consequently, to enable movement of the skeletal system through their attachment to bones<sup>(4)</sup>. This force generation, referred to as muscle strength, results from both morphological changes (hypertrophy) and neuromuscular adaptations, which play a key role particularly in the early stages of strength development<sup>(5)</sup>.

Percutaneous electrical stimulation (PES) has emerged as an innovative and effective approach to the treatment of neuromusculoskeletal pathologies, primarily in terms of pain and functionality<sup>(6)</sup>. Common clinical techniques based on PES are percutaneous neuromodulation (PNM) and electroacupuncture (EA). While both techniques use a needle as an electrode to stimulate peripheral nerves, EA involves the insertion of the needle into predefined acupoints<sup>(7)</sup>, whereas PNM involves the insertion of a needle close to the nerve pathway to stimulate it directly<sup>(8)</sup>.

In addition to the utility of PES in improving key clinical variables such as pain and functionality in pathological populations, studies have also highlighted its potential to enhance active muscle functionality in both healthy and pathological populations.<sup>(9-13)</sup> This active muscle functionality refers to aspects in which the muscle actively participates, including strength, endurance, contractile function and nerve excitability, without considering passive aspects such as elasticity or flexibility. These improvements in active muscle functionality following PES application can be attributed to various mechanisms, all based on the principle that PES activates motor units in a different sequence from the normal voluntary activation pattern<sup>(14)</sup>.

One perspective suggests that when PES is combined with exercise and applied to healthy individuals, it enhances strength gains through three main factors: continuous and exhausting contractile activity within the same group of motor units throughout the exercise period, supra-maximal temporal recruitment when high frequencies (up to 40 Hz) are used, and synchronous activation of neighboring muscle fibers<sup>(15)</sup>. Other theories propose that type II muscle fibers, characterized by fast motor units, are more susceptible to electrical stimulation, requiring lower intensity for activation and, therefore, a lower dose to achieve strength gains<sup>(15,16)</sup>. Additionally, PES not only induces muscle activation in the directly treated muscles but may also trigger reflex contractions by stimulating sensory fibers, potentially contributing to additional force production in skeletal muscle<sup>(17)</sup>.

Recognizing the growing use of PES therapies in medical and physiotherapy fields, a systematic review synthesizing data from experimental clinical studies is warranted to provide a comprehensive analysis of the effect of PES techniques on active muscle functionality.

## 2. Methods

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard protocol<sup>(18)</sup> and has been registered with the PROSPERO international prospective register of systematic reviews (reference number: CRD42024605747).

### 2.1 Eligibility criteria

Study eligibility was based on the PRISMA checklist and the PICOS formula (P-Participants; I-Interventions; C-Comparators; O-Outcome; S-Study design). Studies were included if they met the following criteria: 1) involved either healthy or pathological populations; 2) patients underwent isolated PES; 3) compared with any other treatment; 4) reported outcomes related to active muscle functionality; 5) only randomized controlled trials written in English or Spanish were considered. Exclusion criteria were: 1) studies involving transcutaneous electrical stimulation, stimulation via surgical implants, transcranial stimulation, or central nervous system stimulation; 2) studies that included muscular training or pharmacological treatments.

### 2.2 Data sources and Search Strategy

An electronic search for randomized controlled trials was conducted and ended on 10 July 2024. The PubMed, Cochrane, BVS, Science Direct, Web Of Science and Scopus databases were evaluated and consulted to identify studies. Regarding the search terms, four categories were defined: the first related to PES ("Electric Stimulation Therapy"[Mesh]) OR (electric\*) OR ("percutaneous"), the second related to needle use (needl\*), the third related to active muscle functionality (("Muscles"[Mesh]) AND ("Contraction" OR "Strength" OR "functionality" OR "endurance" OR "power" OR "neuromuscular")) and the fourth related to exclusion criteria ("transcutaneous" OR "TENS" OR "TES" OR "EMG"). Once these terms were established, they were entered into the search engine of the different databases and combined with the boolean operators "AND", "OR" and "NOT". Two independent researchers (MB, JF) reviewed the titles and abstracts of the publications identified through the search strategy and assessed the full texts for potential inclusion. Any disagreements between the two researchers were resolved through discussion and consultation with a third reviewer (AC).

### 2.3 Study Selection

To decide if the studies met the inclusion criteria, two reviewers reviewed each report (MB, JF). They worked independently to avoid bias and followed the same methodology after agreement on how to perform the search equations, and then compared their results.

First, all registers were retrieved from the six databases and duplicated publications were removed. An initial screening of the articles was then carried out and the articles that could meet the inclusion criteria in terms of information available in the title and abstract were selected. A second screening phase followed, in which the studies were read in full text, and those that met all inclusion criteria were selected. The selected studies were then compared by both reviewers (MB, JF), and in case of disagreement, a third researcher was consulted to reach consensus (AC).

## 2.4 Data extraction process

The same two reviewers (MB, JF) who performed the study selection independently extracted the data. Disagreements between them were discussed, and a third review author (AC) was consulted when necessary. During data extraction, the following information was extracted from each study: Authors and year of publication, sample characteristics (sample size, gender, age and baseline pain and functionality values), inclusion criteria, intervention (type of intervention, parameters of application and duration), comparator/control group, main outcomes and their evaluation time points (pain and/or functionality), other outcomes, main results and other results.

## 2.5 Assessment of methodological quality/risk of bias

Regarding the methodological quality of the included studies, PEDro scale was used. The two reviewers worked independently (MB, JF), and the results were then compared. The intervention of a third reviewer was not required. The PEDro scale, which was developed specifically for randomized controlled trials, comprises 11 items, giving a score of 1 if the article meets the criteria and 0 if it does not. Item 1 confirms whether the eligibility criteria have been established (external validity), items 2–9 assess the study design (internal validity) and items 10 and 11 assess the interpretability of the results. The maximum score is 10 points, as the first item is not considered in the final score. In the interpretation of the score, the articles that scored at least 6 out of 10 were considered to be of “high quality”, the studies between 4 and 5 were considered to be of “moderate quality” and the articles with less than 4 points were considered to be of “low quality”<sup>(19,20)</sup>.

On the other hand, regarding the risk of bias of the included studies, the two reviewers worked independently (MB, JF), and the results were subsequently compared, without involving a third reviewer. As these were randomized controlled trials, the Cochrane Risk of Bias 2.0 (RoB2) tool was used<sup>(21)</sup>. Risk of bias was assessed based on ‘allocation to intervention’ for all five domains: 1) randomization process, 2) deviations from planned interventions, 3) missing outcome data, 4) outcome measurement, and 5) selection of reported outcome. The overall risk of bias was assessed as either ‘low risk’, ‘some concern’ or ‘high risk’ of bias for each outcome.

# 3. Results

## 3.1. Study selection

After applying the previously described strategies, a total of 1321 studies were found in the 6 databases (PubMed: 281, Cochrane: 666, BVS: 59, WOS: 63, Science Direct: 57, Scopus: 195). After removing duplicate studies, 1272 articles were selected for title and abstract screening, leaving a total of 49 articles. These 49 studies were analyzed in full text and 41 of them were excluded due to not meeting the inclusion criteria. Thus, a total of 8 articles were considered for the systematic review. The flow chart (Figure 1) shows in more detail the process of search and selection of studies as well as the different reasons for exclusion, according to the PRISMA criteria.

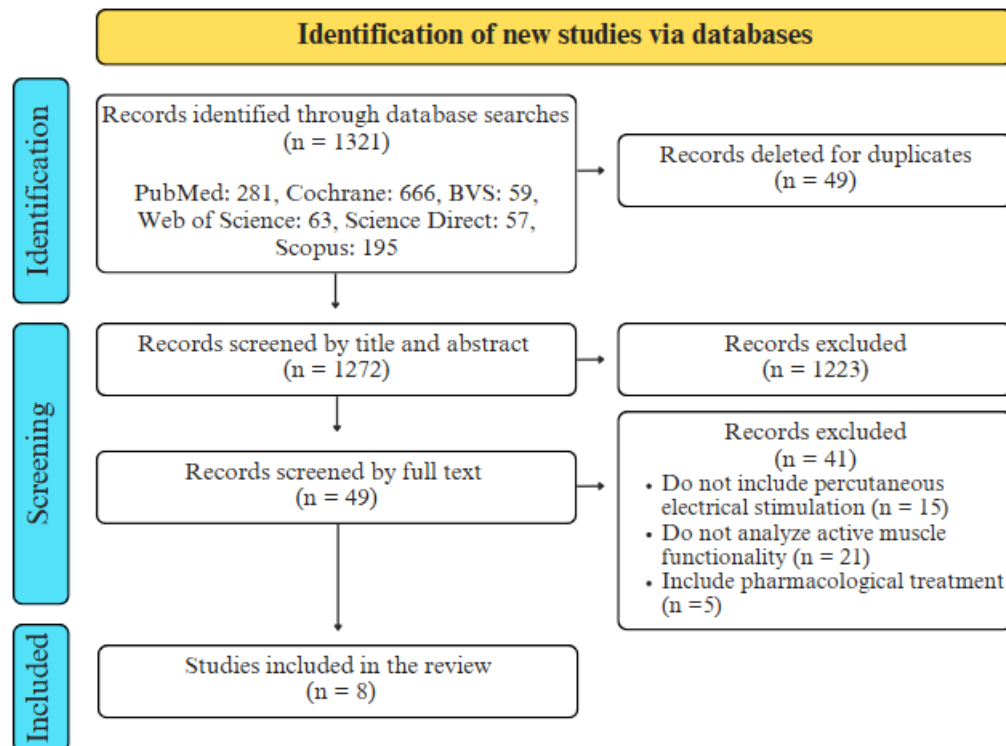


**Figure 1.** Flow Chart.

### 3.2. Study characteristics

The data extracted from the eight articles are presented in Table 1 and Table 2, arranged alphabetically by the last name of the first author.

#### 3.2.1. Sample characteristics

A total of 359 participants were included in the analysis. All participants underwent a physiotherapy intervention based on the percutaneous electrical stimulation (PES) and aimed at improving muscle strength ( $n = 234$ ), skeletal muscle contractile properties ( $n = 80$ ), or endurance ( $n = 45$ ). The sample sizes of the selected studies ranged from 20 to a maximum of 80 participants. In four studies, the male-to-female ratio was 50%, while one study included only men<sup>(12)</sup>, another included only women<sup>(9)</sup>, one reported 43.3% male participants<sup>(22)</sup>, and one study did not specify the gender distribution<sup>(23)</sup>. The mean age of the participants was  $28.79 \pm 7.5$  years and ranged from 17 to 54 years. The populations included in the studies varied from healthy individuals to specific groups such as female ballet professionals, dancers with personal psychological apprehension, and patients with conditions including lateral elbow epicondylitis, bilateral short hamstring syndrome, and low back pain. The variables related to active muscle functionality included in this systematic review are maximum isometric strength, muscle endurance, contractile properties and nerve excitability.

### 3.2.2. Intervention and follow-up

Interventions and follow-up varied across the studies. All studies conducted a pre-intervention assessment as baseline. Post-intervention assessments differed, with some studies conducting a single assessment immediately after treatment<sup>(9,10)</sup>, after 2 weeks<sup>(23)</sup>, after 1 week<sup>(13)</sup>, or after 1 month<sup>(11)</sup>. Others included multiple follow-up points, lasting up to 3 weeks<sup>(12)</sup>, 10 days<sup>(24)</sup>, or 15 minutes<sup>(21)</sup>. Regarding the number of interventions, 62% of the studies applied a single US-guided PNM session<sup>(9,10,13,22,24)</sup> or US-guided DN<sup>(10)</sup>, while the remaining studies included multiple sessions: 24 EA sessions over 8 weeks<sup>(12)</sup>, 6 EA sessions over 2 weeks<sup>(23)</sup>, and 3 US-guided PNM sessions over 3 weeks<sup>(11)</sup>. Overall, 75% of the studies used US-guided PNM<sup>(9-11,13,22,24)</sup>, while the remaining 25% employed EA<sup>(12,23)</sup>.

### 3.2.3. Outcomes

Active muscle functionality was analyzed in all included studies<sup>(9-13,22-24)</sup>. Additionally, some studies analyzed range of motion (ROM)<sup>(9,10,13)</sup>, pain<sup>(11,13,22,24)</sup>, neural variables contributing to muscle function<sup>(10-12)</sup>, and temperature<sup>(22)</sup>.

Regarding active muscle functionality, 30% of the studies analyzed variables related to the changes at the neural level that directly affect active muscle functionality. On one hand, chronaxie and accommodation index was assessed through the strength-duration curve<sup>(11)</sup>, a test of nerve excitability based on the relationship between the intensity of a monophasic rectangular electrical impulse and its duration in eliciting a motor response when a motor nerve is electrically stimulated<sup>(25)</sup>. And on the other hand, contraction time was assessed through tensiomyography<sup>(10)</sup>, a technique used to evaluate the contractile properties of the skeletal musculature<sup>(26,27)</sup>.

The remaining 70% of the studies analyzed variables related to broader active muscle capabilities, including muscle endurance<sup>(9)</sup> and maximum isometric strength (MIS) in various muscle groups: ankle dorsiflexors<sup>(12)</sup>, hip muscles<sup>(13)</sup>, handgrip muscles<sup>(23,24)</sup>, and finger flexors<sup>(22)</sup>. Endurance was assessed through repeated exercise until fatigue or inability<sup>(9)</sup>, specifically using a heel-raise exercise. MIS was primarily evaluated using dynamometry<sup>(13,22,24)</sup>, a device that measures force based on the stretching or compression of a spring, following Hooke's law of elasticity within its measurement range. Additionally, MIS was assessed using a vigorimeter<sup>(23)</sup>, a type of handgrip dynamometer consisting of a rubber balloon compressed in the hand, connected by a rubber tube to a manometer that records air pressure in kilopounds per square centimeter. In another study, MIS was evaluated through the maximum voluntary contraction test<sup>(12)</sup>, which involves performing maximal isometric contractions against a force transducer as quickly and forcefully as possible.

**Table 1.** Characteristics of included studies.

| Authors and year               | Sample Characteristics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Inclusion criteria                                                                                                                                                                                                                                                                              | Intervention                                               | Comparator                                                                                                        | Main Outcomes and Follow-up                                                                                                                               | Main Results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| De-la-Cruz-Torres et al., 2021 | N: US-guided PNM (12); CG (12)<br>Gender (Male/Female): US-guided PNM (6/6); CG (6/6)<br>Age (years): US-guided PNM (49.4 ± 7.6); CG (49.4 ± 5.5)<br>BMI (kg/m2): US-guided PNM (23.44 ± 2.5); CG (22.98 ± 2.23)<br>Duration symptoms (months): US-guided PNM (13.6 ± 9.10); CG (12.4 ± 8.06)<br>Baseline Chronaxie (strength-duration curve): US-guided PNM (0.70 ± 0.2); CG (0.74 ± 0.2)<br>Baseline Accomodation Index (strength-duration curve): US-guided PNM (2.35 ± 0.5); CG (2.45 ± 0.4)                                                                                                                                                                                                                                                                                                                                                                                                                                               | Unilateral pain in the lateral aspect of the elbow ≥3 months.<br>Unilateral pain within 2 cm of the lateral epicondyle on resisted wrist extension.                                                                                                                                             | US-guided PNM                                              | No intervention                                                                                                   | Chronaxie and accomodation index (strenght-duration curve test of nerve):<br><br>Baseline and 1 month                                                     | <b>Chronaxie:</b><br><br>There were no SSD either intragroup or between groups.<br><br><b>Accomodation Index:</b><br><br>SSD in favour of the US-guided PNM group were observed at post-intervention assesment (p = 0.001).                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| De-la-Cruz-Torres et al., 2020 | N: US-guided PNM (20); Needling (20); NeuroD (20); Stretching (20)<br>Gender (Male/Female): US-guided PNM (10/10); Needling (10/10); NeuroD (10/10); Stretching (10/10)<br>Age (years): US-guided PNM (22.8 ± 3.01); Needling (23.7 ± 4.26); NeuroD (22.8 ± 6.76); Stretching (21.3 ± 4.26)<br>BMI (Kg/m2): US-guided PNM (23.01 ± 2.08); Needling (22.8 ± 2.15); NeurdoD (23.1 ± 2.33); Stretching (22.3 ± 1.73)<br>Baseline TcBF-L (ms): US-guided PNM (37.9 ± 14.18); Needling (36.5 ± 10.23); NeuroD (37.5 ± 10.40); Stretching (39.5 ± 13.11)<br>Baseline TcBF-R (ms): US-guided PNM (41.4 ± 7.74); Needling (45.6 ± 7.62); Neuro D (40.4 ± 10.03); Stretching (40.8 ± 5.09)<br>Baseline TcST-L (ms): US-guided PNM (39.1 ± 7.41); Needling (38.8 ± 7.34); NeuroD (38.9 ± 7.90); Stretching (29.3 ± 11.78)<br>Baseline TcSt-R (ms): US-guided PNM (37.9 ± 7.72); Needling (34.7 ± 6.45); NeurdoD (39.1 ± 11.55); Stretching (37.7 ± 6.72) | Bilateral short hamstring syndrome<br>Straight Leg Raise Test ≤ 70º                                                                                                                                                                                                                             | US-guided PNM                                              | Stretching: Passive Stretching<br><br>NeuroD: Neurodynamic Sliders<br><br>Needling:<br><br>US-guided Dry Needling | Non-intervention leg Contraction Time (tensiomyography):<br><br>Baseline and immediately post-intervention.                                               | <b>Non-intervention leg Contraction Time:</b><br><br>There were no SSD between groups for the non-intervention leg contraction time in the biceps femoris (p = 0.068) or the semitendinosus (p = 0.998).<br>Intragroup analysis was not performed for this outcome; however, the non-intervention leg post-intervention showed the following changes in mean and SD for contraction time:<br>Biceps femoris: US-guided PNM group (−1.6 ± 5.36), Stretching group (−0.1 ± 2.42), NeuroD group (−0.1 ± 3.27), and Needling group (−3.0 ± 3.87)<br>Semitendinosus: US-guided PNM group (0.7 ± 6.43), Stretching group (1.4 ± 6.19), NeuroD group (1.8 ± 35.77), and Needling group (1.5 ± 4.69). |
| De-la-Cruz-Torres et al., 2019 | N: US-guided PNM (15); Eccentric (15); Stretching (15)<br>Gender (Male/Female): 0/45<br>BMI (Kg/cm2): US-guided PNM (18±4.12); Eccentric (18±2.62); Stretching (17±2.91)<br>Age (years): US-guided PNM (21±3.07); Eccentric (19±3.07); Stretching (20±4.07)<br>Baseline Endurance test (nº of repetitions): US-guided PNM (19.7±5.18); Eccentric (19.7±5.07); Stretching (16.9±3.50)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Female ballet professionals dancers.<br>Personal Psychological Apprehension Scale: score>37.5                                                                                                                                                                                                   | US-guided PNM                                              | Stretching:<br><br>Static Stretching<br><br>Eccentric:<br><br>Eccentric Exercise                                  | Endurance - Ankle Plantarflexors (Modified Unilateral Heel Raise Fatigue Test):<br><br>Baseline and immediately post-intervention.                        | <b>Ankle Plantarflexors Endurance:</b><br><br>SSD in favour of the US-guided PNM group were observed at post-intervention assesment (p < 0.001).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Huang et al., 2015             | N: EA (10); sEA (8); MA (9); sMA (8); CG (10)<br>Gender (Male/Female): 45/0<br>Age (years): EA (22.5 ± 2.5); sEA (22.1 ± 2.2); MA (21.6 ± 1.7); sMA (20.9 ± 1.8); CG (24.2 ± 1.5)<br>BMI (Kg/m2): EA (22.7); sEA (24.2); MA (21.2); sMA (24.3); CG (22.5)<br>Baseline MIS left ankle dorsiflexion (MVC test): EA (211.7 ± 38.5); sEA (253.3 ± 27.7); MA (228.0 ± 55.9); sMA (223.2 ± 50.4); CG (260.3 ± 24.4)<br>Baseline MIS right ankle dorsiflexion (MVC test): EA (229.7 ± 47.8); sEA (254.1 ± 20.7); MA (239.2 ± 53.2); sMA (244.9 ± 34.2); CG (255.8 ± 15.2)                                                                                                                                                                                                                                                                                                                                                                             | Healthy volunteer men.<br>No musculoskeletal disorders.<br>No previous experience with acupuncture.<br>Right-foot dominant.                                                                                                                                                                     | EA: Electroacupuncture<br><br>sEA: sham Electroacupuncture | MA:<br><br>Manual Acupuncture<br><br>sMA:<br><br>sham Manual Acupuncture<br><br>CG:<br><br>no intervention        | MIS - Ankle Dorsiflexors (Maximum Voluntary Contraction Test):<br><br>Baseline, immediately post-intervention, and 2 weeks and 3 weeks post-intervention. | <b>Ankle Dorsiflexors MIS:</b><br><br>SSD in favour of the EA and sEA groups were observed at post-intervention and at week 3 assessments (p < 0.001).<br>There were no SSD between groups at 3 weeks evaluation.                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Martin-Caro et al., 2023       | N: US-guided PNM (10); US-guided sPNM (10)<br>Gender (Male/Female): US-guided PNM (5/5); US-guided sPNM (6/4)<br>Age (years): US-guided PNM (28 ± 8.6); US-guided sPNM (26.8 ± 9.8)<br>BMI (kg/m2): US-guided PNM (24.8 ± 3.1); US-guided sPNM (23.8 ± 23.7)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Healthy volunteers.<br>Not being diagnosed with any physical, cognitive or psychological disorder.<br>Not medical and/or physiotherapy treatment during the trial and in the last 10 days.<br>Not presenting contraindications against receiving puncture and/or electric currents stimulation. | US-guided PNM                                              | US-guided sPNM:<br><br>sham Percutaneous Neuromodulation                                                          | MIS - Handgrip (digital hand dynamometer):<br><br>Baseline, immediately post-intervention, and 1 day and 10 days post-intervention.                       | <b>Handgrip MIS:</b><br><br>No SSD were found between the US-guided PNM and the US-guided sPNM groups.<br>No intragroup SSD were observed for the US-guided sPNM group. However, US-guided PNM group experienced a significant decrease of 10.4% (p = 0.02) at 24 hr postintervention compared to baseline. Subsequently, a significant increase of 14.3% (p = 0.01) was also observed when comparing values at 10 days postintervention against 24 hr. postintervention.                                                                                                                                                                                                                     |

| Authors and year                   | Sample Characteristics                                                                                                                                                                                                                                                                             | Inclusion criteria                                                                                                                                                                                                                                                          | Intervention                                                                                                                                                                                               | Comparator                                                                    | Main Outcomes and Follow-up                                                                                           | Main Results                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Martin-Caro et al., 2022           | N: 10 KHz (20); 20KHz (20); US-guided sPNM (20)<br>Gender (Male/Female): 10 KHz (11/9); 20KHz (9/11); US-guided sPNM (6/14)<br>Age (years): 10 KHz (22.9 ± 4.8); 20KHz (20.8 ± 1.9); US-guided sPNM (21 ± 2.5)<br>BMI(Kg/m2): 10 KHz (23.7 ± 3.9); 20KHz (22.6 ± 3.3); US-guided sPNM (23.2 ± 2.4) | Healthy volunteers ranging 18-40 years.<br>No allergy to nickel or intolerance to the percutaneous application of electric currents. No surgical procedure in the upper limb. No fear of needles or any other contraindication to receive invasive physiotherapy treatment. | 10 KHz:<br>US-guided PNM at a frequency of 10 KHz<br><br>20 KHz:<br>US-guided PNM at a frequency of 20 KHz                                                                                                 | US-guided sPNM:<br><br>sham Percutaneous Neuromodulation                      | MIS - Finger Flexors (digital hand dynamometer):<br><br>Baseline, immediately post-intervention and 15 minutes later. | <b>Finger Flexors MIS:</b><br><br>SSD were found between both intervention groups and US-guided sPNM (p < 0.001). Both intervention groups experienced a decrease in Finger Flexors MIS immediately postintervention and 15 minutes after its finalization versus baseline, in contrast to the US-guided sPNM group where no changes were observed. |
| San-Emeterio-Iglesias et al., 2022 | N= ProxStim (20); MidStim (20); DisStim (20)<br>Gender (Male/Female): ProxStim (10/10); MidStim (10/10) ; DisStim (10/10)<br>Age (Years): ProxStim (42.40±12.1); MidStim (43.9±15.3); DisStim (39.65±11.3)<br>BMI (kg/m2): ProxStim (24.56±3.23); MidStim (24.22±3.84); DisStim (23.9±2.76)        | LBP patients without medical treatment, knee prothesis, belenophobia or trochanteritis.                                                                                                                                                                                     | ProxStim:<br>US-guided PNM in the proximal sciatic nerve pathway<br><br>MidStim:<br>US-guided PNM in the middle sciatic nerve pathway<br><br>DisStim:<br>US-guided PNM in the distal sciatic nerve pathway | Each intervention group acts as an active comparator of the other two groups. | MIS - Hip Muscles (hand-held dynamometer):<br><br>Baseline and 1 week post-intervention.                              | <b>Hip MIS:</b><br><br>There were intragroup SSD (p=0.001) for all hip strenght variables in all intervention groups.<br>Between groups SSD (p=0.029) were only found for hip flexion strenght of the non-intervention limb.                                                                                                                        |
| Tsui et al., 2002                  | N = EA (10); MA (10)                                                                                                                                                                                                                                                                               | Pain over the lateral epicondyle at palpation, resisted wrist extension, resisted finger extension and passive stretching of the forearm extensors.                                                                                                                         | EA: Electroacupuncture                                                                                                                                                                                     | MA:<br>Manual Acupuncture                                                     | MIS - Pain Free Handgrip (vigorimeter):<br><br>Baseline and 2 weeks post-intervention.                                | <b>Pain Free Handgrip MIS:</b><br><br>SSD were found between EA and MA groups (p=0.045) in favour of the EA group.                                                                                                                                                                                                                                  |

Data are presented as Mean ± Standard deviation. BMI: body mass index; CG: control group; DisStim: distal stimulation; EA: electroacupuncture; LBP: low back pain; MA: manual acupuncture; MidStim: middle stimulation; MIS: maximum isometric strength; NeuroD: neurodynamic; PNM: percutaneous neuromodulation; ProxStim: proximal stimulation; s: sham; SSD: statistically significant differences; TcBF-L: left biceps femoris contraction time ; TcBF-R: right biceps femoris contraction time; TcST-L: left semitendinosus contraction time; TcST-R: right semitendinosus contraction time; US: ultrasound.

**Table 2.** Description of the intervention.

| Authors and year               | Interventions                                                                                                                                                                          | Description of the intervention                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Parameters of application                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Duration of the intervention                                                                                                           |
|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| De-la-Cruz-Torres et al., 2021 | <b>IG:</b> US-guided PNM<br><br><b>CG:</b> No intervention                                                                                                                             | <b>US-guided PNM:</b> it was administered by an experienced physiotherapist. Subjects lied supine, with forearms pronated and elbows moderately flexed. The radial nerve was located at 4 cm proximal to the lateral epicon-dyle of the humerus using an US. Prior to inserting the needle, isopropyl alcohol was used to clean the underlying skin.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <b>US-guided PNM:</b> A stainless-steel acupuncture needle (0.30 mm × 30 mm) was inserted in a short axis approach, perpendicular to the skin, up to the perineurium of the radial nerve. Electrical stimulation was administered using a square wave biphasic electrical current, with a 10 Hz frequency, a 250-μs pulse width, and sufficient intensity to cause a visible muscle contraction for 1.5 minutes.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <b>US-guided PNM:</b> once a week for 3 weeks.                                                                                         |
| De-la-Cruz-Torres et al., 2020 | <b>IG:</b> US-guided PNM<br><br><b>CG-1:</b> Passive Stretching<br><b>CG-2:</b> Neurodynamic Sliders<br><b>CG-3:</b> Dry Needling                                                      | <b>US-guided PNM:</b> The participant lay prone with his or her feet outside the table. The sciatic nerve was located in a cross section at 50% of the distance between the greater trochanter and the knee joint line using an US machine with a high-frequency linear US transducer. Prior to inserting the needle, the overlying skin was cleaned with isopropyl alcohol. A trained physiotherapist performed the PNM intervention.<br><br><b>Passive Stretching:</b> Participants underwent passive stretching of the ham-string muscles in their right leg. The stretching was performed with the participant in a supine position, while a researcher passively maintained the leg in the SLR test position (hip in flexion, knee in extension, and ankle in a neutral position) until the movement barrier was reached. Throughout the procedure, the researcher monitored the participants to prevent any compensatory movements that could alter the stretching position.<br><br><b>Neurodynamic Sliders:</b> Participants received passive sciatic neurody-namic sliders in their right leg Participants were lied in supine position with their neck and thoracic spine supported in a forward flexed position. Sliders involved the application of movement/stress to the nervous system proximally while releasing movement/stress distally and subsequently the sequence was reversed. Concurrent hip and knee flexion were alternated dynamically with concurrent hip and knee extension. A physiotherapist trained in neurodynamic therapy applied this technique.<br><br><b>US-guided Dry Needling:</b> Participants received mechanical stimulation of the sciatic nerve using a needle. The same US as for the US-guided PNM group was used to guide the intervention. | <b>US-guided PNM:</b> A stainless-steel acupuncture needle (0.30 mm × 40 mm) was inserted in a short axis approach, perpendicular to the skin, until it reached the perineurium of the sciatic nerve. Electrical stimulation was administered using a square wave biphasic electrical current, with a 10 Hz frequency, a 250-μs pulse width, maximal tolerable intensity to cause an exacerbated muscle contraction, for 1,5 minutes.<br><br><b>Passive Stretching:</b> Stretching in passive SLR test position was main-tained for 30 s and repeated three times (total duration of 1.5 minutes).<br><br><b>Neurodynamic Sliders:</b> It was performed for 1.5 min (approximately 12 repetitions) on the right lower limb.<br><br><b>US-guided Dry Needling:</b> The same needles (0.30 mm × 40 mm), insertion technique, and intervention duration (1.5 minutes) were used as in the US-guided PNM group. However, no electrical stimulation was applied. | <b>US-guided PNM, Passive Stretching, Neurodynamic Sliders and US-guided Dry Needling:</b> one single session.                         |
| De-la-Cruz-Torres et al., 2019 | <b>IG:</b> US-guided PNM<br><br><b>CG-1:</b> Static Stretching<br><b>CG-2:</b> Eccentric Exercise                                                                                      | <b>US-guided PNM:</b> Participants lay prone with their feet outside the table. The flexor hallucis longus muscle was located in cross section at 50% of the distance between the fibular head and inferior border of the lateral malleolus on the posterior aspect of the fibula using an ultrasound ma-chine and then the needle was inserted and the electrical stimulation was administered. Prior to needle insertion, the overlying skin was cleaned with isopropyl alcohol. A physiotherapist with 5 years of experience in invasive therapy administered the intervention.<br><br><b>Static Stretching:</b> Participants performed static stretching exercise of the flexor hallucis longus muscle. They stood facing the step while placing the first metatarsophalangeal into dorsiflexion. With the heel kept on the floor, the ankle was maximally dorsiflexed by bending the knee. During the stretching, the therapist supervised the participants to ensure they assumed the correct stretching position.<br><br><b>Eccentric Exercise:</b> Participants performed eccentric exercise of the flexor hallucis longus muscle. Participants positioned their foot the same way as in the Static Stretching group before performing flexion–extension of the of hip, knee, ankle and first toe.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>US-guided PNM:</b> a needle (0.30mm×40mm) was inserted, perpendicular to the surface of the skin, into the muscle belly. Then, a square wave biphasic electrical current (10Hz frequency, 250μs pulse width, maximal tolerable intensity) was applied for a total of 1.5 minutes to cause an exacerbated muscle contraction.<br><br><b>Static Stretching:</b> The maximally dorsiflexed position was held for 20 seconds and then the patient resumed the starting position. This was repeated four times.<br><br><b>Eccentric Exercise:</b> 4 sets of 20 repetitions.                                                                                                                                                                                                                                                                                                                                                                                   | <b>US-guided PNM, Static Stretching and Eccentric Exercise:</b> one single session.                                                    |
| Huang et al., 2015             | <b>IG-1:</b> Electroacupuncture<br><b>IG-2:</b> sham Electroacupuncture<br><br><b>CG-1:</b> Manual Acupuncture<br><b>CG-2:</b> sham Manual Acupuncture<br><b>CG-3:</b> no intervention | For all interventions, participants took a supine position and were instruct-ed not to voluntarily contract the muscle during the needling.<br><br><b>Electroacupuncture and Manual Acupuncture:</b> The acupoints of ST-36 and ST-39 were targeted. Participants were required to experience the sensation of "Deqi" to confirm correct application. Deqi is a mixture of ach-ing, pressure, soreness, heaviness, fullness, warmth, cooling, numbness, tingling, and dull pain, but not sharp pain.<br><br><b>sham Electroacupuncture and sham Manual Acupuncture:</b> Two acupunc-ture needles were applied to the muscle belly of the tibialis anterior, ~3 cm laterally to the anterior crest of the tibia. One of them at one point on the top one-third, and the other one on the lower one-third of the muscle. Participants were not required to experience Deqi.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | For all interventions, a stainless-steel acupuncture needle (0.3 mm x 50 mm) was inserted perpendicularly to the skin into the muscle at the des-ignated locations to a depth of 20-30 mm. The time of treatment in each session was progressively increased from 15 minutes for the 1st week to 20 minutes in Week 2 and 30 minutes in Weeks 3-8.<br><br><b>Manual Acupuncture and sham Acupuncture:</b> twirling and lift-thrusting techniques were applied for 15 seconds every 5 minutes.<br><br><b>Electroacupuncture and sham Electroacupuncture:</b> electrical stimulation consisted on a constant-current square-wave pulses at a frequency of 40 Hz, pulse width of 1 millisecond, with a gradually increased intensity up to the maximal level that participants could tolerate.                                                                                                                                                                 | <b>Electroacupunture, sham Electroacupuncture, Manual Acu-puncture, sham Manual Acupuncture:</b> three sessions per week, for 8 weeks. |

| Authors and year                   | Interventions                                                                                                                                                                                        | Description of the intervention                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Parameters of application                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Duration of the intervention                                                                  |
|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Martin-Caro et al., 2023           | <b>IG:</b> US-guided PNM<br><b>CG:</b> US-guided sham PNM                                                                                                                                            | <p>Both interventions were applied at the upper nondominant limb with the subject in standing position. The skin of the participants was treated with an antiseptic. An approach to the long axes of the median and cubital nerves was conducted placing the point of the needle next to the nerves epineurium (1 mm), on the inner side of the distal third.</p> <p><b>US-guided PNM:</b> Electric stimulation was applied percutaneously to the needle with a pointer. The intervention was applied first to the median nerve and then to the cubital nerve without any rest time.</p> <p><b>US-guided sham PNM:</b> Same procedure but no electric current was delivered. However, patients were blinded to this, as they perceived a very low sound each time the pointer contacted the needle, leading them to believe they were receiving electrical stimulation.</p> | <p>For both interventions a dry puncture needle (0.30 x 0.40 mm) was used.</p> <p><b>US-guided PNM:</b> The employed electric current was low-frequency (10 Hz), had a biphasic and symmetric waveform, and a width pulse of 240 μs. The intensity was adjusted above the motor threshold, up to provoking visible contractions of the muscles innervated by both nerves, and below the pain threshold of the participants. The stimulation was delivered in intervals of 10 seconds followed by pauses of 5 seconds up to reaching a total intervention time of 60 seconds on each of the nerves.</p> <p><b>US-guided sham PNM:</b> No electric current was administered.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>US-guided PNM and US-guided sham PNM:</b> one single session.                              |
| Martin-Caro et al., 2022           | <b>IG-1:</b> US-guided PNM at a frequency of 10 KHz<br><b>IG-2:</b> US-guided PNM at a frequency of 20 KHz<br><b>CG:</b> US-guided sham PNM                                                          | <p>The interventions were delivered to the nondominant arm after skin disinfection. The participants lay in supine position. A short-axis approach to the median nerve was performed on the anterior aspect of the middle third of the forearm.</p> <p><b>US- guided PNM 10 KHz and US- guided PNM 20 KHz:</b> High frequency electric stimulation was applied, 10Khz or 20 KHz were administered depending on the group.</p> <p><b>US- guided sham PNM:</b> The electric current was initially applied at a very low intensity, just reaching the sensory threshold, and was then gradually decreased to zero.</p>                                                                                                                                                                                                                                                         | <p>The duration of all interventions was 20 minutes. Two acupuncture needles (0.30 mm × 40 mm) were placed close to the epineurium of the median nerve (1 mm), one needle on each side of the nerve, at an average depth of 3 cm.</p> <p><b>US- guided PNM 10 KHz and US- guided PNM 20 KHz:</b> High-frequency alternating currents with sinusoidal waveform were applied at a frequency of either 10 kHz or 20 kHz in the active intervention groups. The intensity progressively increased until producing a feeling of “strong but comfortable” tingling, just under the motor threshold. Subsequently, the intensity was increased until a minimal visible contraction was observed and then slightly lowered below the motor threshold. Due to the accommodation to the stimulus, the intensity was adjusted every two minutes.</p> <p><b>US- guided sham PNM:</b> The same parameters were used as in the 10 kHz intervention except for the current intensity, which was initially adjusted up to the sensitive threshold and, once the participant perceived a tingling sensation for a few seconds, the intensity was gradually lowered to and maintained at 0 mA for the entire session.</p> | <b>US-guided PNM 10 KHz, US-guided PNM 20 KHz and US-guided sham PNM:</b> one single session. |
| San-Emeterio-Iglesias et al., 2022 | <b>IG-1:</b> US-guided PNM in the proximal sciatic nerve pathway<br><b>IG-2:</b> US-guided PNM in the middle sciatic nerve pathway<br><b>IG-3:</b> US-guided PNM in the distal sciatic nerve pathway | <p><b>US-guided PNM:</b> The skin surface was cleaned before the intervention with chlorhexidine. Subsequently, the sciatic nerve was located using an US. All the participants lay prone with their feet outside the therapeutic table. The stimulation was carried out on the limb that had the restricted hip internal rotation by the decision of the researchers.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <p>The therapist inserted an acupuncture needle, using a long axis approach, until it reached the perineurium of the sciatic nerve. The procedure was based on the application of a biphasic continuous waveform, at low (3 Hz) frequency, pulse width 250 μs and at a sufficient intensity to see muscle contraction: 10 stimulations of 10 seconds and 10 seconds of rest between them. The needle was different for each group:<br/><b>US-guided PNM proximal:</b> A needle (0.30 mm × 75 mm) was placed in the proximal posterior thigh.<br/><b>US-guided PNM middle:</b> A needle (0.30 mm × 60 mm) was placed in the mid posterior thigh.<br/><b>US-guided PNM distal:</b> A needle (0.30 mm × 40 mm) was placed in the distal posterior thigh.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                               | <b>US-guided PNM:</b> one single session.                                                     |
| Tsui et al., 2002                  | <b>IG:</b> Electroacupuncture<br><b>CG:</b> Manual Acupuncture                                                                                                                                       | <p><b>Manual Acupuncture:</b> Patients adopted long sitting in the bed comfortably with back support. The skin was cleansed with alcoholic swab. After needling the GB34 acupoint, the needle was manipulated manually until the patient felt Deqi. Then another needle was inserted into the ST38 acupoint.</p> <p><b>Electroacupuncture:</b> After the needles insertion into the GB34 and ST38 and the Deqi sensation obtained, the two needles received electric stimulation.</p>                                                                                                                                                                                                                                                                                                                                                                                       | <p><b>Manual Acupuncture:</b> A sterile acupuncture needle (0.22mm x 25mm) was inserted 2 cm into both acupoints. During the needling, the patients were asked to move the painful arm by performing the general active flexion and extension mobilizing exercise 50 times in 5 minutes. The acupuncture treatment time was 20 minutes.</p> <p><b>Electroacupuncture:</b> Same needles and acupoints were used. For electric stimulation, low-frequency with 4 pulses/second was adopted and the intensity was adjusted up to a tolerable and non-painful sensation. The treatment was lasted for 20 minutes.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <b>Electroacupuncture and Manual Acupuncture:</b> 3 times a week for 2weeks.                  |

CG: control group; EA: electroacupuncture; IG: intervention group; MA: manual acupuncture; PNM: percutaneous neuromodulation; US: ultrasound.

### 3.3. Assessment of methodological quality/risk of bias

The methodological quality of the studies was analyzed using the PEDro scale. Except for one study<sup>(23)</sup>, which received a score of 4, indicating moderate quality, all the other studies included in this systematic review were classified as "high quality" with scores ranging from 6 to 9 points (Table 3). The average quality of all studies analyzed using the PEDro scale was 6.62. Specifically, two studies achieved the highest score of 9<sup>(22,24)</sup>, another scored 7 points<sup>(11)</sup>, and the remaining four studies received 6 points each<sup>(9,10,12,13)</sup>. Any study achieved item 6, related to blinding of the therapists administering the therapy. Only two studies achieved item 5, the blinding of participants<sup>(22,24)</sup>. In all studies, evaluators were blinded (item 7), choice criteria were specified and subjects were randomized, (item 1 and 2), measures of at least one of the key outcomes were obtained in more than 85% of subjects, (item8), results were reported for all subjects receiving treatments (item9), results of statistical comparisons between groups were reported for at least one key outcome, (item10), the study provides measures of power and variability for at least one key outcome (item 11). In all studies except for Tsui et al.<sup>(23)</sup>, the groups were similar at baseline with respect to the most important prognostic indicators (item 4). Finally, allocation was concealed in the 37.5% of studies, (item 3),<sup>(11,22,24)</sup>.

The risk of bias was evaluated using the RoB2 tool. The results indicated that the overall risk of bias varied from low risk in two studies<sup>(13,22)</sup>, to high risk in another study<sup>(23)</sup>, with some concerns for the remaining five studies<sup>(11, 10, 9, 22, 12)</sup> (Figure 2).

**Table 3.** Assessment of methodological quality by PEDro scale.

| Authors and year                                   | 1   | 2   | 3   | 4   | 5   | 6  | 7   | 8   | 9   | 10  | 11  | Total | Quality  |
|----------------------------------------------------|-----|-----|-----|-----|-----|----|-----|-----|-----|-----|-----|-------|----------|
| De-la-Cruz-Torres et al., 2021 <sup>(11)</sup>     | Yes | Yes | Yes | Yes | No  | No | Yes | Yes | No  | Yes | Yes | 7     | High     |
| De-la-Cruz-Torres et al., 2020 <sup>(10)</sup>     | Yes | Yes | No  | Yes | No  | No | Yes | Yes | No  | Yes | Yes | 6     | High     |
| De-la-Cruz-Torres et al., 2019 <sup>(9)</sup>      | Yes | Yes | No  | Yes | No  | No | Yes | Yes | No  | Yes | Yes | 6     | High     |
| Huang et al., 2015 <sup>(12)</sup>                 | Yes | Yes | No  | Yes | No  | No | Yes | Yes | No  | Yes | Yes | 6     | High     |
| Martín-Caro et al., 2023 <sup>(24)</sup>           | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | 9     | High     |
| Martín-Caro et al., 2022 <sup>(22)</sup>           | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | 9     | High     |
| San-Emeterio-Iglesias et al., 2022 <sup>(13)</sup> | Yes | Yes | No  | Yes | No  | No | Yes | Yes | No  | Yes | Yes | 6     | High     |
| Tsui et al., 2002 <sup>(23)</sup>                  | Yes | Yes | No  | No  | No  | No | Yes | No  | No  | Yes | Yes | 4     | Moderate |

NO: the study does not present the criterion studied; YES: the study presents the criterion studied; 1: Eligibility criteria were specified (this item is not taken into account for the final score); 2: Subjects were randomly allocated to groups; 3: Allocation was concealed; 4: The groups were similar at baseline regarding the most important prognostic indicators; 5: There was blinding of all subjects; 6: There was blinding of all therapists who administered the therapy; 7: There was blinding of all assessors who measured at least one key outcome; 8: Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; 9: All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"; 10: The results of between-group statistical comparisons are reported for at least one key outcome; 11: The study provides both point measures and measures of variability for at least one key outcome.



Figure 2. RoB2 risk of bias plots.

### 3.4 Synthesis of results

Active muscle functionality was evaluated through different clinical approaches across all studies included in this systematic review. Recognizing active muscle functionality as a muscle-nervous complex, some studies focused on MIS<sup>(12,13,22-24)</sup> and endurance<sup>(9)</sup>, while others focused on nerve excitability<sup>(11)</sup> and contractile properties of the muscles<sup>(10)</sup>.

#### 3.4.1. Maximum Isometric Strength (MIS)

MIS values were widely investigated in the studies included in this systematic review. Huang et al.<sup>(12)</sup> reported significant improvement in foot dorsiflexion MIS after 8 weeks of EA intervention ( $p<0.001$ ), whereas the control group, which did not receive any intervention, showed no improvement ( $p=0.846$ ). However, EA and shamEA did not perform better than manual acupuncture or sham acupuncture ( $p>0.05$ ), though all techniques showed MIS gains in both treated and non-treated limbs ( $p<0.001$ ). The study by San-Emeterio-Iglesias et al.<sup>(13)</sup> found statistically significant improvements in hip MIS with US-guided PNM for hip abduction, external and internal rotation, flexion, and extension ( $p=0.001$ ). However, only flexion strength in the non-treated limb showed significant differences when the intervention was applied at different thigh locations (proximal, medial or distal) ( $p=0.029$ ), though with a small effect size ( $\text{Eta}^2=0.1$ ). The study by Tsui et al.<sup>(23)</sup> examined painless handgrip MIS, finding that both EA and conventional acu-

puncture significantly outperformed the control group ( $p=0.000$  and  $p=0.003$ , respectively), with EA showing greater benefit than conventional acupuncture ( $p=0.045$ ). The study by Martín-Caro et al.<sup>(24)</sup> also studied handgrip MIS, but in this case without considering pain, finding no differences between the US-guided PNM group and the sham group at any time point. Interestingly, within the US-guided PNM group, handgrip MIS decreased by 10.4% at 24 hours post-intervention, followed by an increase of 14.3% at 10 days post-intervention. Similarly, Martín-Caro et al.<sup>(22)</sup> studied the MIS of finger flexion, finding significant differences between US-guided PNM and US-guided shamPNM groups. The US-guided PNM showed a reduction in MIS immediately and after 15 minutes post intervention, compared to the sham intervention, which showed no changes from the baseline ( $p<0.001$ ).

### 3.4.2. Muscle Endurance

Muscle endurance after US-guided PNM has been evaluated using the modified unilateral heel raise fatigue test. It was demonstrated significantly higher muscle endurance levels when an intervention based on US-guided PNM was applied compared to stretching ( $p<0.001$ ) and eccentric ( $p<0.001$ ) interventions, (effect size: large;  $d=1.83$ )<sup>(9)</sup>.

### 3.4.3. Contractile Properties of the Muscles and Nerve Excitability

In the study by De-la-Cruz-Torres et al.<sup>(11)</sup>, the investigators used the strength-duration curve to evaluate nerve excitability in terms of chronaxie and accommodation index. They found no significant differences in chronaxie between the US-guided PNM group and the control group with no intervention ( $p>0.05$ ). However, only the US-guided PNM group showed significant improvement in the accommodation index, indicating normalized nerve excitability in radial nerves ( $p<0.001$ ). Additionally, investigators from the study by De-la-Cruz-Torres et al.<sup>(10)</sup> employed teniomyography to assess contraction time, and their results did not show any statistically significant differences between groups of US-guided PNM, needling, neurodynamic and stretching.

## 4. Discussion

The aim of this systematic review was to determine whether invasive physiotherapy interventions using PES are effective in improving muscle active function. For this purpose, a total of 8 studies of moderate to high methodological quality and moderate risk of bias were included, all of which were randomized controlled trials.

### 4.1 Maximum Isometric Strength (MIS)

With regard to PES and MIS, the study by Huang et al.<sup>(12)</sup> demonstrated strength gains in healthy individuals up to three weeks after EA intervention, both in the treated limb and the contralateral limb through the cross-transfer effect, aligning with previous studies using the same methodology<sup>(28,29)</sup>. EA also showed an improvement in handgrip MIS in patients with lateral epicondylalgia, which was greater than with manual acupuncture<sup>(23)</sup>, as already hypothesized and demonstrated in previous studies, pointing that EA has additional effects to manual stimulation when targeting acupoints<sup>(30,31)</sup>.

In contrast, another study concluded that there were no differences between EA and manual acupuncture in terms of quadriceps strength gains<sup>(32)</sup>. This lack of difference may be attributed to an insufficient dose, as participants received only a single session. Another study reported an intriguing finding, indicating that a single session of both EA and manual acupuncture led to a short-term reduction in muscle strength (immediately and 40 minutes post-intervention for EA, and 40 minutes post-intervention for manual acupuncture). The authors suggested that the acupuncture methodology may have influenced the quadriceps reflex loop, leading to decreased muscle strength. However, no measurements were taken beyond 40 minutes post-intervention, leaving the long-term effects unknown<sup>(33)</sup>.

The results of this systematic review demonstrate that US-guided PNM has also shown positive effects in increasing MIS in patients with low back pain<sup>(13)</sup>, aligning with previous studies in individuals with unilateral knee pathology<sup>(34)</sup>. Additionally, a study on healthy soccer players who underwent US-guided PNM combined with a training program reported improvements in active muscle functionality<sup>(35)</sup>. Similarly, in professional dancers, US-guided PNM led to an immediate increase in muscle strength, surpassing the effects of stretching and eccentric exercises<sup>(9)</sup>. Regarding the duration of US-guided PNM effectiveness, the study from San-Emeterio-Iglesias et al.<sup>(13)</sup> found that its effects persisted for at least one week, consistent with prior findings in the same low back pain population<sup>(36)</sup> and in patients with unilateral anterior knee pain<sup>(37)</sup>.

In our systematic review, only two studies reported negative results when US-guided PNM was applied to improve MIS. The study by Martín-Caro et al.<sup>(24)</sup> observed a decrease in handgrip MIS in healthy volunteers 24 hours post-intervention with low-frequency (10 Hz) PNM, which recovered after 10 days. Similarly, Martín-Caro et al.<sup>(22)</sup> reported a reversible decrease in MIS of the finger flexors following high-frequency (10 kHz and 20 kHz) PNM. These findings may be explained by two hypotheses: First, increases in MIS are primarily attributed to the enhanced activation of type II muscle fibers in the stimulated muscles<sup>(15)</sup>. This may clarify the results of Martín-Caro et al.<sup>(24)</sup>, where low-frequency stimulation (10 Hz) may have been insufficient to effectively activate type II fibers in healthy individuals, whereas the same frequency might be adequate for damaged musculature in pathological populations<sup>(34)</sup>. Second, the study by Martín-Caro et al.<sup>(22)</sup> used high-frequency stimulation (10 kHz and 20 kHz) but did not observe MIS gains. The authors attributed this to the potential selective blockade of certain nerve fibers induced by high-frequency stimulation.

## 4.2 Muscle Endurance

The study by De-la-Cruz-Torres et al.<sup>(9)</sup> found significant improvements in muscle endurance in professional dancers after a single US-guided PNM session. Endurance was assessed using a modified unilateral heel raise exercise on a stable block, ensuring that the participant's toes were off the edge to eliminate the influence of intrinsic toe musculature. These findings are particularly relevant given that another study using the same endurance test in the same population found that professional dancers performed worse in endurance compared to non-dancers<sup>(38)</sup>. While this may seem counterintuitive, this study also revealed that dancers exhibited superior balance ability during single-leg stance on the toes. Together, these findings suggest that professional dancers rely more on toe musculature than non-dancers for balance and endurance tasks. Given the importance of toe musculature for this population, the results from

De-la-Cruz-Torres et al.<sup>(9)</sup> highlight the potential of US-guided PNM. Future research should explore US-guided PNM application in improving endurance in non-athletic populations.

### 4.3 Contractile properties of the muscles and nerve excitability

The study by De-la-Cruz-Torres et al.<sup>(10)</sup> used tensiomyography to assess contraction time in the hamstring musculature. Their findings revealed no significant improvement after a single session of US-guided PNM compared to needling, neurodynamic, and stretching interventions. This lack of positive results may be attributed to evidence suggesting that neural tension improvements can occur even without changes in electromyographic signals<sup>(39)</sup>.

On the other side, the study by De-la-Cruz-Torres et al.<sup>(11)</sup> found a normalization in nerve excitability, as significant improvements in the accommodation index of the S-D curve test were observed after US-guided PNM intervention. This evidence supports the use of the S-D curve for evaluating nerve excitability in peripheral neuropathy conditions<sup>(40)</sup>.

### 4.4 Limitations and future research

This systematic review, despite its relevant findings, has certain limitations that must be considered when interpreting its results. The main limitation is the significant heterogeneity in PES intervention protocols across the included studies, with variations in stimulation localization and electrical parameters (frequency, intensity, pulse duration, number of sessions), making direct comparisons challenging. Another limitation is the difficulty in comparing findings from studies involving different populations. As previously discussed, the effectiveness of an intervention may depend on the degree of dysfunction in the target population, with some PES parameters being sufficient to improve active muscle functionality in pathological populations but potentially insufficient for healthy individuals. Lastly, the diversity of control groups, ranging from no intervention or sham procedures to passive or active treatments such as passive stretching, eccentric exercises, or manual acupuncture, further complicates result interpretation. The variability in comparison groups hinders the homogenization of outcomes and limits the ability to draw definitive conclusions regarding the relative effectiveness of PES. It is important to exercise caution when comparing PNM with EA, as the EA interventions included in this review did not utilize ultrasound guidance, which is a relevant aspect to consider.

Despite these limitations, this systematic review offers a comprehensive synthesis of the available evidence on the effects of PES on active muscle functionality. The findings suggest that these invasive physiotherapy techniques hold promise as a therapeutic tool for rehabilitating various musculoskeletal conditions. However, further research with more rigorous study designs and larger sample sizes is needed to confirm these results. Future studies should focus on establishing standardized PES intervention protocols, optimizing stimulation parameters, and defining the most effective application sites. Additionally, well-designed randomized controlled trials with homogeneous comparison groups are essential to accurately assess the clinical effectiveness of PES in specific populations.

## 5. Conclusions

PES, including EA and PNM interventions, has proven effective in enhancing active muscle functionality in both healthy individuals and those with musculoskeletal conditions. These techniques have demonstrated improvements in MIS and muscle endurance, as well as the normalization of nerve excitability in specific populations. However, contraction time did not show greater improvement compared to non-percutaneous interventions. Further research is needed to establish standardized protocols and conduct larger, more homogeneous randomized controlled trials to strengthen the evidence on the clinical effectiveness of PES in rehabilitation settings.

## References

1. Morgan J, Partridge T. Skeletal muscle in health and disease. *Dis Model Mech*. 2020;13(2). doi:10.1242/dmm.042192
2. Castellano L, Gache V. Microtubular network and functionality of the striated skeletal muscle. *Med Sci (Paris)*. 2023;54–7. doi:10.1051/medsci/2023146
3. Costa BD de V, et al. Does Varying Resistance Exercises for the Same Muscle Group Promote Greater Strength Gains? *J Strength Cond Res*. 2022;36(11):3032–9. doi:10.1519/JSC.0000000000004042
4. Sánchez Riera C, et al. Muscle Diversity... *Int J Mol Sci*. 2021;22(5):2502. doi:10.3390/ijms22052502
5. Tumkur Anil Kumar N, et al. The Influence of Growth... *Sports (Basel)*. 2021;9(5):59. doi:10.3390/sports9050059
6. Fidalgo-Martin I, et al. Effects of percutaneous neuromodulation... *Medicine (Baltimore)*. 2022;101(41):e31016. doi:10.1097/MD.00000000000031016
7. Yue C, et al. Systematic Review... *J Arthroplasty*. 2018;33(7):2330–7. doi:10.1016/j.arth.2018.01.070
8. Strand NH, et al. Mechanism of Action... *Curr Pain Headache Rep*. 2021;25(7):47. doi:10.1007/s11916-021-00962-3
9. De-la-Cruz-Torres B, et al. Immediate effects... *Acupunct Med*. 2019;37(2):91–7. doi:10.1136/acupmed-2013-010489
10. De-la-Cruz-Torres B, et al. Crossover effects... *Acupunct Med*. 2020;39(5):512–21. doi:10.1177/0964528420920283
11. De-la-Cruz-Torres B, et al. Ultrasound-Guided Percutaneous... *Int J Environ Res Public Health*. 2021;18(9):4877. doi:10.3390/ijerph18094877
12. Huang LP, et al. Unilateral intramuscular needling... *J Exerc Sci Fit*. 2015;13(2):86–93. doi:10.1016/j.jesf.2015.07.001
13. San-Emeterio-Iglesias R, et al. Effect of Ultrasound-Guided... *J Clin Med*. 2022;11(22):6672. doi:10.3390/jcm11226672
14. Heyters M, et al. Twitch Analysis... *Can J Appl Physiol*. 1994;19(4):451–61. doi:10.1139/h94-037
15. Requena Sánchez B, et al. Percutaneous electrical stimulation... *J Strength Cond Res*. 2005;19(2):438–48. doi:10.1519/13173.1

16. Sinacore DR, et al. Type II Fiber Activation... *Phys Ther.* 1990;70(7):416–22. doi:10.1093/ptj/70.7.416
17. Powers RK. “Extra” force evoked... *J Appl Physiol* (1985). 2009;106(2):353–5. doi:10.1152/japplphysiol.91540.2008
18. Page MJ, et al. The PRISMA 2020 statement... *BMJ.* 2021;372:71–71. doi:10.1136/bmj.l4898
19. Maher CG, et al. Reliability of the PEDro Scale... *Phys Ther.* 2003;83(8):713–21. PMID:12882612
20. Albanese E, et al. Construct validity of the PEDro scale... *Res Synth Methods.* 2020;11(2):227–36. doi:10.1002/jrsm.1385
21. Sterne JAC, et al. RoB 2: a revised tool... *BMJ.* 2019;366:l4898. doi:10.1136/bmj.l4898
22. Martín-Caro D, et al. Effect of Percutaneous Electric Stimulation... *J Clin Med.* 2022;11(7):1832. doi:10.3390/jcm11071832
23. Tsui P, Leung MCP. Comparison... *Acupunct Electrother Res.* 2002;27(2):107–17. doi:10.3727/036012902816026040
24. Martín-Caro D, et al. The effect on handgrip strength... *Anat Rec (Hoboken).* 2023;306(4):720–7. doi:10.1002/ar.24887
25. Stillman BC. Some aspects of the theory... *Aust J Physiother.* 1967;13(2):62–71. doi:10.1016/S0004-9514(14)60976-4
26. Dahmane R, et al. Evaluation of the ability... *Med Biol Eng Comput.* 2001;39(1):51–5. doi:10.1007/BF02345266
27. Rey E, et al. The Effect of Recovery Strategies... *J Strength Cond Res.* 2012;26(11):3081–8. doi:10.1519/JSC.0b013e3182470d33
28. Yang H, et al. Electrical acupoint stimulation... *Zhongguo Zhen Jiu.* 2006;26(5):313–5. PMID:16739839
29. Ozerkan KN, et al. Comparison of the Effectiveness... *Acupunct Electrother Res.* 2007;32(1):71–9. doi:10.3727/036012907815844129
30. Zhou S, et al. Bilateral effects of 6 weeks’... *Arch Phys Med Rehabil.* 2012;93(1):50–5. doi:10.1016/j.apmr.2011.08.010
31. Langevin HM, et al. Mechanical signaling through connective tissue... *FASEB J.* 2001;15(12):2275–82. doi:10.1096/fj.01-0015hyp
32. Plaster R, et al. Immediate effects... *Acupunct Med.* 2014;32(3):236–41. doi:10.1136/acupmed-2013-010489
33. Kim D, et al. Electroacupuncture and Manual Acupuncture... *Healthcare (Basel).* 2020;8(4):414. doi:10.3390/healthcare8040414
34. Álvarez-Prats D, et al. Changes in Maximal Isometric Quadriceps Strength... *JITPT.* 2019;2(1):39–45. doi:10.1055/s-0039-1688551
35. Gallego-Sendarrubias GM, et al. Effects of Percutaneous Electrical Nerve Stimulation... *J Clin Med.* 2021;10(4):690. doi:10.3390/jcm10040690
36. San-Emeterio-Iglesias R, et al. Correct Sciatic Nerve Management... *J Clin Med.* 2021;24(6):1067–74. doi:10.1111/ner.13396
37. Garcia-Bermejo P, et al. Ultrasound-Guided Percutaneous Neuromodulation... *Appl Sci.* 2020;10(13):4647. doi:10.3390/app10134647

**38.** Rowley KM, et al. Toe Flexor Strength, Flexibility... Med Probl Perform Art. 2015;30(3):152–6. doi:10.21091/mppa.2015.3029

**39.** McHugh MP, et al. The role of neural tension... Scand J Med Sci Sports. 2012;22(2):164–9. doi:10.1111/j.1600-0838.2010.01180.x

**40.** Friedli WG, Meyer M. Strength-duration curve... J Neurol Neurosurg Psychiatry. 1984;47(2):184–9. doi:10.1136/jnnp.47.2.184

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