

- A – Research concept and design
 B – Collection and/or assembly of data
 C – Data analysis and interpretation
 D – Writing the article
 E – Critical revision of the article
 F – Final approval of article

Received: 2021-12-28
 Accepted: 2022-01-31
 Published: 2022-02-01

Efficacy of biofeedback in rehabilitation of musculoskeletal disorders: A systematic review

Hernán Andrés de la Barra Ortiz^{A,C-F*} , Alexandra Meza Matamala^{A-C,E-F} , Francisca López Inostroza^{B-F} , Catalina Lobos Araya^{B-D,F} , Valeria Núñez Mondaca^{B-D,F} 

Exercise and Rehabilitation Sciences Laboratory, Faculty of Rehabilitation Sciences, School of Physical Therapy, Universidad Andres Bello, Chile

***Correspondence:** Hernán Andrés de la Barra Ortiz; Exercise and Rehabilitation Sciences Laboratory, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago 7591538, Chile; e-mail: hdelabarra@unab.cl, handresdelabarra@yahoo.es

Abstract

Musculoskeletal disorders (MSD) are a frequent reason for consultation and the main cause of disability in population. Electromyographic biofeedback or myofeedback (MF) is a promising treatment in rehabilitation, although studies supporting its benefits in MSD have declined in recent years. The objective of this review was to describe the efficacy of MF in function recovery, strength increase and muscle relaxation in MSD. Randomized clinical trials (RCTs) were identified in Pubmed, Scopus, Web of Science, Cinahl and Science Direct databases dated September 2, 2021. Four independent researchers reviewed articles titles and abstracts to determine their eligibility. Risk of bias and articles quality was assessed using Rob2 tool (Cochrane) and PEDro scale. Functionality improvement, strength increase, and muscle relaxation were considered as main outcome. Search strategy yielded 160 articles after eliminating duplicates, reducing to 26 when selection criteria were applied. Articles were classified in strengthening (n = 16) and muscle relaxation (n = 10) according to MF therapeutic aim. Eighteen articles were rated as low risk of bias (69.22%) and an average internal validity of 6 points was obtained. Studies showed improvements in functionality, strength increase and pain reduction with statistical significance when MF were complemented with therapeutic exercises or other physical agents modalities (p < 0.005). MF also showed a decrease in fear of movement, depression, and pain perception, suggesting central modulating effects. This review supports MF efficacy in MSD rehabilitation, showing improvements in functionality and pain reduction. The review allowed to establish a dosage recommendation based on articles analysis which can be considered for future RCTs.

Keywords: rehabilitation, biofeedback, musculoskeletal diseases, myofeedback, recovery of function

Introduction

Musculoskeletal pain (MSP) is currently recognized as one of the main reasons for medical consultation and the most common cause of disability in adults worldwide, affecting about 47% of the population [1,2]. MSP is classified chronologically as acute or chronic

depending on whether it persists for more than three months, which occurs in 39 to 45% of patients [1,3]. Chronic MSP is associated with sleep disturbances, fatigue, depression, and activity limitations, which affect life quality and work productivity [4,5]. Currently, its prevalence in adults is 20%, and it is estimated that, by 2050, it will reach 50% [3].



This is an Open Access journal, all articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0). License (<http://creativecommons.org/licenses/by-nc-sa/4.0/>).

Although MSP is usually of nociceptive origin, people with chronic disorders may experience neuropathic pain (NP) or nociplastic pain (NCP) [6,7]. NP occurs due to injury or dysfunction of the nervous system, manifesting clinically with hyperalgesia and allodynia, muscle weakness, and impaired reflexes [8]. NCP is characterized by altered nociception phenomena in which there is no clear disease evidence, real tissue damage or somatosensory system injury, causing fibromyalgia, regional pain complex, and nonspecific lumbar pain [7,8]. The transition from acute or chronic MSP to NCP is associated with central sensitization phenomena produced by changes in ion channels expression of nociceptive neurons, which triggers their greater excitability, reinforced synaptic transmission, and decreased pain inhibition processes at the spinal cord posterior horn, subcortical and cortical areas such as the thalamus, somatosensory cortex, or primary motor cortex [5,9,10]. Furthermore, less neural connectivity between the prefrontal cortex and somatosensory areas has been documented in patients with chronic MSP, along with more synaptic networks with the insula, which exacerbates the psychological and emotional components [11,12].

Currently, more than 150 musculoskeletal disorders (MSD) have been recognized, highlighting degenerative and autoimmune joint diseases, fractures, dislocations, muscle injuries, sprains, and tendinopathies [1,2,6]. Most frequent presentations include the back, neck, shoulders, and knees, although multiregional MSDs are also described [1,13]. MSD can debut at any age; however, their prevalence increases from adolescence onwards [14].

MSD medical treatment has been oriented to their clinical symptoms with analgesic drugs, non-steroidal anti-inflammatory drugs (NSAIDs), opiates or corticosteroids infiltration, which produce symptoms relief, although they aren't a functional improvement guarantee, added to the fact that for some conditions their efficacy and safety are uncertain [15,16]. In addition, the overuse of drugs has been associated with analgesic tolerance, hyperalgesia, and adverse effects, such as nausea, vomiting, gastrointestinal irritation, arterial hypertension, kidney problems, or hepatotoxicity [15–17]. Surgery is an alternative for many MSD with refractory symptoms or pharmacological treatment resistance, although its efficacy is dependent on clinical conditions, personal and contextual variables, added to patient economic costs [15,18].

Physical therapy is a non-pharmacological option for pain management and functional recovery in MSD, using treatments such as therapeutic ultrasound (US), transcutaneous electrical nerve stimulation (TENS), photobiomodulation (PBM), manual therapy, and

therapeutic exercise [19–21]. Another therapeutic alternative is electromyographic biofeedback or myofeedback (MF), a safe and non-invasive intervention supported for strength increase, muscle relaxation, and functional recovery in a variety of MSD [22–25] being used for motor reeducation and muscle training in musculoskeletal, neurological, and pelvic floor conditions [26,27]. MF captures motor neuron's myoelectric signals through surface electrodes (extracellular technique) or percutaneous (intracellular technique), converting them into visual or auditory information that provides patient immediate feedback on voluntary muscle contraction (VMC) or muscle activity at rest. MF electrodes perceive voltage changes in microvolts associated with neuromuscular activity, transmitting them to an amplifier and processor that filters, integrates, and rectifies bioelectric waves, transforming them into digital signals represented graphically or audibly. This information is used to promote or decrease motor activity depending on whether the objective is to strengthen, relax or re-educate motor patterns [28].

Biological feedback processes are essential for human movement realization and regulation. Motor neurons activity is the result of the interaction between the central nervous system (CNS) and sensory function, through an intrinsic feedback system formed by neurological circuits between the motor system, proprioceptors, joint receptors, skin receptors, vestibular system, and visual system [28–30]. On the other hand, visual and/or auditory biofeedback favors the different levels of afferent and efferent integration in CNS, allowing the patient to control motor activity [28].

Even though the literature describes MF as a valuable therapeutic resource, publications that support its use for MSD have decreased in recent years, showing greater development in neurological and pelvic floor rehabilitation, so an update in musculoskeletal rehabilitation is necessary. Thus, the objective of this systematic review (SR) was to describe the efficacy of MF in function recovery, strength increase and muscle relaxation in MSD.

Materials and methods

Study design

This SR adheres to the PRISMA statement on the reporting of preference items for systematic reviews and meta-analysis (available at <http://www.prisma-statement.org>) [31]. The research was uploaded electronically to the International SR Prospective Registry (PROSPERO) of the National Institute for Health Research (NIHR), obtaining the identification code CRD42021228046.

The PICO acronym (participants, intervention, comparison, and outcome) was used to structure the research question and search algorithm based on the following elements: patients with MSD, intervened with MF, compared with a control, sham application or placebo, and evaluating, as main outcome, changes in functionality and, as secondary result, pain decrease, range of motion (ROM) increase, or muscle strength.

Search strategy

The SR was performed considering PubMed, Scopus, Web of Science (WoS), Cinahl, and Science Direct electronic databases with the last update on September 2, 2021. For the search, keywords from the MeSH dictionary were chosen (Medical Subject Headings, <https://www.ncbi.nlm.nih.gov/mesh>). Search terms included “Biofeedback”, “Myofeedback”, “Myoelectric biofeedback”, “Rehabilitation”, “Recovery of Function” and “Musculoskeletal Diseases” connected through the boolean terms “OR” and “AND” obtaining the following algorithm: (((“Biofeedback”) OR (“Myofeedback”)) OR (“Myoelectric biofeedback”)) AND ((“Rehabilitation”) OR (“Recovery of Function”)) AND ((“Musculoskeletal Diseases”) OR (“Musculoskeletal Pain”)).

Searches for each database were downloaded (nbib, ris or ciw formats) and the files were analyzed with the Rayyan tool developed for the preliminary selection of abstracts and article titles (<https://www.rayyan.ai>) [32]. Four independent researchers (AM, FL, CL, VN) analyzed articles titles and abstracts based on the selection criteria, classifying them in the “included”, “maybe” and “excluded” categories. In addition, the references of the studies were examined and revised in terms of their country of origin, author, affiliated institutions, and enrollment periods to identify and exclude duplicate publications. Articles in the “maybe” category were reviewed by the research team to determine their inclusion in the final count. Articles with incomplete abstracts were discarded from the analysis, and each investigator recorded their reasons for exclusion.

For included articles, study objective, PEDro scale score, participants demographic data, follow-up period, evaluation time, treatment protocol with MF and results in the interest outcomes were analyzed [33].

Selection criteria

Inclusion criteria considered: (1) randomized clinical trials (RCT), (2) human studies, (3) articles in English or Spanish, (4) participants older than 18 years, (5) participants with MSD, (6), studies that used MF alone or with another intervention in MSD rehabilitation, (7) comparison with another treatment, sham, or placebo, (7) outcome measures including changes in function, muscle strength, muscle relaxation, pain, or range of

motion. The exclusion criteria were: (i) case report studies, systematic reviews (SR), meta-analysis (MT) and literature reviews, (ii) animal-testing or in vitro studies, (iii) use of MF in non-musculoskeletal conditions, and (iv) studies with incomplete abstracts or texts.

Article’s quality and risk of bias

The articles’ internal validity was determined with the PEDro scale [33]. Each researcher performed an independent assessment, and any disagreement was subsequently discussed to establish consensus. RCTs with scores less than five were classified as “low quality,” while scores greater than or equal to 5 were considered “high quality.”

Risk of bias was assessed using the RoB.2 tool (Cochrane Collaboration tool for RCT analysis in SR) for the following domains [34]; (1) bias arising from randomization process, (2) bias due to deviations from planned interventions, (3) bias due to missing outcome data, (4) outcome measurements bias, (5) bias in reported outcome selection, and (6) overall article bias. The investigators rated the risk of bias for each criterion as high, low, unclear, or no information in case the data provided were not sufficient to decide. Box and summary plots were constructed with the Robvis tool [35]. Studies with two or more high risks of bias were considered as low quality [34].

Results

Search results

Preliminary search strategy yielded a total of 5,141 articles for selected databases (Pubmed, $n = 25$; Scopus, $n = 2918$; WoS, $n = 10$; Cinahl, $n = 1494$, and Science Direct, $n = 695$). After reviewing titles and abstracts, 160 articles were classified as “possible” and “included” when applying selection criteria. The researchers reached consensus on these articles, discarding 134 studies, and finally including 26 for analysis [22–25,35–55]. The main reasons for exclusion were surface electromyography studies, other types of studies, articles in another language, studies that addressed non-musculoskeletal conditions, and articles with incomplete or unavailable abstracts. Figure 1 shows the PRISMA flow chart with a summary of the screening results [57].

Risk of bias and quality

This SR rated 7.69% of articles ($n = 2$) as high risk of bias [23,25,27,33,36,38,43,45], especially in domains 1 and 2 for RoB.2 tool [56,57]. On the other hand, 26.92% ($n = 7$) did not present risks of bias for any of domains [22,24,26,28,35,37,42,44], while 42.30% presented at least some concern, especially for

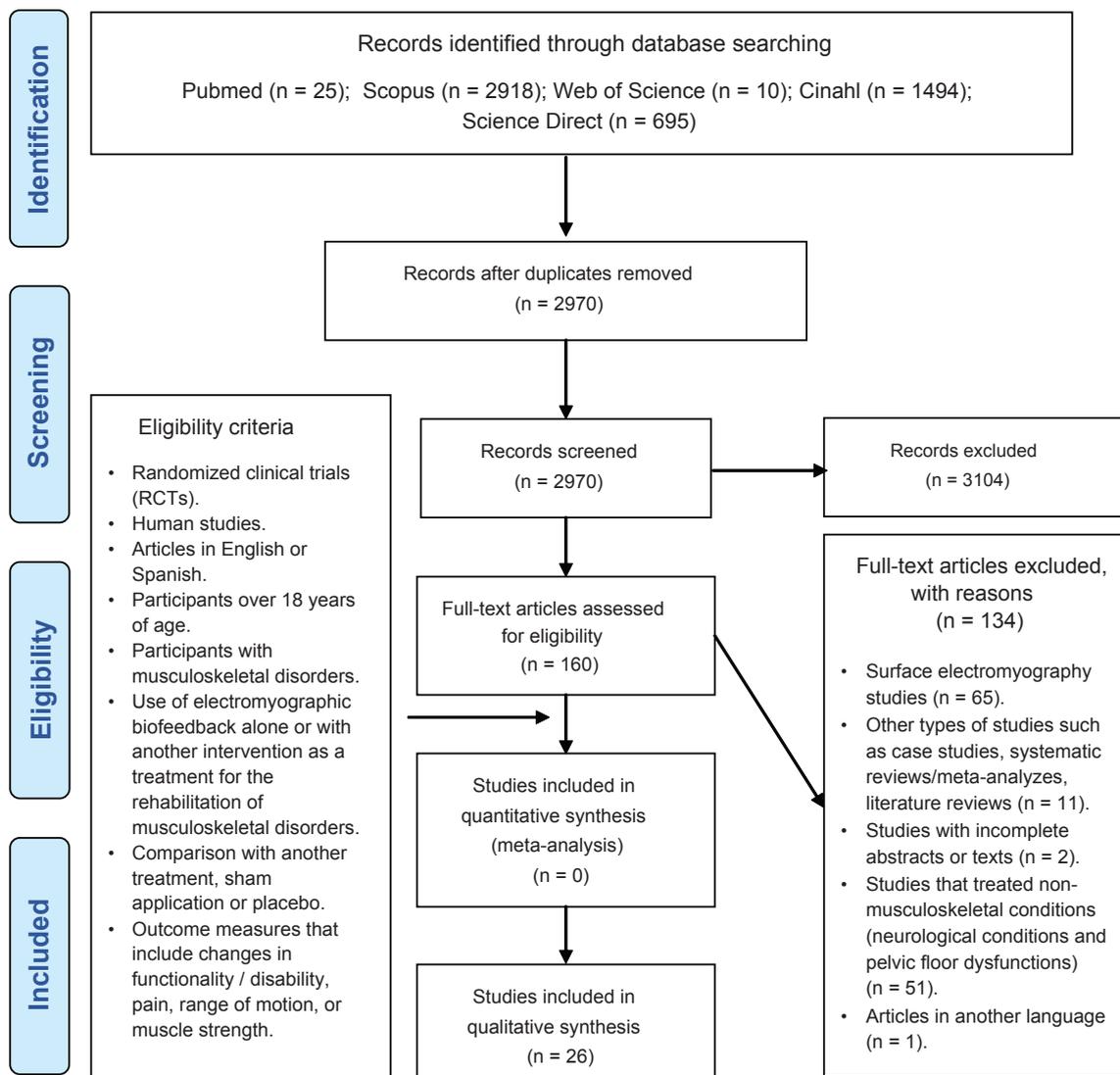


Fig. 1. Flowchart of included studies in accordance with PRISMA guidelines

random assignment. Figure 2 summarizes risk of bias of the selected articles.

Table 1 shows the PEDro score for the 26 RCT. Internal validity shows that 65.38% of articles (n = 17) are of high quality (score greater than or equal to 5 for PEDro scale) with an average of 7 points for all the articles [33].

Study characteristics

Studies were grouped in Tables 2 and 3 according to their MF therapeutic aim (strengthening or muscle relaxation), summarizing the characteristics of 26 RCT in study groups, evaluation sessions, treatment sessions and the outcome measures of the variables of interest. Table 2 shows that 16 articles (61.53%) report MF for muscle strengthening, while table 3 shows 10 studies for muscle relaxation (38.46%). Strengthening MF studies included post-arthroscopic meniscal injury (n = 4, 25.00%), subacromial impingement syndrome

(SAIS) (n = 2, 12.5%), patellofemoral pain syndrome (PFPS) (n = 2, 12.5%), anterior cruciate ligament reconstruction (ACLR) (n = 2, 12.5%), knee osteoarthritis (OA) (n = 5, 31.25%), non-surgical meniscal injuries (n = 3, 18.75%) and nucleus hernia pulposus (n = 1, 6.25%) [22,23,35–48]. On the other hand, MF muscle relaxation studies included cervicobrachialgia (n = 3, 30.00%), neck pain (n = 2, 20.00%), whiplash syndrome (WPS) (n = 2, 20.00%), cervical radiculopathy (n = 1, 10.00%), fibromyalgia (n = 1, 10.00%), low back pain syndrome (LBPS) (n = 1, 10.00%) [24,25,49–56].

Six studies (23.07%) used MF in experimental groups (EG) without other added treatment [41,50,51,54–56], while the remaining ones applied MF combined with another treatment. Isolated MF applications were mainly aimed at achieving muscle relaxation in neck pain, cervicobrachialgia, and LBPS [50,51,55,56], while only Choi (2015) applied isolated MF for strengthening in knee OA [41].

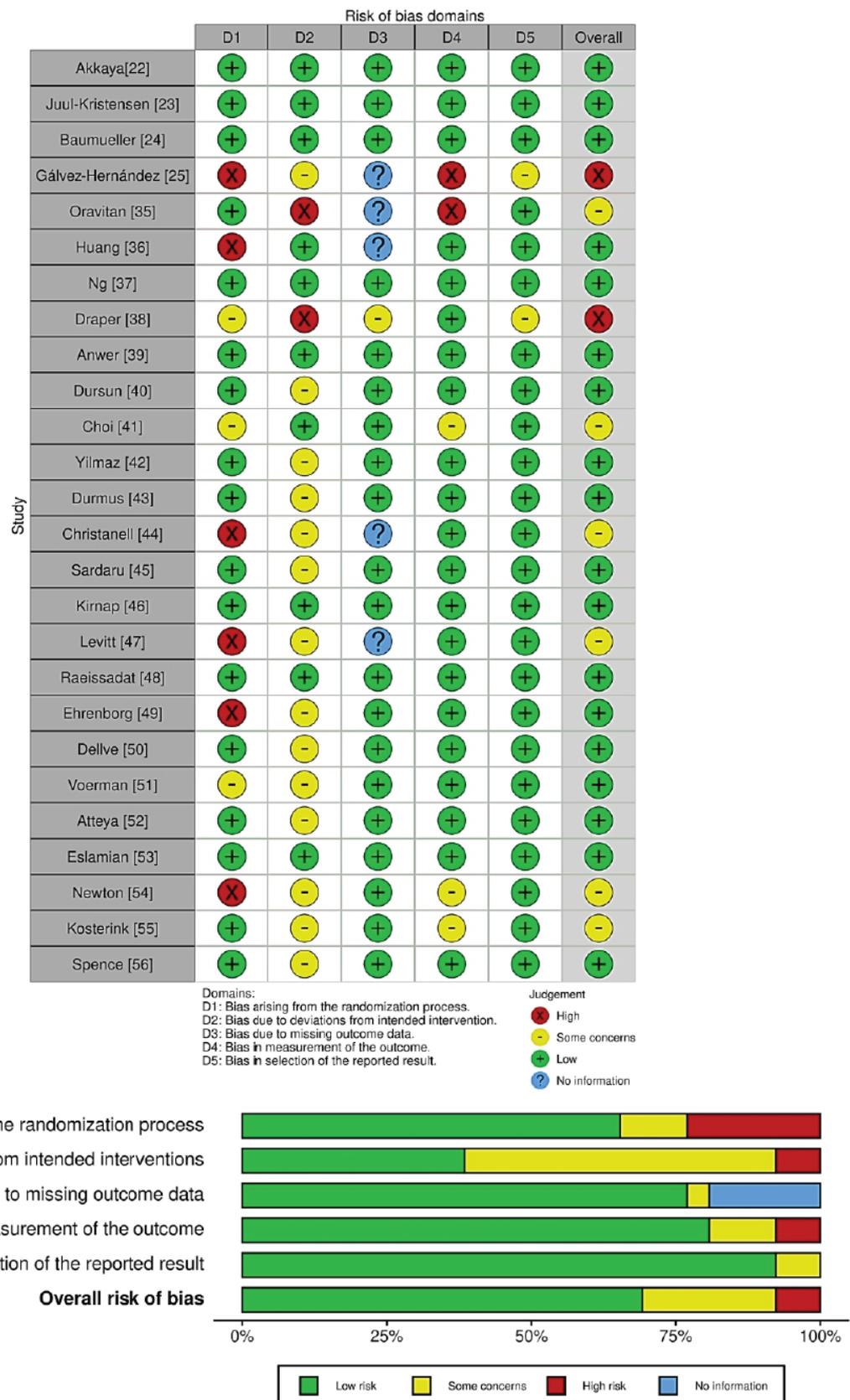


Fig. 2. Risk of bias for the selected studies (ROBVIS tool)

Tab. 1. PEDro scale scores of analyzed studies

Clinical trial number	Author, year of publication	PEDro scale criteria											Total score
		1	2	3	4	5	6	7	8	9	10	11	
1	Akkaya, 2012 [22]	0	1	1	1	0	0	1	1	0	1	1	7
2	Juul-Kristensen, 2019 [23]	1	1	1	1	0	0	1	1	1	1	1	8
3	Baum Mueller, 2007 [24]	1	1	0	0	1	0	0	1	0	1	1	5
4	Gálvez-Hernández, 2016 [25]	1	0	0	0	0	0	0	0	0	1	0	1
5	Oravitan, 2013 [35]	0	1	0	1	0	0	0	0	0	1	1	4
6	Huang, 2013 [36]	1	0	0	1	1	0	0	1	0	1	1	5
7	Ng, 2008 [37]	0	1	0	1	0	0	1	1	0	0	1	5
8	Draper, 1997 [38]	0	1	0	0	0	0	0	0	0	1	0	2
9	Anwer, 2011 [39]	0	1	0	0	1	0	0	0	1	1	1	5
10	Dursun, 2001 [40]	1	1	0	1	0	0	0	1	0	1	1	5
11	Choi, 2015 [41]	1	1	0	1	0	0	0	0	0	1	1	4
12	Yilmaz, 2010 [42]	1	1	0	1	0	0	0	1	0	1	1	5
13	Durmus, 2007 [43]	1	1	0	1	0	0	0	1	0	1	1	5
14	Christanell, 2012 [44]	1	0	0	1	0	0	0	1	0	1	1	4
15	Sardaru, 2018 [45]	1	1	0	1	0	0	0	1	1	1	1	6
16	Kirnap, 2005 [46]	0	1	0	1	0	0	0	1	0	1	1	5
17	Levitt, 1995 [47]	1	0	0	1	0	0	0	0	0	1	1	3
18	Raeissadat, 2018 [48]	1	1	0	1	0	0	1	1	1	1	1	7
19	Ehrenborg, 2010 [49]	1	0	0	1	0	0	0	1	1	1	1	5
20	Dellve, 2011 [50]	1	1	1	1	0	0	0	0	0	1	1	5
21	Voerman [51]	1	1	0	1	0	0	0	1	1	0	1	5
22	Atteya, 2004 [52]	1	1	0	1	0	0	0	1	1	0	1	5
23	Eslamian, 2020 [53]	1	1	1	1	0	0	1	1	1	1	1	8
24	Newton, 1995 [54]	1	0	0	1	0	0	0	0	0	1	1	3
25	Kosterink, 2010 [55]	1	1	0	1	0	0	0	0	0	1	1	4
26	Spence, 1995 [56]	0	1	0	0	0	0	0	1	0	1	1	4

PEDro (Physiotherapy Evidence Database) scale criteria:

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

Tab 2. Characteristics of muscle strengthening MF studies

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age ± DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
1	Efficacy of electromyographic biofeedback and electrical stimulation following arthroscopic partial meniscectomy: a randomized controlled trial [22].	Akkaya [2012] Turkey	Meniscal injury	n = 45 Men = 19 Women = 26 47 ± 11.6	EG = 15 (10 women; 5 men) CG1 = 15 (7 women; 8 men) CG2 = 15 (9 women; 6 men)	EG = QF MF + exercise program (Phase 1: hamstring stretching, drainage exercises; Phase 2: ABD and ADD exercises, knee flexion and extension, QF and GN stretching exercises; Phase 3: CKC exercises lower limb, progressive resistance exercises). CG 1 = Exercise program (Phase 1: hamstring stretching, drainage exercises; Phase 2: hip ABD and ADD exercises, knee flexion and extension, QF and GN stretching exercises; Phase 3: lower limb CKC exercises, progressive resistance exercises). CG 2 = NMES + exercise program (Phase 1: hamstring stretching, drainage exercises; Phase 2: hip ABD and ADD exercises, knee flexion and extension, QF and GN stretching exercises; lower, progressive resistance exercises).	Sessions: 10 sessions (5 weekly sessions) – 2 weeks total Treatment time: NS	T0: baseline (before surgery) T1: week 2 (10 sessions) T2: week 6 (30 sessions)	Walking pain intensity (VAS) Running speed (2-MWT) Functionality (Lyshom scale) Flexion and extension ROM (goniometer) Edema (perimetry) Quadriceps femoris muscle strength (EMG)	Walking pain intensity (VAS) Running speed (2-MWT) Functionality (Lyshom scale) Flexion and extension ROM (goniometer) Edema (perimetry) Quadriceps femoris muscle strength (EMG) Not reported Quadriceps femoris muscle strength (EMG)

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age \pm DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
2	Positive effects of neuromuscular shoulder exercises with or without EMG-biofeedback, on pain and function in participants with subacromial pain syndrome – A randomised controlled trial [23]	Juul-Kristensen [2019] Denmark	SAIS	n = 49 Men = 24 Women = 25 43 \pm NS	EG = 26 (NS) CG = 23 (NS)	EG = UT, MT, LT and SA MF + exercise protocol (phase 1: scapular stabilization and stretching exercises; phase 2: functional resistance exercises with scapular stabilization). CG = exercise protocol (phase 1: scapular stabilization and stretching exercises; phase 2: functional resistance exercises with scapular stabilization).	Sessions: 40 sessions (5 per week) – 8 weeks total Treatment time: 4 to 6 minutes (30 seconds of contraction and 60 seconds of relaxation)	T0: baseline (before treatment) T1: 8 weeks	Pain intensity (NPRS) Disability EESS (DASH) Functionality (OSS) Electromyographic activity UT, MT, LT and SA (EMG)	Pain intensity (NPRS) EG: T1 < T0 CG: T1 < T0 EG < CG for T1* Disability EESS (DASH) EG: T1* < T0 CG: T1* < T0 EG = CG for T0 Functionality (OSS) EG: T1* > T0 CG: T1* > T0 EG = CG for T0 Electromyographic activity UT, MT, LT and SA (EMG) EG: T1 > T0 CG: T1 > T0 EG = CG for T0
3	The Effectiveness of Electromyographic Biofeedback as Part of a Meniscal Repair Rehabilitation Programme [35]	Oravitan [2013] Romania	Meniscal injury	n = 64 Men = 43 Women = 21 35 \pm 6.5	EG = 33 (11 women; 22 men) CG = 31 (10 women; 21 men)	EG = QF and HS MF + rehabilitation program (mobility exercises, partial weight bearing, total weight bearing, scar mobilization, NMES, cryotherapy, stretching and coordination exercises). CG = rehabilitation program (mobility exercises, partial weight bearing, total weight bearing, scar mobilization, NMES, cryotherapy, stretching and coordination exercises).	Sessions: 40 sessions (5 per week) – 8 weeks total Treatment time: 20 minutes (20 seconds of contraction and 5 seconds of relaxation)	T0: baseline (before treatment) T1: 8 weeks (40 sessions)	Pain intensity (KOOS) Knee functionality (KOOS) Knee flexor and extensor strength (MD) Electromyographic QF activity (EMG) HS electromyographic activity (EMG)	Pain intensity (KOOS) EG: T1 > T0 CG: T1 > T0 EG = CG for T1 Knee functionality (KOOS) EG: T1 > T0 CG: T1 > T0 EG > CG for T1* (sports and recreational activities item) Knee flexor and extensor strength (MD) EG: T1 > T0 CG: T1 > T0 EG = CG for T1 Electromyographic activity (EMG) EG: T1* > T0 CG: T1 > T0 EG > CG for T1* HS electromyographic activity (EMG) EG: T1 > T0* CG: T1 > T0 EG > CG for T1*

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age ± DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
4	EMG biofeedback effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement [36]	Huang [2013] Taiwan	SAIS	n = 25 Men = NS Women = NS 24 ± 3.6	GE 1 = 13 (NS) GE 2 = 12 (NS) CG 1 = 13 (NS) CG 2 = 12 (NS)	EG 1 = UT, MT, LT and SA MF + resistance exercises (shoulder flexion movements, shoulder external rotation and KPP) + scapular exercises (scapular upward and posterior tilt). EG 2 = UT, MT, LT and SA MF + resistance exercises (shoulder flexion movements, shoulder external rotation and KPP) + scapular exercises (scapular upward and posterior tilt). CG 1 = resistance exercises (shoulder flexion movements, shoulder external rotation and KPP) + scapular exercises (scapular upward and posterior tilt). CG 2 = resistance exercises (shoulder flexion movements, shoulder external rotation and KPP) + scapular exercises (scapular upward and posterior tilt).	Sessions: 1 session Treatment time: 4 minutes (6 seconds for each repetition, 3 repetitions for each exercise except for KPP; 1 minute rest between each exercise).	T0: baseline (before treatment) T1: end of treatment	MVC relationship between UT, MT, LT and SA for shoulder flexion (EMG) MVC relationship between UT, MT, LT and SA for external rotation of the shoulder (EMG) MVC relationship between UT, MT, LT and SA for external rotation of the shoulder (EMG) Scapular kinematics of upward and posterior tilt (EMG)	MVC relationship between UT, MT, LT and SA for shoulder flexion (EMG) EG 1: T1 < T0 EG 2: T1 < T0 CG 1: T1 > T0 CG 2: T1 > T0 CG 1 y CG 2 > EG 1 y EG 2 for T1 MVC relationship between UT, MT, LT and SA for external rotation of the shoulder (EMG) EG 1: T1 < T0 EG 2: T1 < T0 CG 1: T1 > T0 CG 2: T1 > T0 GC 1 y GC 2 > GE 1 y GE 2 para T1 MVC relationship between UT and SA (EMG) EG 1: T1 < T0 EG 2: T1 < T0 CG 1: T1 > T0 CG 2: T1 > T0 GC 1 y GC 2 > GE 1 y GE 2 para T1 Scapular kinematics of upward and posterior tilt (EMG) EG 1: T1* > T0 EG 2: T1* > T0 CG 1: T1 > T0 CG 2: T1 > T0 EG 1 y EG 2 > CG 1 y CG 2 for T1*

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age \pm DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
5	Biofeedback exercise improved the EMG activity ratio of the medial and lateral vasti muscles in subjects with patellofemoral pain syndrome [37]	Ng [2008] China	PPPS	n = 26 Men = 10 Women = 16 38 \pm NS	EG = 13 (NS) CG = 13 (NS)	EG = QF MF + therapeutic exercises (warm-up, strengthening, proprioceptive exercises and agility exercises) CG = Therapeutic exercises (warm-up, strengthening, proprioceptive exercises and agility exercises)	Sessions: 40 sessions (5 per week) – 8 weeks total Treatment time: 30 minutes	T0: baseline (before treatment) T1: 8 weeks (end of treatment)	EMG activity relationship between VMO/VLM (EMG) EG: T1* > T0 CG: T1 > T0	EMG activity relationship between VMO/VLM (EMG) EG: T1* > T0 CG: T1 > T0
6	Electrical Stimulation Versus Electromyographic Biofeedback in the Recovery of Quadriceps Femoris Muscle Function Following Anterior Cruciate Ligament Surgery [38]	Draper [1997] USA	ACL	n = 30 Men = 16 Women = 16 25 \pm 7.8	EG = 15 (6 women; 9 men) CG = 15 (8 women; 7 men)	EG = QF MF exercises (weeks 1 and 2: isotonic resistance exercises, week 3 and 4: isometric exercises, week 5 and 6: isokinetic exercises) + SLR CG = QF NMES + QF quadriceps exercises (weeks 1 and 2: isotonic resistance exercises, week 3 and 4: isometric exercises, week 5 and 6: isokinetic exercises) + SLR	Sessions: 20 sessions (5 sessions per week) – 4 weeks total Treatment time: 30 minutes (10 seconds of contraction and 20 seconds of relaxation, 3 times a day)	T0: baseline (before treatment) T1: week 1 T2: week 2 T3: week 4 T4: week 6	Knee Extension ROM (GM) EG: T4 > T3 > T2 > T1 > T0 CC: T4 > T3 > T2 > T1 > T0 EG = CG for T4-T1 QF torque ratio between healthy and operated limb (IE) EG: T4 > T3 > T2 > T1 > T0 CG: T4 > T3 > T2 > T1 > T0 EG = CG for T4-T1	Knee Extension ROM (GM) EG: T4 > T3 > T2 > T1 > T0 CC: T4 > T3 > T2 > T1 > T0 EG = CG for T4-T1 QF torque ratio between healthy and operated limb (IE) EG: T4 > T3 > T2 > T1 > T0 CG: T4 > T3 > T2 > T1 > T0 EG = CG for T4-T1
7	Effectiveness of electromyographic biofeedback training on quadriceps muscle strength in osteoarthritis of knee [39].	Anwer [2011] India	Knee OA	n = 33 Men = 10 Women = 23 53 \pm 7.73	EG = 17 (11 women; 4 men) CG = 16 (10 women; 5 men)	EG = QF MF + HP CG = QF sham MF + HP	Sessions: 25 sessions (5 weekly sessions) – 5 weeks total Treatment time: NS	T0: baseline (before treatment) T1: week 2 T2: week 3 T3: week 5	QF isometric strength at 60 ° flexion (DM) EG: T3* > T2* > T1 > T0 CG: T3 = T2 = T1 > T0 EG > CG for T3 and T2	QF isometric strength at 60 ° flexion (DM) EG: T3* > T2* > T1 > T0 CG: T3 = T2 = T1 > T0 EG > CG for T3 and T2

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age ± DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
8	Electromyographic biofeedback-controlled exercise versus conservative care for patellofemoral pain syndrome [40].	Dursun [2001] Turkey	PFPS	n = 60 Men = 12 Women = 48 37 ± 9.2	EG = 24 (18 women; 6 men) CG = 24 (18 women; 6 men)	GE = QF MF + exercise program (CKC isometric exercises, flexibility, proprioception and resistance training on a cycle ergometer). CG = Exercise program (CKC isometric exercises, flexibility, proprioception and resistance training on a cycle ergometer).	Sessions: 12 sessions (4 weekly sessions) - 4 weeks total Treatment time: 30 minutes (10 seconds of contraction and 20 seconds of relaxation)	T0: baseline (before treatment) T1: 4 weeks T2: 8 weeks T3: 12 weeks (EMG)	Pain intensity (VAS) Disability (FCI) VMO MVC and AMVC (EMG) VL MVC and AMVC (EMG)	Pain intensity (VAS) EG: T3 < T2 < T1 < T0 CG: T3 < T2 < T1 < T0 EG = CG for T3, T2 y T1 Disability (FCI) EG: T3 > T2 > T1 CG: T3 > T2 > T1 EG = EG for T3, T2 y T1 VMO MVC and AMVC (EMG) EG: T3 > T2 > T1 CG: T3 > T2 > T1 EG = EG for T3, T2 y T1 VL MVC and AMVC (EMG) EG: T3 > T2 > T1 CG: T3 > T2 > T1 EG > CG for T2*
9	Effects of isometric exercise using biofeedback on maximum voluntary isometric contraction, pain, and muscle thickness in patients with knee osteoarthritis [41].	Choi [2015] Korea	Knee OA	n = 30 Men = 0 Women = 30 72 ± 8.8	EG = 10 (10 women; 0 men) CG 1 = 10 (10 women; 0 men) CG 2 = 10 (10 women; 0 men)	EG = QF MF CG 1 = QF exercises CG 2 = HP + US + TENS	Sessions: 24 sessions (3 weekly sessions) - 8 weeks total Treatment time: 20 minutes (5 seconds of contraction and 5 seconds of relaxation)	T0: baseline (before treatment) T1: 8 weeks (after treatment)	Pain intensity (VAS) MIVC (DM) VMO thickness (USG)	Pain intensity (VAS) EG: T1* < T0 CG 1: T1* < T0 CG 2: T1* < T0 CG 2 < EG < CG 1 for T1* MIVC (DM) EG: T1* > T0 CG 1: T1* > T0 CG 2: T1 < T2 EG = CG 1 > CG 2 for T1* VMO thickness (USG) EG: T1* > T0 CG 1: T1 > T0 CG 2: T1 < T2 EG > CG 1 > CG 2 for T1*

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age \pm DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
10	Efficacy of EMG-biofeedback in knee osteoarthritis [42]	Yilmaz [2010] Turkey	Knee OA	n = 40 Men = 5 Women = 35 58 \pm 7.7	EG = 19 (17 women; 2 men) CG = 20 (17 women; 3 men)	EG = QF MF + isometric exercises (CKC for QF and hip ADD) + progressive resistance exercises (OKC without load for week 1, 0.5 kg for week 2 and 1.5 kg for week 3). CG = Isometric exercises (CKC for QF and hip ADD) + progressive resistance exercises (OKC without load for week 1, 0.5 kg for week 2 and 1.5 kg for week 3).	Sessions: 9 sessions (3 weekly sessions twice a day) – 3 weeks total Treatment time: NS	T0: baseline (before treatment) T1: 3 weeks (after treatment)	Pain intensity at rest, walking and climbing stairs (VAS) EG: T1* < T0 CG: T1* < T0 EG = CG for T1 Knee ROM (goniometry) QF isokinetic strength (EI) NS Disability (WOMAC) Subjective Health Perception (NHS)	Pain intensity at rest, walking and climbing stairs (VAS) EG: T1* < T0 CG: T1* < T0 EG = CG for T1 Knee ROM (goniometry) NS QF isokinetic strength (EI) Disability (WOMAC) Subjective Health Perception (NHS) EG: T1* > T0 (physical activity, pain, sleep and energy domains) CG: T1* > T0 (physical activity and pain domains) EG = CG for T1 (sleep and energy domains) Disability (WOMAC) EG: T1* < T0 CG: T1* < T0 EG = CG for T1 Subjective Health Perception (NHS) EG: T1* < T0 CG: T1* < T0 EG = GC for T1
11	Effects of quadriceps electrical stimulation program on clinical parameters in the patients with knee osteoarthritis [43]	Durmus [2007] Turkey	Knee OA	n = 50 Men = 0 Women = 50 57 \pm 1.77	EG = 25 (25 women; 0 men) CG = 25 (25 women; 0 men)	EG = QF MF + isometric exercises CG = QF NMES	Sessions: 20 sessions (5 sessions per week) – 4 weeks total Treatment time: 20 minutes (10 seconds of contraction and 50 seconds of relaxation)	T0: baseline (before treatment) T1: 4 weeks (after treatment)	Pain intensity at rest and activity (VAS) Disability (WOMAC) Functionality (50-MWT) Muscle strength (RM and 10RM)	Pain intensity at rest and activity (VAS) EG: T1* < T0 CG: T1* < T0 Disability (WOMAC) EG: T1* < T0 CG: T1* < T0 Functionality (50-WMT) EG: T1* < T0 CG: T1* < T0 Muscle strength (RM and 10RM) EG: T1* > T0 CG: T1* > T0

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age ± DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
12	The influence of electromyographic biofeedback therapy on knee extension following anterior cruciate ligament reconstruction: A randomized controlled trial [44]	Christanelli [2012] Swiss	ACL	n = 16 Men = 12 Women = 4 30 ± NS	EG = 8 (NS) CG = 8 (NS)	EG = QF MF + therapeutic exercises (isometric, isotonic and balance exercises) + postoperative protocol (NMES, manual lymphatic drainage, water exercises) CG = Postoperative protocol (NMES, manual lymphatic drainage, water exercises)	Sessions: 16 sessions (3 weekly sessions the first 4 weeks and 2 sessions the last 2 weeks) – 6 weeks total Treatment time: NS	T0: baseline (before treatment) T1: week 1 T2: week 2 T3: week 4 T4: week 6	Pain intensity (VAS) Knee edema (rating scale) Heel Height (HHD) Knee flexion and extension ROM (goniometry) VMO Electromyographic activity (EMG) Functionality (IKDC)	Pain intensity (VAS) EG: T4 < T3-T1 CG: T4 < T3-T1 EG = CG for T4-T1 Knee edema (rating scale) EG: T4 < T3-T1 CG: T4 < T3-T1 EG = CG for T4-T1 Heel Height (HHD) EG: T4* < T3-T1 CG: T4 < T3-T1 EG < CG for T4-T1* Knee flexion and extension ROM (goniometry) EG: T4 > T3-T1* CG: T4 > T3-T1 EG > CG for T4-T1* VMO Electromyographic activity (EMG) EG: T4 > T3-T1* CG: T4 > T3-T1 EG > CG for T4-T1 Functionality (IKDC) EG: T4 > T3-T1 CG: T4 > T3-T1 GE = GC para T4-T1
13	Effects of biofeedback versus switch-triggered functional electrical stimulation on sciatica-related foot drop [45]	Sardaru [2018] Romania	Lumbar nucleus pulposus hernia	n = 50 Men = 26 Women = 24 40 ± NS	EG = 35 (11 women; 14 men) CG = 25 (13 women; 12 men)	EG = TA MF + TA FES CG = TA FES	Sessions: 20 sessions (5 weekly sessions) – 4 weeks total Treatment time: 30 minutes	T0: baseline (before treatment) T1: week 4	NCV (EMG) CMAP (EMG) TA muscle strength (DM) Functionality (ODI)	NCV (EMG) EG: T1 = T0 CG: T1 = T0 EG = CG for T1 CMAP (EMG) EG: T1 > T0 CG: T1 > T0 EG > CG for T1* TA muscle strength (DM) EG: T1 > T0 CG: T1 > T0 EG > CG for T1* Functionality (ODI) EG: T1* < T0 CG: T1 < T0 EG < CG for T1*

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age \pm DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
14	The efficacy of EMG-biofeedback training on quadriceps muscle strength in patients after arthroscopic meniscectomy [46]	Kirnap [2005] Turkey	Meniscal injury	n = 40 Men = 40 Women = 0 35 \pm 10.3	EG = 20 (0 women; 20 men) CG = 20 (0 women; 20 men)	EG = QF MF + home exercise program (3 phases; P1 = cryotherapy + isometric exercises QF + patella mobilization and SLR, P2 = ADD and QF strengthening, and P3 = CKC lower limb exercises and step side). CG = Home exercise program (3 phases; P1 = cryotherapy + isometric exercises QF + patella mobilization and SLR, P2 = ADD and QF strengthening, and P3 = CKC lower limb exercises and step side).	Sessions: 30 sessions (5 times a week) - 6 weeks total Treatment time: 5 minutes (5 seconds of contraction and 10 seconds of relaxation)	T0: baseline (before surgery) T1: 3 days after surgery. T2: week 2 T3: week 6	Functionality (Lysholm scale) QF circumference (perimetry) Knee flexion passive ROM (goniometry) MVC ratio of VMO between operated and non-operated limb (EMG) MVC ratio of VL between operated and non-operated limb (EMG)	Functionality (Lysholm scale) EG: T3* > T2* > T1 < T0 CG: T3* > T2* > T1 < T0 EG > CG for T2* y T1* QF circumference (perimetry) Not reported Knee flexion passive ROM (goniometry) Not reported Knee flexion passive ROM (goniometry) EG: T3* > T2* > T1 < T0 CG: T3* > T2* > T1 < T0 EG > CG for T2* y T1* MVC ratio of VMO between operated and non-operated limb (EMG) EG: T3* > T2* > T1 < T0 CG: T3 > T2 > T1 < T0 EG > GC for T2* y T1* MVC ratio of VL between operated and non-operated limb (EMG) EG: T3* > T2* > T1 < T0 CG: T3 > T2 > T1 < T0 EG > GC for T2* y T1* MVC ratio of VL between operated and non-operated limb (EMG) EG: T3* > T2* > T1 < T0 CG: T3 > T2 > T1 < T0 EG > GC for T2* y T1* MVC ratio of VMO between operated and non-operated limb (EMG)
15	EMG feedback-assisted postoperative rehabilitation of minor arthroscopic knee surgeries [47]	Levitt [1995] USA	Meniscal injury	n = 51 Men = 35 Women = 16 26 \pm 15	EG = 28 (7 women; 21 men) CG = 23 (9 women; 14 men)	EG = QF MF + isometric exercises at home (3 times a day) CG = isometric exercises at home (3 times a day)	Sessions: 10 sessions (daily) - 2 weeks total Treatment time: NS	T0: baseline (before surgery) T1: 10 days (post-surgery)	QF activity (EMG) ROM (IE) Isokinetic QF strength (IE) Post-surgery pain intensity (NPRS)	QF activity (EMG) EG: T1* > T0 CG: T1 > T0 EG > CG for T1* ROM (IE) EG: T1* > T0 CG: T1 > T0 EG > CG for T1* Isokinetic QF strength (IE) EG: T1* > T0 CG: T1 > T0 EG > CG for T1* Post-surgery pain intensity (NPRS) EG: T1 < T0 CG: T1 < T0 EG = CG for T1

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men women mean age ± DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
16	The efficacy of electromyographic biofeedback on pain, function, and maximal thickness of vastus medialis oblique muscle in patients with knee osteoarthritis: a randomized clinical trial [48]	Raeissadat [2018] Iran	Knee OA	n = 46 Men = 7 Women = 39 61 ± 7.9	EG = 21 (women 19; men 2) CG = 23 (women 16; men 4)	EG = QF MF + isometric exercises CG = isometric exercises	Sessions: 12 sessions – 8 weeks total Treatment time: 15 minutes (5 seconds of contraction and 10 seconds of relaxation)	T0: baseline (before treatment) T1: week 8	Pain intensity (VAS) VMO Thickness (USG) Electrical activity VL (EMG) Functionality (WOMAC) Functionality (Lequesne index)	Pain intensity (VAS) EG: T1* < T0 CG: T1* < T0 EG < CG for T1* VMO Thickness (USG) EG: T1 = T0 CG: T1 = T0 EG = GC for T1 Electrical activity VL (EMG) EG: T1* > T0 CG: T1* > T0 EG = CG for T1 Functionality (WOMAC) EG: T1* < T0 CG: T1* < T0 EG < CG for T1* Functionality (Lequesne index) EG: T1* < T0 CG: T1* < T0 EG = CG for T1

2-MWT, two meters walking test; 10RM, 10 maximum resistance; 50-MWT, fifty meters walking test; ACLR, Anterior cruciate ligament reconstruction; ABD, hip abductor muscles; ADD, hip adductor muscles; AMVC, average maximal voluntary contraction; CG, control groups; CKC, closed kinematic chain exercises; CMAP, compound action potential; DASH, the Disabilities of the Arm, Shoulder and Hand questionnaire; DM, dynamometry; EG, experimental groups; EMG, surface electromyography; FES, functional electrical stimulation; FIC, functional capacity index; GN, gastrocnemius muscles; HP, hot packs; HS, hamstring muscles; IE, isokinetic evaluation; IKDC, international knee documentation Committee; KPP, knee push-up plus; KOOS, Knee injury and Osteoarthritis Outcome Score; MVC, maximum voluntary contraction; MIVC, maximum isometric voluntary contraction; MF, myofeedback; MT, middle trapezius muscle; NCV, nerve conduction velocity; NHS, Nottingham Health Profile; NMES, neuromuscular electrical stimulation; NPRS, numeric pain rating scale; NS, not specified; OA, LT, lower trapezius muscle; ODI, Oswestry Disability Index; Osteoarthritis; OKC, open kinematic chain exercise; OSS, the Oxford Shoulder Score; PFPs, Patellofemoral pain syndrome; QF, quadriceps femoris muscle; RCT, randomized clinical trial; RM, maximum resistance; ROM, range of movement; SA, serratus anterior muscle; SAIS, subacromial impingement syndrome; SLR, straight leg raising; TA, tibialis anterior muscle; UT, upper trapezius muscle; US, therapeutic ultrasound; USG, ultrasonography; VAS, visual analogue scale; VMO, vastus medialis oblique muscle; VL, vastus lateralis muscle; *p < 0.05.

Tab 3. Characteristics of muscle relaxation MF studies

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men, women mean age \pm DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
1	Management of patients with fibromyalgia using biofeedback: A randomized control trial [24]	Baumüller [2007] Germany	Fibromyalgia	n = 36 Men = NS Women = NS 40 \pm NS	EG = 18 (NS) CG = 18 (NS)	EG = UT MF + standard treatment for fibromyalgia CG = Standard treatment for fibromyalgia	Sessions: 14 sessions (3 sessions per week for 3 weeks, 1 weekly session for 5 weeks) – 8 weeks total Treatment time: 15 minutes	T0: baseline (before treatment) T1: week 8 (post-treatment) T2: 12 weeks follow-up	Disability (FIC) Pain intensity in ST (self-surgery with Likert 6 scale) Pain intensity (ALG) Quality of life (SF-36) Depression (BDI)	Disability (FIC) EG: T2 < T1 < T0 CG: T2 < T1 < T0 EG = CG for T2 and T1 TS Pain intensity (self-perception with Likert scale) EG: T2 < T1 < T0 CG: T2 < T1 < T0 EG = CG for T2 and T1 Pain intensity (ALG) Quality of life (SF-36) Depression (BDI) GE: T1 > T0 (T2 not assessed) GC: T1 > T0 (T2 not assessed) GE > GC for T1* Quality of life (SF-36) EG: T2 > T1 > T0 CG: T2 > T1 > T0 EG = GC for T2 and T1 Depression (BDI) EG: T2 < T1 < T0 CG: T2 < T1 < T0 EG = CG for T2 and T1

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men, women mean age ± DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
2	Biofeedback treatment for acute whiplash patients [25]	Gálvez-Hernández [2016] Mexico	WPS	n = 11 Men = 2 Women = 9 32 ± NS	EG = 6 (5 women; 1 man) CG = 5 (4 women; 1 man)	EG = UT MF + progressive relaxation techniques CG = NT	Sessions: 3 sessions (once a week) – 3 weeks total Treatment time: 60 minutes	T0: baseline (before treatment) T1: week 3	UT muscle activity symmetry (EMG) EG: T1* < T0 CG: T1 < T0 UT resting muscle activity (EMG) EG: T1 > T0 CG: T1 > T0 Anxiety (BDI) EG: T1 < T0 CG: T1 = T0 Depression (BDI) EG: T1 < T0 CG: T1 = T0 Functionality (NDI) EG: T1 < T0 CG: T1 = T0 Pain intensity (VAS) EG: T1* < T0 CG: T1 = T0 Fear of movement (TSK) EG: T1 = T0 CG: T1 = T0	UT muscle activity symmetry (EMG) EG: T1* < T0 CG: T1 < T0 UT resting muscle activity (EMG) EG: T1 > T0 CG: T1 > T0 Anxiety (BDI) EG: T1 < T0 CG: T1 = T0 Depression (BDI) EG: T1 < T0 CG: T1 = T0 Functionality (NDI) EG: T1 < T0 CG: T1 = T0 Pain intensity (VAS) EG: T1* < T0 CG: T1 = T0 Fear of movement (TSK) EG: T1 = T0 CG: T1 = T0
3	Is surface EMG biofeedback an effective training method for persons with neck and shoulder complaints after whiplash-associated disorders concerning activities of daily living and pain – a randomized controlled trial [49].	Ehrenborg [2010] Sweden	Cervicobrachialgia	n = 65 Men = 31 Women = 34 39 ± 11.1	EG = 36 (NS) CG = 29 (NS)	EG = UT MF + functional hand exercises CG = functional hand exercises	Sessions: 8 sessions (2 sessions per week) – 4 weeks total Treatment time: 15 minutes (5 minutes of contraction and 10 minutes of rest)	T0: baseline (before treatment) T1: week 4 to 6 (after treatment) T2: week 24	Occupational performance (COPM) EG: T2* > T1* CG: T2* > T1* Occupational performance satisfaction (COPM) EG: T2* > T1* CG: T2* > T1* Psychosocial functioning (MPI-S) EG = CG for T2 and T1 Psychosocial functioning (MPI-S) EG: T2* < T1* (only for pain interference activities criteria) CG: T2* > T1* (only for distraction response criteria) EG = CG for T2 and T1	Occupational performance (COPM) EG: T2* > T1* CG: T2* > T1* Occupational performance satisfaction (COPM) EG: T2* > T1* CG: T2* > T1* Psychosocial functioning (MPI-S) EG = CG for T2 and T1 Psychosocial functioning (MPI-S) EG: T2* < T1* (only for pain interference activities criteria) CG: T2* > T1* (only for distraction response criteria) EG = CG for T2 and T1

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men, women mean age \pm DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
4	Myofeedback training and intensive muscular strength training to decrease pain and improve work ability among female workers on long-term sick leave with neck pain: a randomized controlled trial [50]	Dellve [2011] Sweden	Neck pain	n = 60 Men = 0 Women = 60 48 \pm NS	EG = 20 (20 women; 0 men) CG 1 = 20 (20 women; 0 men) CG 2 = 20 (20 women; 0 men)	EG = UJT MF CG 1 = protocol of stretching exercises, strengthening, UE coordination and breathing exercises CG 2 = No intervention	Sessions: 16 sessions (4 weekly sessions) – 4 weeks total Treatment time: 120 minutes	T0: baseline (before treatment) T1: 4 weeks (after treatment) T2: 12 weeks	Job ability skills (WAI) EG: T2 < T1 > T0 CG 1: T2* > T1 > T0 CG 2: T2 < T1 > T0 CG 1 > CG 2 > EG for T2 and T1 Job ability skills (WAI) EG: T2* < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 > T1 < T0 EG > CG 1 > CG 2 for T1 and T2 Pain intensity (NPRS) EG: T2* < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 > T1 < T0 Dexterity and gross movements (PPT) Self-reported mental health and vitality (COPSOQ) Grip strength (DM) EG: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 < T1 < T0 CG 2 < EG < CG 1 for T1 and T2 Dexterity and gross movements (PPT) EG: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 < T1 < T0 CG 2 < EG < CG 1 for T1 and T2 Self-reported mental health and vitality (COPSOQ) EG: T2 < T1 > T0 CG 1: T2 > T1 > T0 CG 2: T2 < T1 < T0 CG 1 > EG > CG 1 for T1 and T2	Job ability skills (WAI) EG: T2 < T1 > T0 CG 1: T2* > T1 > T0 CG 2: T2 < T1 > T0 CG 1 > CG 2 > EG for T2 and T1 Job ability skills (WAI) EG: T2* < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 > T1 < T0 EG > CG 1 > CG 2 for T1 and T2 Pain intensity (NPRS) EG: T2 < T1* < T0 CG 1: T2 < T1 < T0 CG 2: T2* > T1 < T0 EG > CG 1 > CG 2 for T1 and T2 Grip strength (DM) EG: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 < T1 < T0 CG 2 < EG < CG 1 for T1 and T2 Dexterity and gross movements (PPT) EG: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 < T1 < T0 CG 2 < EG < CG 1 for T1 and T2 Self-reported mental health and vitality (COPSOQ) EG: T2 < T1 > T0 CG 1: T2 > T1 > T0 CG 2: T2 < T1 < T0 CG 1 > EG > CG 1 for T1 and T2

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men, women mean age ± DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
5	Myofeedback training and intensive muscular strength training to decrease pain and improve work ability among female workers on long-term sick leave with neck pain: a randomized controlled trial [51]	Voerman [2006] Netherlands	WPS	n = 40 Men = 9 Women = 5 39 ± 10.0	EG = 14 (5 women; 9 men) CG = 14 (5 women; 9 men)	EG = UT MF (bilateral application)	Sessions: 8 sessions (2 weekly sessions) – 4 weeks total Treatment time: 120 minutes	T0: baseline (before treatment) T1: week 4 (end of treatment)	Pain intensity (VAS) Disability (NDI) UT activation patterns (EMG)	Pain intensity (VAS) GE: T1 < T0* Disability (NDI) GE: T1 < T0 UT activation patterns (EMG) GE: T1 < T0*
6	Biofeedback traction versus conventional traction in cervical radiculopathy [52]	Atteya [2004] Saudi Arabia	Cervical radiculopathy	n = 20 Men = NS Women = NS 45 ± NS	EG = 10 (NS) CG = 10 (NS)	EG = HP + cervical traction + PVC MF CG = HP + cervical traction	Sessions: 12 sessions (2 weekly sessions) – 6 weeks total Treatment time: 20 minutes	T0: baseline (before treatment) T1: week 1 T2: week 2 T3: week 3 T4: week 4 T5: week 5 T6: week 6	PVM EMG-A at C5 / C6 level before traction (EMG) C6 level before traction (EMG) PVM EMG-A at C5 / C6 level during traction (EMG) PVM EMG-A at C5 / C6 level after traction (EMG)	PVM EMG-A at C5 / C6 level before traction (EMG) EG: T6 < T5-T1* CG: T6 < T5-T1 EG < CG for T6-T4*, T2* and T1* PVM EMG-A at C5 / C6 level during traction (EMG) EG: T6 < T1* CG: T6 < T1 EG < CG for T6-T4*, T2* and T1* PVM EMG-A at C5 / C6 level after traction (EMG) EG: T6 < T1* CG: T6 < T1 EG < CG for T6-T4*, T2* and T1* PVM EMG-A at C5 / C6 level after traction (EMG) EG: T6 < T1* CG: T6 < T1 EG < CG for T6-T4*, T2* and T1*

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men, women mean age \pm DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
7	Relative Effectiveness of Electroacupuncture and Biofeedback in the Treatment of Neck and Upper Back Myofascial Pain: A Randomized Clinical Trial [53]	Eslamian [2020] Iran	Neck pain	n = 50 Men = 11 Women = 39 40 \pm 5.6	EG = 25 (21 women; 4 men) CG = 25 (18 women; 7 men)	EG = UT, DA and PVC MF + pharmacology (meloxicam) + isometric exercises and neck and shoulder stretching exercises (3 sets of 10 repetitions, each repetition of 5 seconds). CG = acupuncture + pharmacology (meloxicam) + isometric exercises and neck and shoulder stretching exercises (3 sets of 10 repetitions, each repetition of 5 seconds).	Sessions: 6 sessions (2 times a week) – 3 weeks in total Treatment time: 30 minutes (5 seconds of contraction and 10 of relaxation) – 3 attempts per muscle	T0: baseline (before treatment) T1: week 3 T2: week 12	Cervical functionality (NDI) Neck pain (VAS) TrPS Painful pressure threshold (ALG) Cervical spine ROM (IM)	Cervical functionality (NDI) EG: T2* < T1* < T0 CG: T2* < T1* < T0 CG < EG for T2 and T1 Neck pain (VAS) EG: T2* < T1* < T0 CG: T2* < T1* < T0 CG < EG for T2 and T1 TrPS Painful pressure threshold (ALG) Cervical spine ROM (IM) TrPS Painful pressure threshold (ALG) EG: T2* > T1* > T0 CG: T2* > T1* > T0 CG > EG for T2 and T1 Cervical spine ROM (IM) EG: T2* > T1* > T0 CG: T2* > T1* > T0 CG > EG for T2 and T1
8	Cognitive-Behavioural Therapy versus EMG Biofeedback in the treatment of chronic low back pain [54]	Newton J. y cols. [1995] Australia	LBPS	n = 44 Men = 17 Women = 27 46 \pm NS	EG = 16 (NS) CG 1 = 16 (NS) CG 2 = 12 (NS)	EG = UT and SE MF CG 1 = CBT CG 2 = WLC	Sessions: 8 sessions (2 times a week) – 4 weeks total Treatment time: 60 minutes	T0: baseline (before treatment) T1: week 4 (end of treatment) T2: 24 weeks (follow-up)	Depression (BDI) Anxiety (STAI) Behavioral strategies for coping with pain (CSQ) Disability (PDI) Beliefs about pain (PBQ) General Activity Level (GALS) Daily pain (self-report)	Depression (BDI) EG: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 = T1 = T0 EG < CG 1 < CG 2 for T2* Anxiety (STAI) EG: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 = T1 = T0 EG = CG 1 < CG 2 for T2 Behavioral strategies for coping with pain (CSQ) EG: T2* > T1 > T0 CG 1: T2 > T1 > T0 CG 2: T2 = T1 = T0 EG = CG 1 < CG 2 for T2

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men, women mean age ± DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
8										Disability (PDI) EG: T2* < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 = T1 = T0 EG < CG 1 < CG 2 for T2* Beliefs about pain (PBQ) EG: T2* < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 = T1 = T0 EG < CG 1 < CG 2 for T2* General Activity Level (GALS) EG: T2 > T1 > T0 CG 1: T2 > T1 > T0 CG 2: T2 = T1 = T0 EG = CG 1 < CG 2 for T2 Daily pain (self-report) EG: T2* < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T2 = T1 = T0 EG < CG 1 < CG 2 for T2*
9	The clinical effectiveness of a myofeedback-based telereatment service in patients with non-specific neck and shoulder pain: A randomized controlled trial [55]	Kosterink [2010] Netherlands	Cervicobrachialgia	n = 71 Men = 0 Women = 71 40 ± 12.4	EG = 36 (36 women; 0 men) CG = 35 (35 women; 0 men)	EG = UT MF (TRH and face-to-face modality) CG = conventional treatment (medication + physical therapy + chiropractic + osteopathy + acupuncture)	Sessions: 20 sessions (5 times a week) – 4 weeks total Treatment time: 60 minutes	T0: baseline (before treatment) T1: week 4 T2: 12 weeks	Pain intensity (VAS) Disability (PDI)	Pain intensity (VAS) EG: T1 < T0 CG: T1 < T0 EG = CG for T1 Disability (PDI) EG: T1* < T0 CG: T1* < T0 EG = CG for T1

Clinical trial number	Study	Author Year Country	Musculoskeletal condition	Sample size (n) men, women mean age \pm DE (years)	EG and CG (women; men)	Intervention	MF sessions and treatment time	Evaluations	Outcomes	Conclusion
10	Effect of EMG biofeedback compared to applied relaxation training with chronic, upper extremity cumulative trauma disorders [56]	Spence [1995] England	Cervicobrachialgia	n = 48 Men = 8 Women = 40 42 \pm 7.86	EG 1 = 12 (NS) EG 2 = 12 (NS) CG 1 = 12 (NS) CG 2 = 12 (NS)	EG 1 = UT and EF MF EG 2 = UT and EF MF + relaxation exercises CG 1 = relaxation exercises CG 2 = NT	Sessions: 8 sessions (2 weekly sessions) – 4 weeks total Treatment time: 90 minutes	T0: baseline (before treatment) T1: week 4 (end of treatment) T2: 24 weeks (follow-up)	Depression (BDI) Pain intensity (PBQ) Pain (WHYMPI) Stress caused by pain (self-monitored pain, distress, interference and medication) Pain (WHYMPI) interference daily living activities (self-monitored pain, distress, interference and medication) EG 1 = EG 2 = CG 1 = CG 2 for T2 and T1 Pain (WHYMPI) interference daily living activities CG 1 = EG 2 = CG 1 = CG 2 for T2 and T1 Stress caused by pain (self-monitored pain, distress, interference and medication) EG 1: T2 < T1 < T0 EG 2: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T1 > T0 EG 1 < EG 2 < CG 1 < CG 2 for T2* and T1* Pain interference daily living activities (self-monitored pain, distress, interference and medication) EG 1: T2 < T1 < T0 EG 2: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T1 > T0 EG 1 < EG 2 < CG 1 < CG 2 for T2* and T1* Pain interference daily living activities (self-monitored pain, distress, interference and medication) EG 1: T2 < T1 < T0 EG 2: T2 < T1 < T0 CG 1: T2 < T1 < T0 CG 2: T1 > T0 CG 1 < EG 1 < EG 2 < CG 2 for T2* and T1*	

ALG, algometry; BDI, Beck Depression Inventory; CBT, cognitive behavioral therapy; CSQ, Coping Style Questionnaire; CG, control groups; COMP, Canadian Occupational Performance Measure; COPSOQ, Copenhagen Psychosocial Questionnaire; DA, anterior deltoid muscle; DM, dynamometry; EG, experimental groups; EF, elbow flexors muscles; EMG, surface electromyography; IM, inclinometer; FIC, functional capacity index; GALS, general activity level scale; LBPS, low back pain syndrome; HP, hot packs; MPI-S, multidimensional Pain Inventory; NDI, the Neck disability Index; NPRS, numeric pain rating scale; NS, not specified; NT, no treatment; PBQ, personality belief questionnaire; PDI, pain disability index; PPT, purdue perbog test; UE, upper extremities; UT, upper trapezius muscle; ROM, range of movement; SE, spinal erectors muscles; STAI, State Trait Anxiety Inventory; TrPs, myofascial trigger points; TRH, telerehabilitation; TS, tender spots; TSK, TAMPA Scale for Kinesiophobia; VAS, visual analogue scale; WAI, Work Ability Index; WLC, waiting list controls; WHYMPI, West Haven-Yale Multidimensional Pain Inventory; WPS, whiplash syndrome; *p < 0.5.

Complementary treatments for muscle strengthening MF included therapeutic exercises (stretching exercises, resistance, mobility, coordination, proprioception or water exercises) (n = 14, 53.84%) [22,23,35–37, 39,40,42–44,46–48] functional electrical stimulation (FES) (n = 1, 6.25%) [45], neuromuscular electrical stimulation (NMES) (n = 2, 12.5%) [35,44], lymphatic drainage (n = 2, 12.5%) [22,44], hot packs (HP) (n = 1, 6.25%) [28] and cryotherapy (n = 1, 6.25%) [46]. On the other hand, complementary treatments for muscle relaxation MF included cervical distraction (n = 1, 6.25%) [41], HP (n = 1, 6.25%) [41], relaxation techniques (n = 1, 6.25%) [56] and therapeutic exercises (stretching and functional exercises) (n = 2, 12.5%) [49,53]. Only Eslamian (2020) used NSAIDs in participants with neck pain in addition to MF relaxation [53].

The control groups in the strengthening MF studies received therapeutic exercises (resistance exercises, flexibility, functional and home exercises) [22,23,35–38,40,42,46–48], NMES [22,38,43,44], FES [45], superficial thermotherapy (HP) [50,52], TENS [41], US [41], postoperative lymphatic drainage and water exercises [44]. In addition, it should be noted that no articles reported the use of drugs for CG. On the other hand, for CG in muscle relaxation MF studies, superficial thermotherapy (HP) [52], joint distraction [52], acupuncture [53], therapeutic exercises (isometric exercises, stretching and relaxation) [49,53,56], cognitive behavioral therapy (CBT) [54], joint manipulation [55], and medication [53,55] were used. The studies by Dellve (2011), Spence (2016) and Gálvez-Hernández (1995) did not administer treatment for CG [25,50,56].

Regarding the treatment sessions, an average of 5 sessions was observed for strengthening MF and 8 sessions for relaxation MF. Minimum sessions for strengthening MF studies were 1 (Huang, 2013) [36] with a maximum of 30 (Kimap, 2005) [46], while minimum sessions for muscle relaxation MF studies were 3 (Gálvez-Hernández, 2016) [25] with a maximum of 16 (Dellve, 2011) [50]. Strengthening studies (n = 9, 56.25%) sessions were mostly carried out in continuous days in an average of 5 weeks [23,24,26,27,28,32, 34–36], while muscle relaxation MF studies (n = 9, 90.00%) included interval sessions averaging 5 weeks [24,25,50–56].

The average treatment time for strengthening MF was 20 to 30 minutes, with a minimum of 4 minutes reported by Huang [36] and a maximum of 30 minutes [37,38,40,45], while the average treatment time for relaxation MF was between 40 and 50 minutes, with a minimum of 5 minutes reported by Ehrenborg (2010) [51], and a maximum of 120 minutes by Dellve [50].

The review revealed, for most of relaxation MF studies, 3 evaluation sessions (before and two after

treatment; T0, T1 and T2) (n = 8, 80.00%) [50–56], while the strengthening studies documented mostly 2 evaluation sessions (before and after treatment; T0 and T1) (n = 10, 62.50%) [23,35–37,30–43,45,47,48]. On the other hand, Draper (1997) and Christanell (2012) carried out 5 evaluation sessions for strengthening MF (T0–T4) [38,44], while Atteya (2004) reported 7 sessions for relaxation MF (T0–T6) [52]. An average evaluation time of 1 week between sessions is highlighted for both MF applications.

Main outcomes

Strengthening MF studies

The main outcomes of the strengthening MF studies included functionality (disability) (n = 12, 75.0%) [22,23,40,42–46,48], pain intensity (n = 9, 56.25%) [22,23,35,40–44,47,48], gait speed (n = 1, 3.8%) [22], range of motion (ROM) changes (n = 6, 37.5%) [22,36,38,42,44,46], decreased edema (n = 2, 12.5%) [22,44], changes in electromyographic activity (n=13, 81.25%) [22,23,35,36,40–42,44–48], muscle strength changes (n = 7, 43.75%) [35,38,39,41,43,44,47], muscular thickness (n = 3, 18.75%) [41,46,48] and subjective health assessment (n = 1, 0.06%) [42]. Functionality was assessed with the Lyshom scale [22,46], the Knee injury and Osteoarthritis Outcome Score (KOOS) [46], the hand, arm and shoulder disability index (DASH) [23], the Oxford shoulder scale (OSS) [23], functional capacity index (FCI) [40], 50-meter walk test (50-WMT) [43], the Western Ontario and McMaster questionnaire (WOMAC) [42,43,48], the International Knee Documentation Committee (IKDC) guideline [44], the Oswestry Disability Index (ODI) [45] and Lequesne Index [48]. On the other hand, pain intensity was evaluated with the visual analog scale (VAS) [22,40,41–44,48], KOOS [35] and numerical pain rating score (NPRS) [23,47], while gait speed was assessed with the 2-meter walk test (2-WMT) [22]. Electromyographic activity (EMG-A) was evaluated with surface electromyography [23,35–37,40,44,45,47,48], while muscle strength assessment was performed through dynamometry [35,39,41,45,47], isokinetic assessment [38,42] and maximum resistance estimation (Rmax) [43]. Muscle thickness was examined by ultrasonography [41,48] and muscle circumference measurement [46], while perimetry was used to quantify edema [22,44]. Subjective health assessment was assessed with the Nottingham Health Profile (NHS) [42].

Results show an improvement in intragroup functionality for Lyshom, KOOS, OSS, DASH, IKDC, ODI, WOMAC, and Lequesne index, although with statistical significance in favor of EG (intergroup) for meniscal rehabilitation studies (Lyshom scale, $p < 0.001$)

[22,46], knee OA (50-WMT, $p < 0.01$; WOMAC, $p < 0.05$) [42,43], and lumbar hernia (ODI, $p < 0.0001$) [45]. MF applications focused on quadriceps femoris strengthening for knee conditions, and tibialis anterior muscle in patients with low back pain. Likewise, a statistically significant functionality improvement is seen for CG that received alternative treatment in meniscal injuries [22,46], SAIS [23] and knee OA [42,43,48], although they did not show to be better than MF treatment. On the other hand, a decrease in pain is observed in favor of EG for VAS, KOOS, and NPRS, although with statistical significance only for strengthening MF in meniscal injuries and OA ($p < 0.05$) aimed at increasing quadriceps femoris strength (medial and lateral vastus) [22,41–43,48]. Gait speed shows an improvement in both groups between evaluation sessions, although without significant differences [22]. EMG-A increased in both study groups, although with greater significance ($p < 0.05$) in EG when using strengthening MF in participants with meniscal injury [22,35,46,47], SAIS [36], PFPS [37], ACLR [44], and knee OA [48].

The main muscles trained in knee conditions were quadriceps femoris, trapezius and anterior serratus in SAIS. On the other hand, 4 studies evaluated muscle strength changes in patients with knee OA showing an increase in both groups, although with significant differences ($p < 0.05$) in favor of MF groups in which the vastus medialis was trained [39,40,42,43]. On the other hand, Choi reported an increase in vastus medialis thickness in patients with knee OA with significant changes compared to CG ($p < 0.05$) [41]. Regarding ROM, an improvement is observed after MF treatment, although with controversial results, reporting statistical significance by Akkaya, Christanell, and Kirnap [22,44,46], and without differences between groups according to Draper and Yilmaz [38,42]. Although the decrease in edema was documented as a secondary outcome, only Christanell reported its changes, showing a subjective reduction in patients with ACLR [44].

Muscle relaxation MF studies

Main outcomes for muscle relaxation MF studies included functionality (disability) changes ($n = 8$, 80.0%) [24,25,49–51,53–55], pain intensity decrease ($n = 7$, 70.0%) [24,25,50,53–56], mental health improve ($n = 5$, 50%) [24,25,50,54,56], EMG-A ($n = 2$, 20.0%) [24,52], ROM changes ($n = 1$, 10.0%) [53], movement fear ($n = 1$, 10.0%) [25], muscle strength changes [50] and health state ($n = 1$, 10.0%) [24]. Functionality was assessed with the Canadian Occupational Performance Scale (COPM) [49,51], Psychosocial Functioning Scale (MPI-S) [49,51], Work Ability Index (WAI) [50], Purdue Pegboard Test (PPT) [26], FCI [24], ODI [25], neck disability index [53], pain disability index [54,55] and

general activity level scale (GALS) [54]. Pain intensity was assessed with NPRS [50], pain self-perception scale [24], pressure algometry (PA) [24,53], symptom checklist [24], VAS [25,53,55], pain beliefs personality questionnaire (PBQ) [54,56], pain self-report [54], and West Haven Yale multidimensional inventory (WHYMPI) [56]. On the other hand, mental health was assessed through participants' self-report [50], Beck's depression inventory (BDI) [24,25,54,56] and state-trait anxiety inventory (STAI) [54]. EMG-A, ROM and movement fear were evaluated using surface electromyography, inclinometry, and Tampa scale for kinesiphobia (TSK) respectively [25,52,53]. Finally, muscle strength and health status were assessed through dynamometry and the SF-36 health questionnaire [24,50].

Results show an improvement in functionality for EG and CG, although with significance in favor of MF for COMP ($p < 0.01$), MPI-S ($p < 0.016$), WAI ($p < 0.01$), NDI ($p < 0.01$), and PDI ($p < 0.03$) in participants with cervicobrachialgia [49,55], neck pain [50,53] and WPS [51], in whom the aim was to reduce the activity of the trapezius muscle. CG also shows an improvement in functionality ($p < 0.05$) between the evaluation sessions for the COMP, MPI-S, and WAI, although without being better than MF [49–51]. A decrease in pain is observed in EG for NPRS [50], VAS [25,53], PA [24,53], PBQ [54], and pain self-report [54] in participants with neck pain, fibromyalgia, LBPS, although without statistical significance ($p > 0.05$). These studies show MF applications in the upper trapezius for cervical conditions and spinal erector for LBPS. Despite the above, Dellve (2011) reported a greater decrease in pain in patients with neck pain for one CG that did not receive treatment ($p < 0.046$) [50]. Mental health shows improvements for both study groups, although Spence (1995) reports statistical significance in favor of controls for BDI in cervicobrachialgia ($p < 0.01$) [56]. EMG-A shows a decrease in patients with cervical radiculopathy in favor of MF ($p < 0.01$) [52] and WPS ($p < 0.046$) [25]. On the other hand, ROM increased for both groups in patients with neck pain highlights (intragroup changes) ($p < 0.001$) but without differences between them ($p > 0.05$). Finally, movement fear, muscle strength and health state evaluated do not show statistically significant intra – or intergroup changes ($p > 0.05$) [24,50,51].

Discussion

The objective of this SR was to investigate the scientific evidence on the MF efficacy in function recovery, strength increase, and muscle relaxation in MSD. Low risk of bias was assessed for most of the articles, showing only some concerns in the random assignment

domain for the RoB2 tool [22,23,37,39,40–51,53,55,56]. PEDro score shows good internal validity for 17 studies (65.38%) supporting the methodology and results of the analyzed articles [33].

The studies were classified in two therapeutic applications: strengthening (n=16, 61.53%) and muscle relaxation (n = 10, 38.46%). Both applications are interesting because they support MF's ability to detect subtle changes in motor neurons' activity, often difficult to objectify with palpation or observation, in patients treated to increase (strengthen) or decrease (relaxation) muscle activity. It should be noted that MF systems are based on the information principle (Ross Ashby's law), in which a variable is correctly controlled (strength or relaxation) if the controller (patient) has enough information (visual and/or audible).

Strengthening MF applications

This review supports MF efficacy for strengthening in knee OA, meniscal injury, SAISS, PFPS, ACLR, and lumbar discopathy when it is complemented with therapeutic exercises, FES, NMES, lymphatic drainage, and superficial thermotherapy showing greater benefits than controls that received the same treatments, but without MF. MF applications focused on joint MSD that included knee conditions (n = 13) [22,23,37–44,46–48], shoulder (n = 2) [23,36] and lumbar spine (n = 1) [45]. Knee conditions included postsurgical (n = 10) and non-surgical (n = 3) MF rehabilitation focusing on quadriceps femoris strength recovery. Quadriceps femoris strengthening in these disorders is key due to muscle inhibition caused by pain and joint inflammation (arthrogenic muscle inhibition, AMI). AMI results in an altered proprioceptive information decreasing quadriceps femoris strength, whose role is essential for lower limb functional activities [58].

MF stimulates neural circuits, providing new somatosensory information (visual and/or auditory) to motor activities, recovering afferent and proprioceptive information. Motor control is influenced by visual and auditory systems through motor pathways modulation (corticospinal pathway) that regulates A-alpha motor neurons. In this line, MF favors the activation of these systems by modulating motor activity at different levels of CNS [29,30]. On the other hand, shoulder and LBPS treatments included MF training in trapezius and serratus anterior, and tibialis anterior respectively [23,36,45]. MF can recover scapulothoracic muscles strength, whose imbalances lead to scapular dysfunctions in addition to biomechanical alterations, such as decreased subacromial space and scapular upward [59]. MF in shoulder rehabilitation protocols can be a valuable resource to correct muscle imbalances by providing patients with visual or auditory information to activate

stabilizer scapular muscles while performing exercises. Likewise, it is suggested, for muscular imbalance management, to first use relaxation MF in facilitated muscles and later activation MF in inhibited muscles. This review shows the MF application in the tibialis anterior muscle reporting improvements in functionality in patients with LBPS [45]. Although this peripheral activation has not been clarified, facilitation of neurological circuits of lumbar spinal cord segments (L4-L5), responsible for motor control at the lumbar level, is recommended. Peripheral activation could facilitate lumbar spinal segments motor neurons, also associated with lower back muscles so that an MF training could result in lumbar muscles indirect activation.

Strengthening MF offered increased functionality, decreased pain, increased ROM, and electromyographic activity. Functionality was tested with different validated instruments which support stable, safe, and consistent results for strengthening MF therapy: Lyshom scales, test-retest (TRT) = 0.91 and internal consistency (IC) = 0.65; KOOS, TRT=0.87-0.96 and IC = 0.78; DASH, TRT = 0.97 and IC = 0.96; OSS, TRT = 0.82–0.91; ODI, TRT = 0.83-0.99 and IC = 0.71–0.87; WOMAC, TRT = 0.83-0.90 and IC = 0.70–0.93 [60–64]. This review shows an improvement in functionality, supporting the efficacy of strengthening MF in meniscal injuries, SAIS, and knee OA. Although it is complex to explain a direct relationship between MF and functionality, these changes could be the result of the visual and auditory integration, at different levels, of the CNS due to biofeedback, which allows patients to better control their motor activity as occurs with daily life tasks in which motor patterns are constantly fed back by the somatosensory and proprioceptive systems [65]. Functional improvements can also be explained by the “pain-fear-disability” circle interruption, a model that explains the close relationship between pain, its emotional factors, and consequent disability, and that would be modulated by visual or auditive stimuli when the patient trains with MF [66].

Attention and concentration are factors that influence pain perception, involving the participation of descending modulatory mechanisms whose antinociceptive effects may be equal to or better than those of morphine. This antinociceptive effect seem to be supported by the decrease in thalamocortical activity, thalamus, somatosensory areas, insula and anterior cingulate gyrus. The effect results in pain decrease perception when training with MF due to the patient's lessened attention to the injury while concentrating on the visual and auditory stimuli.

Other analgesic mechanisms have supported endogenous opioid peptides release with motor electrical stimulation [68]. MF allows a simultaneous NMES with MVC configuration while feedback is generated, which

could favor endogenous opioids release when training with electrical currents; however, studies do not document combined applications of MF and NMES. On the other hand, MF motor pathways (different levels), visual, and auditory cortex activation modulate muscle tone by adjusting it to perform a certain motor activity, interrupting the muscle spasm-pain circle (muscle tone self-regulation) [69].

According to the results for strengthening MF, 15 to 20 sessions 3 to 5 times per week are recommended to ensure functionality improvements and muscle strength. Although treatment times are varied, it seems that there are sufficient interventions between 15 and 30 minutes.

It should be noted that, for MF training development, the patient must be able to perform voluntary muscle activity. This finding suggests that MF intervention for strengthening is more useful in MSD in which muscle function is preserved. In addition, it is important to explain to patients that the equipment is not the one that improves strength but only monitors their muscle activity.

Relaxation MF applications

Relaxation MF generally uses audible feedback while monitoring motor neuron activity (μV), emitting a sound stimulus when electromyographic activity exceeds a preset baseline activity level, ensuring that the patient consciously inhibits their muscles. Despite the above, mixed biofeedback (visual and auditory) is seen in MF relaxation studies.

This review supports MF efficacy for muscle relaxation in neck pain, cervicobrachialgia, fibromyalgia, and LBPS when it is complemented with cervical distraction, superficial thermotherapy, US, and therapeutic exercises, showing better therapeutic effects than controls that received the same interventions without MF.

MF applications focused on non-specific MSP on the cervical spine and lumbar spine. The applications were on the trapezius muscle (upper portion) for cervical conditions and spinal erectors for participants with LBPS. The trapezius muscle is usually facilitated or appears more active in neck pain conditions due to the fact that it is responsible for dysfunctional postural patterns such as superior cruciate syndrome. A similar phenomenon occurs with lumbar erectors that are facilitated in low back pain conditions and that lead to postural dysfunctions, such as inferior crossed syndrome [70].

MF studies show improvements in functionality and pain decrease. Functionality was evaluated with validated instruments, which supports results for relaxation MF studies: ODI, TRT = 0.83–0.99 and IC = 0.71–0.87; NDI TRT = 0.50–0.98 and IC = 0.85; WAI TRT = 0.92 and IC = 0.74 [71,72].

Improvements in functionality can be explained by the “pain-fear-disability” circle interruption and muscle tone

self-regulation (previously explained). This improvement can also be explained by the “information principle,” in which the variable (muscle tone) is controlled when the person has information about it. On the other hand, self-regulation of muscle tone added to concentration on the task while training with MF could explain the analgesic effects, mediated by changes in attention [67].

It is interesting that some studies considered health status, movement fear, and depression as secondary outcomes, especially considering that MF showed benefits in patients with fibromyalgia and LBPS. These results support the MF central modulation that could exert an inhibitory effect at the limbic system, modifying psycho-affective response and pain perception of the individual [12].

According to the results, 8 to 12 sessions 3 to 5 times per week are suggested to achieve favorable functional changes for relaxation with MF. Although the treatment times are varied, interventions between 30 and 60 minutes are recommended. Likewise, it should be considered that, due to prolonged treatment time, many clinicians could opt for other relaxation strategies despite the clear benefits and comparative advantages that MF therapy shows.

Conclusions

MF is a safe and non-invasive treatment used in rehabilitation for different MSD. This treatment can be used for muscle strengthening (active method) or relaxation (passive method), although both techniques require muscle function indemnity.

This SR shows that strengthening and relaxation MF applications are effective for improving the functionality and reducing pain in the short and long term for different joint and soft tissue disorders, especially when complemented with therapeutic exercises or physical agents. MF treatment shows good results in psycho-affective variables such as movement fear and depression, suggesting a modulating influence on the CNS. Although it was not possible to perform a meta-analysis of the studies due to their heterogeneity, these results seem promising and promote MF in the rehabilitation protocols of the revised MSDs, as well as the development of new research on other musculoskeletal conditions not documented in this review.

Despite the results, a common aspect for MF applications is the time required to prepare the patient as well as the time needed to carry out the training, which could discourage its use despite its benefits. Likewise, this SR allowed the researchers to propose a dosage recommendation for strengthening and relaxation with MF, which can be revised and considered for future research.

Funding

This research received no external funding.

Conflict of interests

The authors have no conflict of interest to declare.

References

- Hawker GA. The assessment of musculoskeletal pain. *Clin Exp Rheumatol*. 2017; 35 Suppl 107(5): 8–12.
- El-Tallawy SN, Nalamasu R, Salem GI, LeQuang JAK, Pergolizzi JV, Christo PJ. Management of musculoskeletal pain: An update with emphasis on chronic musculoskeletal pain. *Pain Ther*. 2021; 10(1): 181–209.
- Booth J, Moseley GL, Schiltenswolf M, Cashin A, Davies M, Hübscher M. Exercise for chronic musculoskeletal pain: A biopsychosocial approach. *Musculoskeletal Care*. 2017; 15(4): 413–21.
- Park PW, Dryer RD, Hegeman-Dingle R, Mardekian J, Zlateva G, Wolff GG, et al. Cost burden of chronic pain patients in a large integrated delivery system in the United States. *Pain Pract*. 2015; 16(8): 1001–11.
- Arendt-Nielsen L, Fernández-de-Las-Peñas C, Graven-Nielsen T. Basic aspects of musculoskeletal pain: from acute to chronic pain. *J Man Manip Ther*. 2011; 19(4): 186–93.
- Blyth FM, Noguchi N. Chronic musculoskeletal pain and its impact on older people. *Best Pract Res Clin Rheumatol*. 2017; 31(2): 160–8.
- Jensen TS, Baron R, Haanpää M, Kalso E, Loeser JD, Rice ASC, et al. A new definition of neuropathic pain. *Pain*. 2011; 152(10): 2204–5.
- Szok D, Tajti J, Nyári A, Vécsei L. Therapeutic approaches for peripheral and central neuropathic pain. *Behav Neurol*. 2019; 2019: 8685954.
- van Griensven H, Schmid A, Trendafilova T, Low M. Central sensitization in musculoskeletal pain: Lost in translation? *J Orthop Sports Phys Ther*. 2020; 50(11): 592–6.
- Pelletier R, Higgins J, Bourbonnais D. Is neuroplasticity in the central nervous system the missing link to our understanding of chronic musculoskeletal disorders? *BMC Musculoskelet Disord*. 2015; 16(1): 25.
- Baliki MN, Mansour AR, Baria AT, Apkarian AV. Functional reorganization of the default mode network across chronic pain conditions. *PLoS One*. 2014; 9(9): e106133.
- Fenton BW, Shih E, Zolton J. The neurobiology of pain perception in normal and persistent pain. *Pain Manag*. 2015; 5(4): 297–317.
- Vos T, Flaxman AD, Naghavi M, Lozano R, Michaud C, Ezzati M, et al. Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 2012; 380(9859): 2163–96.
- GBD 2017 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*. 2018; 392(10159): 1789–858.
- Lin I, Wiles L, Waller R, Goucke R, Nagree Y, Gibberd M, et al. What does best practice care for musculoskeletal pain look like? Eleven consistent recommendations from high-quality clinical practice guidelines: systematic review. *Br J Sports Med*. 2020; 54(2): 79–86.
- Abdel Shaheed C, Maher CG, Williams KA, Day R, McLachlan AJ. Efficacy, tolerability, and dose-dependent effects of opioid analgesics for low back pain: A systematic review and meta-analysis: A systematic review and meta-analysis. *JAMA Intern Med*. 2016; 176(7): 958–68.
- Mercadante S, Arcuri E, Santoni A. Opioid-induced tolerance and hyperalgesia. *CNS Drugs*. 2019; 33(10): 943–55.
- Lin I, Wiles LK, Waller R, Goucke R, Nagree Y, Gibberd M, et al. Poor overall quality of clinical practice guidelines for musculoskeletal pain: a systematic review. *Br J Sports Med*. 2018; 52(5): 337–43.
- Beutler A. Musculoskeletal therapies: Adjunctive physical therapy. *FP Essent*. 2018; 470: 16–20.
- Hidalgo B, Detrembleur C, Hall T, Mahaudens P, Nielen H. The efficacy of manual therapy and exercise for different stages of non-specific low back pain: an update of systematic reviews. *J Man Manip Ther*. 2014; 22(2): 59–74.
- Smith BE, Hendrick P, Bateman M, Holden S, Littlewood C, Smith TO, et al. Musculoskeletal pain and exercise-challenging existing paradigms and introducing new. *Br J Sports Med*. 2019; 53(14): 907–12.
- Akkaya N, Ardic F, Ozgen M, Akkaya S, Sahin F, Kilic A. Efficacy of electromyographic biofeedback and electrical stimulation following arthroscopic partial meniscectomy: a randomized controlled trial. *Clin Rehabil*. 2012; 26(3): 224–36.
- Juul-Kristensen B, Larsen CM, Eshoj H, Clemmensen T, Hansen A, Bo Jensen P, et al. Positive effects of neuromuscular shoulder exercises with or without EMG-biofeedback, on pain and function in participants with subacromial pain syndrome – A randomised controlled trial. *J Electromyogr Kinesiol*. 2019; 48: 161–8.
- Baumweller E, Winkelmann A, Irnich D, Weigl M. Electromyogram biofeedback in patients with

- fibromyalgia: A randomized controlled trial. *Complement Med Res.* 2017; 24(1): 33–9.
25. Gálvez-Hernández CL, Rodríguez-Ortiz MD, Del Río-Portilla Y. Biofeedback treatment for acute whiplash patients. *Rev Med Inst Mex Seguro Soc.* 2016; 54(4): 480–9.
 26. Narayanan SP, Bharucha AE. A practical guide to biofeedback therapy for pelvic floor disorders. *Curr Gastroenterol Rep.* 2019; 21(5): 21.
 27. Dost Sürücü G, Tezen Ö. The effect of EMG biofeedback on lower extremity functions in hemiplegic patients. *Acta Neurol Belg.* 2021; 121(1): 113–8.
 28. Robinson AJ, Snyder-Mackler L, editors. *Clinical Electrophysiology: Electrotherapy and Electrophysiologic Testing.* 3rd ed. Philadelphia, PA: Lippincott Williams and Wilkins; 2007.
 29. Avanzino L, Pelosin E, Vicario CM, Lagravinese G, Abbruzzese G, Martino D. Time processing and motor control in movement disorders. *Front Hum Neurosci.* 2016; 10: 631.
 30. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ.* 2009; 339: b2535.
 31. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. *Syst Rev.* 2016; 5(1).
 32. Albanese E, Bütikofer L, Armijo-Olivo S, Ha C, Egger M. Construct validity of the Physiotherapy Evidence Database (PEDro) quality scale for randomized trials: Item response theory and factor analyses. *Res Synth Methods.* 2020; 11(2): 227–36.
 33. Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ.* 2019; 366: l4898.
 34. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. *Res Synth Methods.* 2021; 12(1): 55–61.
 35. Oravitan M, Avram C. The effectiveness of electromyographic biofeedback as part of a meniscal repair rehabilitation programme. *J Sports Sci Med.* 2013; 12(3): 526–32.
 36. Huang H-Y, Lin J-J, Guo YL, Wang WT-J, Chen Y-J. EMG biofeedback effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement. *J Electromyogr Kinesiol.* 2013; 23(1): 267–74.
 37. Ng GYF, Zhang AQ, Li CK. Biofeedback exercise improved the EMG activity ratio of the medial and lateral vasti muscles in subjects with patellofemoral pain syndrome. *J Electromyogr Kinesiol.* 2008; 18(1): 128–33.
 38. Draper V, Ballard L. Electrical stimulation versus electromyographic biofeedback in the recovery of quadriceps femoris muscle function following anterior cruciate ligament surgery. *Phys Ther.* 1991; 71(6): 455–61.
 39. Anwer S, Quddus N, Miraj M, Equebal A. Effectiveness of electromyographic biofeedback training on quadriceps muscle strength in osteoarthritis of knee. *Hong Kong Physiother J.* 2011; 29(2): 86–93.
 40. Dursun N, Dursun E, Kiliç Z. Electromyographic biofeedback-controlled exercise versus conservative care for patellofemoral pain syndrome. *Arch Phys Med Rehabil.* 2001; 82(12): 1692–5.
 41. Choi YL, Kim BK, Hwang YP, Moon OK, Choi WS. Effects of isometric exercise using biofeedback on maximum voluntary isometric contraction, pain, and muscle thickness in patients with knee osteoarthritis. *J Phys Ther Sci.* 2015; 27(1): 149–53.
 42. Yilmaz OO, Senocak O, Sahin E, Baydar M, Gulbahar S, Bircan C, et al. Efficacy of EMG-biofeedback in knee osteoarthritis. *Rheumatol Int.* 2010; 30(7): 887–92.
 43. Durmuş D, Alaylı G, Cantürk F. Effects of quadriceps electrical stimulation program on clinical parameters in the patients with knee osteoarthritis. *Clin Rheumatol.* 2007; 26(5): 674–8.
 44. Christanell F, Hoser C, Huber R, Fink C, Luomajoki H. The influence of electromyographic biofeedback therapy on knee extension following anterior cruciate ligament reconstruction: a randomized controlled trial. *Sports Med Arthrosc Rehabil Ther Technol.* 2012; 4(1): 41.
 45. Sardaru DP, Matei D, Zaharia-Kezdi D, Pendefunda L. Effects of biofeedback versus switch-triggered functional electrical stimulation on sciatica-related foot drop. *J Back Musculoskelet Rehabil.* 2018; 31(2): 239–45.
 46. Kirnap M, Calis M, Turgut AO, Halici M, Tuncel M. The efficacy of EMG-biofeedback training on quadriceps muscle strength in patients after arthroscopic meniscectomy. *N Z Med J.* 2005; 118(1224): U1704.
 47. Levitt R, Deisinger JA, Remondet Wall J, Ford L, Cassisi JE. EMG feedback-assisted postoperative rehabilitation of minor arthroscopic knee surgeries. *J Sports Med Phys Fitness.* 1995; 35(3): 218–23.
 48. Raeissadat SA, Rayegani SM, Sedighipour L, Bossaghzade Z, Abdollahzadeh MH, Nikray R, et al. The efficacy of electromyographic biofeedback on pain, function, and maximal thickness of vastus medialis oblique muscle in patients with knee osteoarthritis: a randomized clinical trial. *J Pain Res.* 2018; 11: 2781–9.
 49. Ehrenborg C, Archenholtz B. Is surface EMG biofeedback an effective training method for persons with neck and shoulder complaints after whiplash-

- associated disorders concerning activities of daily living and pain – a randomized controlled trial. *Clin Rehabil.* 2010; 24(8): 715–26.
50. Dellve L, Ahlstrom L, Jonsson A, Sandsjö L, Forsman M, Lindegård A, et al. Myofeedback training and intensive muscular strength training to decrease pain and improve work ability among female workers on long-term sick leave with neck pain: a randomized controlled trial. *Int Arch Occup Environ Health.* 2011; 84(3): 335–46.
51. Voerman GE, Vollenbroek-Hutten MMR, Hermens HJ. Changes in pain, disability, and muscle activation patterns in chronic whiplash patients after ambulant myofeedback training. *Clin J Pain.* 2006; 22(7): 656–63.
52. Atteya AA. Biofeedback traction versus conventional traction in cervical radiculopathy. *Neurosciences (Riyadh).* 2004; 9(2): 91–3.
53. Eslamian F, Jahanjoo F, Dolatkah N, Pishgahi A, Pirani A. Relative effectiveness of electroacupuncture and biofeedback in the treatment of neck and upper back myofascial pain: A randomized clinical trial. *Arch Phys Med Rehabil.* 2020; 101(5): 770–80.
54. Newton-John TR, Spence SH, Schotte D. Cognitive-behavioural therapy versus EMG biofeedback in the treatment of chronic low back pain. *Behav Res Ther.* 1995; 33(6): 691–7.
55. Kosterink SM, Huis in 't Veld RMHA, Cagnie B, Hasenbring M, Vollenbroek-Hutten MMR. The clinical effectiveness of a myofeedback-based teletreatment service in patients with non-specific neck and shoulder pain: a randomized controlled trial. *J Telemed Telecare.* 2010; 16(6): 316–21.
56. Spence SH, Sharpe L, Newton-John T, Champion D. Effect of EMG biofeedback compared to applied relaxation training with chronic, upper extremity cumulative trauma disorders. *Pain.* 1995; 63(2): 199–206.
57. Stovold E, Beecher D, Foxlee R, Noel-Storr A. Study flow diagrams in Cochrane systematic review updates: an adapted PRISMA flow diagram. *Syst Rev.* 2014; 3(1): 54.
58. Sonnery-Cottet B, Saithna A, Quelard B, Daggett M, Borade A, Ouanezar H, et al. Arthroscopic muscle inhibition after ACL reconstruction: a scoping review of the efficacy of interventions. *Br J Sports Med.* 2019; 53(5): 289–98.
59. Struyf F, Nijs J, Mollekens S, Jeurissen I, Truijzen S, Mottram S, et al. Scapular-focused treatment in patients with shoulder impingement syndrome: a randomized clinical trial. *Clin Rheumatol.* 2013; 32(1): 73–85.
60. Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ. Reliability, validity, and responsiveness of the Lysholm knee scale for various chondral disorders of the knee. *J Bone Joint Surg Am.* 2004; 86(6): 1139–45.
61. Ebrahimi N, Jalaie S, Salsabili N, Ansari NN, Naghdi S. Knee Injury and Osteoarthritis Outcome Score in patients with isolated meniscus injury; Validity and reliability. *J Res Med Sci.* 2017; 22(1): 55.
62. Raven EEJ, Haverkamp D, Sierevelt IN, van Montfort DO, Pöll RG, Blankevoort L, et al. Construct validity and reliability of the disability of arm, shoulder, and hand questionnaire for upper extremity complaints in rheumatoid arthritis. *J Rheumatol.* 2008; 35(12): 2334–8.
63. van der Linde JA, van Kampen DA, van Beers LWAH, van Deurzen DFP, Terwee CB, Willems WJ. The Oxford Shoulder Instability Score; validation in Dutch and first-time assessment of its smallest detectable change. *J Orthop Surg Res.* 2015; 10(1): 146.
64. Roos EM, Toksvig-Larsen S. Knee injury and Osteoarthritis Outcome Score (KOOS) – validation and comparison to the WOMAC in total knee replacement. *Health Qual Life Outcomes.* 2003; 1(1): 17.
65. Cano-de-la-Cuerda R, Molero-Sánchez A, Carratalá-Tejada M, Alguacil-Diego IM, Molina-Rueda F, Mian-golarra-Page JC, et al. Teorías y modelos de control y aprendizaje motor. Aplicaciones clínicas en neurorehabilitación. *Neurologia.* 2015; 30(1): 32–41.
66. Zale EL, Lange KL, Fields SA, Ditte JW. The relation between pain-related fear and disability: a meta-analysis. *J Pain.* 2013; 14(10): 1019–30.
67. Roy M, Lebus A, Peretz I, Rainville P. The modulation of pain by attention and emotion: a dissociation of perceptual and spinal nociceptive processes. *Eur J Pain.* 2011; 15(6): 641.e1-10.
68. Bi Y, Wei Z, Kong Y, Hu L. Supraspinal neural mechanisms of the analgesic effect produced by transcutaneous electrical nerve stimulation. *Brain Struct Funct.* 2021; 226(1): 151–62.
69. Johnson DS. The spasm-pain-spasm cycle. *Pain Med.* 2012; 13(4): 615.
70. Sembrano JN, Yson SC, Kanu OC, Braman JP, Santos ERG, Harrison AK, et al. Neck-shoulder crossover: how often do neck and shoulder pathology masquerade as each other? *Am J Orthop (Belle Mead NJ).* 2013; 42(9): E76-80.
71. MacDermid JC, Walton DM, Avery S, Blanchard A, Etruw E, McAlpine C, et al. Measurement properties of the neck disability index: a systematic review. *J Orthop Sports Phys Ther.* 2009; 39(5): 400–17.
72. de Zwart BCH, Frings-Dresen MHW, van Duivenbooden JC. Test-retest reliability of the Work Ability Index questionnaire. *Occup Med (Lond).* 2002; 52(4): 177–81.