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Physical therapy interventions for the treatment of delayed onset muscle soreness (DOMS): Systematic review and meta-analysis

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ABSTRACT

Objective: To evaluate the impact of interventions on pain associated with DOMS.
Data sources: PubMed, EMBASE, PEDro, Cochrane, and Scielo databases were searched, from the oldest records until May/2020. Search terms used included combinations of keywords related to “DOMS” and “intervention therapy”.
Eligibility criteria: Healthy participants (no restrictions were applied, e.g., age, sex, and exercise level). To be included, studies should be: 1) Randomized clinical trial; 2) Having induced muscle damage and subsequently measuring the level of pain; 3) To have applied therapeutic interventions (non-pharmacological or nutritional) and compare with a control group that received no intervention; and 4) The first application of the intervention had to occur immediately after muscle damage had been induced.
Results: One hundred and twenty-one studies were included. The results revealed that the contrast techniques ($p = 0{,}002$ $I^2 = 60$ %), cryotherapy ($p = 0{,}002$ $I^2 = 100$ %), phototherapy ($p = 0{,}0001$ $I^2 = 95$ %), vibration ($p = 0{,}004$ $I^2 = 96$ %), ultrasound ($p = 0{,}02$ $I^2 = 97$ %), massage ($p < 0{,}00001$ $I^2 = 94$ %), active exercise ($p = 0{,}0004$ $I^2 = 93$ %) and compression ($p = 0{,}002$ $I^2 = 93$ %) have a better positive effect than the control in the management of DOMS.
Conclusion: Low quality evidence suggests that contrast, cryotherapy, phototherapy, vibration, ultrasound, massage, and active exercise have beneficial effects in the management of DOMS-related pain.

1. Introduction

A type of temporary muscle damage defines delayed onset muscle soreness (DOMS) after high-intensity exercises, especially for eccentric contraction, with a frequency related to unaccustomed intensity activities and mechanical act (Hotfiel et al., 2018; Jeon et al., 2015; Mikesky & Hayden, 2005). The typical clinical sign of this condition is muscle pain associated with increased sensitivity during movement at varying severity levels, proportional to the intensity and duration of the exercise performed (Zhang, Clement, & Taunton, 2000). The hypotheses on DOMS's pathophysiology are based on the primary mechanism triggered by the microdamage caused in the muscle related with subsequent inflammation, which results in pain, edema, flushing, heat, and relative functional impairment (Boobphachart et al., 2017; Haksever et al., 2016). Researchers in the world have studied the mechanisms involved in DOMS development for more than 120 years. Some hypotheses have been suggested to explain the emergence of this condition during this period, including lactate theory, spasm theory, connective tissue damage theory, muscle damage theory, and inflammation theory (Boobphachart et al., 2017; Haksever et al., 2016; Jeon et al., 2015; Mikesky & Hayden, 2005; Zhang et al., 2000).

Besides the pain, clinically, a DOMS reproduces symptoms corresponding to muscle stiffness, reduced range of movement, muscle weakness, and lower peak torque (Hazar Kanik et al., 2019). It is possible that the eventual compromise in levels of muscle

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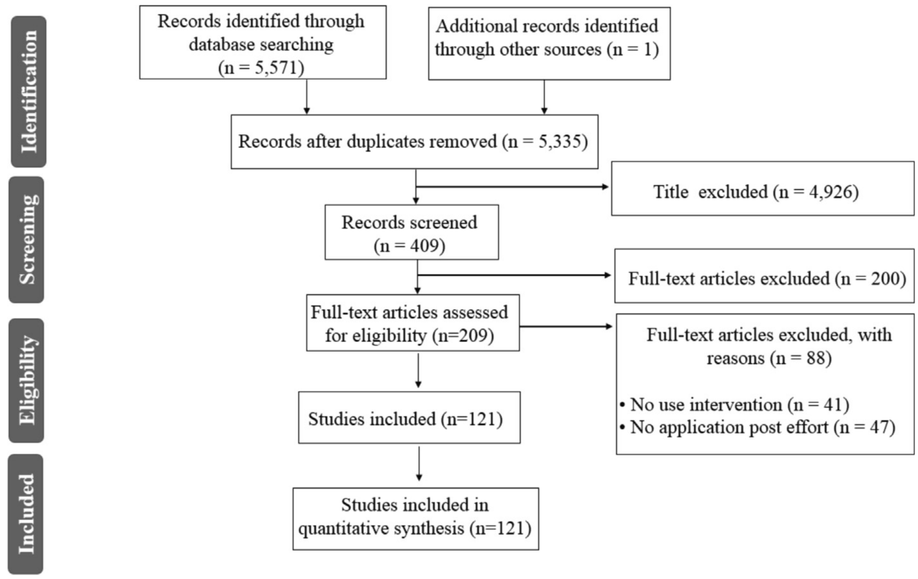

Fig. 1. Study flowchart.

activation and recruitment could result in compensatory stress and activation patterns in ligaments, muscles, and tendons. This has the potential to exacerbate the risk of secondary injuries if the athlete returns early to sports practice. Thus, the detriments listed are used as outcome measures in evaluation routines in clinical practice and by clinical trials as a parameter to measure the level and evolution of improvement from applying specific therapeutic interventions (Haksever et al., 2016). Therefore, it is essential to optimize recovery in a good situation to avoid and/or minimize the mechanisms described above (Haksever et al., 2016; Kirmizigil et al., 2019; Ozmen et al., 2017).

In order to optimize the recovery of body systems and treat symptoms of DOMS, a variety of mechanical-physiological interventions have been observed, based on different protocols in the literature (Haksever et al., 2016; Kirmizigil et al., 2019; Mikesky & Hayden, 2005; Ozmen et al., 2017). Among the interventions widely used for this purpose are cryotherapy, massage, active exercises, compression clothing, acupuncture, stretching, phototherapy, vibration, kinesio taping, foam roller, ultrasound, and electro-stimulation (Dupuy et al., 2018). These modalities applied after exercise are intended to alleviate DOMS, assisting in removing markers of muscle damage and inflammatory markers to restore functional capacity and minimize symptoms in the shortest period possible.

Another important aspect refers to the heterogeneity between the studies, characterized by dosage/the point in recovery they are applied may vary, the manner of inducing DOMs may vary, muscles targeted may vary, the outcomes measured, the manner of assessing a single outcome may (when and how the data are collected) and the population, must be considered and controlled because they can influence the outcomes. So, in this scenario, considering the broad scientific and clinical protocols used to use these interventions associated with the eminent difficulty on uniformity and standardization in the use of methods, studies of review and meta-analysis must synthesize evidence to describe and explore the effects of the interventions used.

Systematic reviews are available in the literature to investigate a single type of technique or a limited group of techniques that highlight good effects, referring mainly to cryotherapy, massage, and active exercise. Thus, there is a gap referring to a single study that encompasses and synthesizes outcomes for all techniques described for DOMS treatment. Concerning the above, given the countless options of clinical interventions described so far, a review and meta-analysis study is indispensable to demonstrate the magnitude of tangible effects on each technique for support the clinical use inherent to DOMS management. Therefore, this review study and meta-analysis aimed to evaluate the impact of interventions on pain associated with DOMS.

2. Methods

This systematic review and meta-analysis study followed all guidelines reported in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which were followed (Lopes et al., 2019). In addition, the systematic review was registered in the International Prospective Register of Systematic Reviews (PROSPERO).

2.1. Search strategy

Searches were conducted on the following databases: PubMed/MEDLINE, PEDro (Physiotherapy Evidence Database), Scielo, and CENTRAL (Cochrane Central Register of Controlled Trials) from the earliest available records until May 30th, 2020 (see details in Appendix I). For such, the search strategy was elaborated with keywords related to the terms: "DOMS" and clinical "therapeutic interventions". Moreover, after selecting the studies, a separate search in the eligible references was performed to complement the electronic searches. This step was carried out by two authors independently.

2.2. Selection of studies

To be included, the studies had to meet the following criteria: 1) To have a clinical trial design randomized; 2) To have induced muscle damage and subsequent measurement of the level of DOMS; 3) To have applied therapeutic interventions (non-pharmacological or nutritional) and compare with a control group that received no intervention; and 4) The first application of the intervention had to occur immediately after muscle damage had been induced.

Case reports, case series, comments, editorials, letters to the editor, and literature reviews were excluded. There was no restriction on the conditions of: age, sex, activity level, publication date, and language of the studies. The selected articles were stored and grouped in Excel spreadsheets for later duplicate titles identification and exclusion. The selection process occurred in stages following by title, abstract, and full text, respectively. Fig. 1 represents the process described.

2.3. Data extraction

The following data were extracted from the selected articles: 1) General information (authors, year of publication and study design); 2) Participants characteristics (sample size, sex distribution, age); 3) Information related to DOMS (evaluation method and intensity); 4) Therapeutic interventions used (type and dose-response); 5) Verified outcomes (level of clinical pain); and 6) Methodological quality according to the PEDRo scale. Two independent authors also performed this step.

When required, the authors of the studies were contacted to provide clarifications on missing information. (details of Appendix 2 and 3).

2.4. Quality and risk of bias assessment

The selected studies' methodological quality was assessed and reported using the PEDRo scale (0-10), where 0 represents the worst possible quality and 10 is the best. The PEDRo scale considers the following criteria: eligibility criteria, random allocation, secret allocation, baseline comparison, participants, therapists, and assessors blindly, follow-up with less than 15 % loss, adequate treatment according to allocation or intention to treat, intergroup statistical comparisons, and measures of accuracy and variability. Scores have been sustained in cases of studies already evaluated in the PEDRo database (http://www.pedro.org.au). In other cases, two independent authors using the scale recommendations performed the evaluation process. A PEDro score of 7 or higher was considered for ranking "high quality," studies with a score of 5 or 6 were considered "moderate quality," and those with a score of 4 or lower represented "low quality" 10. Methodological quality was not considered a criterion for inclusion (Lopes et al., 2019).

An adaptable version of the GRADE approach was used to evaluate the overall quality of evidence, as addressed by Cochrane Back Review Group (Henschke et al., 2010). The GRADE classification was downgraded 1 level for each of the four factors not met: design limitations, inconsistent outcomes, imprecision, and bias reports. The overall quality of evidence has been defined as high quality, moderate quality, low quality, and low quality (Henschke et al., 2010).

2.5. Data analysis

After selecting the studies, we decided to use the VAS outcome to run the meta-analysis as it is the most used outcome in most studies. The studies were grouped into three major sub-modalities of therapeutic resources to allow for specific discussions: 1) Physical methods, which included any techniques involving techniques of electrotherapy, phototherapy, or thermophototherapy origin. . 2) Mechanical methods, which included kinesiotherapy techniques such as stretching, active exercises, and strengthening. 3) Other methods, which included acupuncture and kinesiotaping.

The data were analyzed using Review Manager (RevMan, version 5.3.5), grouped in meta-analyses, and reported as standardized mean difference (SMD) with a 95 % confidence interval (CI). The random-effect model was adopted due to the studies' heterogeneity, reported by the value of I (Mikesky & Hayden, 2005) (heterogeneity measure). In addition, a narrative synthesis was carried out. The results have been considered statistically significant if $p < 0.05$. The quality of evidence of the findings was based on the methodological quality of the clinical trials included.

3. Results

After excluding duplicate titles, the initial databases search has yielded 5335 records. A subsequent review verified the information on title and abstract, resulting in 209 potentially eligible studies. Upon reading the complete text, 41 studies were excluded because they did not perform any intervention, and 47 were because they did not apply the techniques after the exercise. Thus, 121 articles met the inclusion criteria and were considered for data analysis. In manual searches, 1 article was included (Machado et al., 2017). For the selected studies, there was 100 % agreement among researchers who performed the process independently and blindly. All details regarding the described process are presented in the flowchart of Fig. 1.

Therapeutic interventions for the management of DOMS varied, so three studies have evaluated magnetic therapy (Jeon et al., 2015; Mikesky & Hayden, 2005; Zhang et al., 2000); four studies investigated contrast (Elias et al., 2012; Glasgow, Ferris, & Bleakley, 2014; Vaile et al., 2007, 2008); seven studies observed the effects of therapy by vibration technique (Fuller et al., 2015; Imtiyaz, Veqar, & Shareef, 2014; Lau & Nosaka, 2011; Rhea et al., 2009; Romero-Moraleda et al., 2019; Timon et al., 2016; Wheeler & Jacobson, 2013); five studies used foam roller (Akinci, Zenginler, & Altinoluk, 2020; Macdonald et al., 2014; Naderi, Rezvani, & Degens, 2020; Pearcey et al., 2015; Romero-Moraleda et al., 2019); nine studies verified the effects of compression (Carling, Francis, & Lorish, 1995; Ferguson, Dodd, & Paley, 2014; Hill et al., 2017; Hoffman et al., 2016; Jakeman et al., 2010a, 2010b; Kraemer et al., 2001; Northey et al., 2016; Prill, Schulz, & Michel, 2019); 22 studies investigated massage protocols (Andersen et al., 2013; Behringer, Jedlicka, & Mester, 2018; Changa et al., 2020; Frey et al., 2008; Fuller et al., 2015; Hart, Swanik, & Tierney, 2005; Hilbert, Sforzo, & Swensen, 2003; Hoffman et al., 2016; Imtiyaz et al., 2014; Jakeman et al., 2010a, 2010b; Jay et al., 2014; Kargarfard et al., 2016; Kong et al., 2018; Lightfoot, Char, & Dermott, 1997; Micklewright, 2009; Smith et al., 1994; Tiidus & Shoemaker, 1995; Visconti et al., 2020; Weber, Servedio, & Woodall, 1994; Wiewelhove et al., 2018; Xiong et al., 2009; Zainuddin et al., 2005; Zebrowska et al., 2019); eight studies analyzed stretching (Boobphachart et al., 2017; Jayaraman et al., 2004; Lightfoot et al., 1997; Rhea et al., 2009; Torres et al., 2013; Wang, Zhang, & Wang, 2006; Wessel & Wan, 1994; Xie et al., 2018); 33 studies investigated cryotherapy (Abaïdia et al., 2017; Adamczyk et al., 2016; Ascensão et al., 2011; Behringer et al., 2018; de Paiva et al., 2016;

Table 1
The sub-categories of techniques used.

Physical Methods	Mechanical Methods	Other Methods
Magnetic therapy	Foam roller	Kinesiotaping
Contrast	Compression	Acupuncture
Vibration	Massage	
Cryotherapy	Stretching	
TENS	Active exercise	
Microcurrents		
Ultrasound		
Short wave diathermy		
Phototherapy		
Thermotherapy temperature rise		

Denegar & Perrin, 1992; Doungkulsa et al., 2018; Elias et al., 2012; Ferreira-Junior et al., 2015; Fonseca et al., 2016; Glasgow et al., 2014; Goodall & Howatson, 2008; Guilhem et al., 2013; Hassan, 2011; Howatson et al., 2005, 2008; Howatson & Van Someren, 2003; Isabell et al., 1992; Jajtner et al., 2015; Johar et al., 2012; Leeder et al., 2015; Machado et al., 2017; Malmir, Ghotbi, & Mohsen, 2017; Marquet et al., 2015; Micheletti et al., 2019; Paddon-Jones & Quigley, 1997; Pointon et al., 2011; Selkow et al., 2015; Sellwood et al., 2007; Siqueira et al., 2018; Tseng et al., 2013; Vaile et al., 2008; Wiewelhove et al., 2018); 15 studies included active exercises (Akinci et al., 2020; Andersen et al., 2013; Changa et al., 2020; Hart et al., 2005; Isabell et al., 1992; Law & Herbert, 2007; Marquet et al., 2015; Olsen et al., 2012; Rey et al., 2012; Tufano et al., 2012; Wang et al., 2006; Weber et al., 1994; Wheeler & Jacobson, 2013; Wiewelhove et al., 2018; Zainuddin et al., 2006); 17 articles investigated electrotherapy[28,33,54,64-66,94-104;] Eight studies verified sound waves (ultrasound) and shortwave diathermy (Aaron, Delgado-Diaz, & Kostek, 2017; Aytar et al., 2008; Craig et al., 1999a; Hasson et al., 1990; Parker & Madden, 2014; Plaskett, Tiidus, & Livingston, 1999; Shankar, Sinha, & Sandhu, 2006; Visconti et al., 2020); One study investigated shock waves (Fleckenstein et al., 2017); Seven studies observed phototherapy (Craig et al., 1996b, 1999b; de Paiva et al., 2016; Douris et al., 2006; Fleckenstein et al., 2017; Glasgow et al., 2001; Vinck et al., 2006); Five studies observed heat (Engel et al., 1996; Hassan, 2011; Jayaraman et al., 2004; Petrofsky et al., 2012; Vaile et al., 2008); Five studies investigated Kinesiotaping (Boobphachart et al., 2017; Haksever et al., 2016; Hazar Kanik et al., 2019; Kirmizigil et al., 2019; Ozmen et al., 2017); and five studies evaluated acupuncture (Barlas et al., 2000; Cardoso et al., 2020; Fleckenstein et al., 2016; Hübscher et al., 2008; Itoh, Ochi, & Kitakoji, 2008).

As described in the chapter on methods, the included studies' techniques were grouped into the following subcategories: physical methods, mechanical methods, and other methods, according to the nature of the respective therapeutic interventions used (Table 1).

Total, 71.1 % of the studies compared a single type of intervention with the no intervention and/or placebo (passive recovery) and 28.9 % surveyed more than one type of intervention, being in these cases stratified and analyzed. In all studies, “the control group” was characterized as not receiving any intervention.

3.1. Study characteristics

The date of publication varied between 1990 and 2020. In total, it was composed of 3661 individuals between the ages of 13 and 45 years. Concerning the participants' level of conditioning, 29 studies (23.9 %) included athletic populations, and 92 studies (76.1 %) included healthy non-athletic participants. No study addressed populations with diseases. Regarding sex, 13 studies (10.7 %) included only women, 77 studies (63.6 %) included only men and 31 studies (25.6 %) included both sexes.

Regarding the anatomical local of muscle damage induction, 46 studies (38.0 %) applied protocols located in the upper limbs, most commonly in the biceps; 69 studies (57.0 %) applied in the lower limbs, most commonly in quadriceps; while six studies (5 %) applied protocols consisting of systemic aerobic exercises.

To cause muscle damage induced by exercise, studies used different types of protocols with different methods. Like this, 32 studies used the isokinetic dynamometer (26.4 %); 54 studies used weight machines and dumbbells (44.6 %); 20 studies used their body weight through functional exercises (16.5 %); and 15 studies performed aerobic exercises, lasting 30 min or more (12.5 %).

The assessment of the sensation of pain was measured in the included studies following methods: visual analog scale (VAS), in 116 studies (95.8 %); mechanical pain threshold, in 23 studies (18.1 %); and through specific questionnaires in 8 studies (6.6 %). In this respect, of the studies that used VAS, the scores varied so that 62 studies used a scale of 0–10 cm (53.4 %); 30 studies used a 0–100 mm scale (25.8 %); 15 studies used other scores (12.9 %); and five studies did not make clear as to the score used by the applied scales (7.7 %).

The treatment protocols used were also diversified regarding the dose-response as well as the methodology used, mainly influenced by the type of muscle damage caused. However, none of the included studies reported any adverse event associated with treatment. Regarding the results of the clinical interventions used in the analyzed studies, 64 studies, which corresponds to 52.8 % of the total, observed significant effects ($p < 0.05$).

All studies carried out baseline measurements before the exercise. Follow-up measures ranged between from post-exercise (4.9 %), 24 (6.6 %), 48 (23.1 %), 72 (34.7 %), 96 (13.3 %), 120 (9.1 %), 144 (5.8 %) hours and 14 days (2.5 %) after the exercise. The studies analyzed considered a level of significance $p = 0.05$, and everyone found an increase in pain after the induction of muscle damage, with a peak between 24 and 48 h.

3.2. Effects of specific interventions for DOMS

The interventions' analysis is presented below, stratified according to the corresponding method, specifically for the DOMS's treatment. Twelve studies were not included for meta-analysis because they did not use a visual analog scale or presented incomplete data.

3.2.1. Physical methods

The physical methods considered were: magnetic therapy, contrast, vibration, cryotherapy, electrotherapy, ultrasound, shortwave diathermy, phototherapy and heat.

The results obtained regarding magnetic therapy showed beneficial effects in two studies (Jeon et al., 2015; Zhang et al., 2000), while one study1 found no effect. For contrast, two studies (Elias et al., 2012; Vaile et al., 2008) showed significant effects, and two studies did not (Glasgow et al., 2014; Vaile et al., 2007), while the results for vibration showed significant effects in five studies (Imtiyaz et al., 2014; Lau & Nosaka, 2011; Rhea et al., 2009; Romero-Moraleda et al., 2019; Timon et al., 2016) and not significant in the other three studies (Fleckenstein et al., 2017; Fuller et al., 2015; Wheeler & Jacobson, 2013).

The studies used different protocols that included cold water immersion techniques, ice packs, ice massage, and ice compression for cryotherapy. Thus, in 18 studies (Abaïdia et al., 2017; Adamczyk et al., 2016; Ascensão et al., 2011; Denegar & Perrin, 1992; Doungkulsa et al., 2018; Elias et al., 2012; Ferreira-Junior et al., 2015; Fonseca et al., 2016; Glasgow et al., 2014; Leeder et al., 2015; Machado et al., 2017; Malmir et al., 2017; Marquet et al., 2015; Pointon et al., 2011; Selkow et al., 2015; Siqueira et al., 2018; Vaile et al., 2008; Wiewelhove et al., 2018) significant effects were described, while14 studies showed no effects (Behringer et al., 2018; de Paiva et al., 2016; Goodall & Howatson, 2008; Guilhem et al., 2013; Hassan, 2011; Howatson et al., 2005, 2008; Howatson & Van Someren, 2003; Isabell et al., 1992; Jajtner et al., 2015; Johar et al., 2012; Micheletti et al., 2019; Paddon-Jones & Quigley, 1997; Sellwood et al., 2007; Tseng et al., 2013).

For electrotherapy, the protocols used varied between TENS, micro-currents and interferential current, so that seven studies (Curtis et al., 2010; Denegar & Perrin, 1992; Ferguson et al., 2014; Mankovsky-Arnold, Wideman, Larivière, & Sullivan, 2013; McLoughlin et al., 2004; Rocha et al., 2012; Taylor et al., 2015) found positive outcomes while 10 studies (Akinci et al., 2020; Butterfield

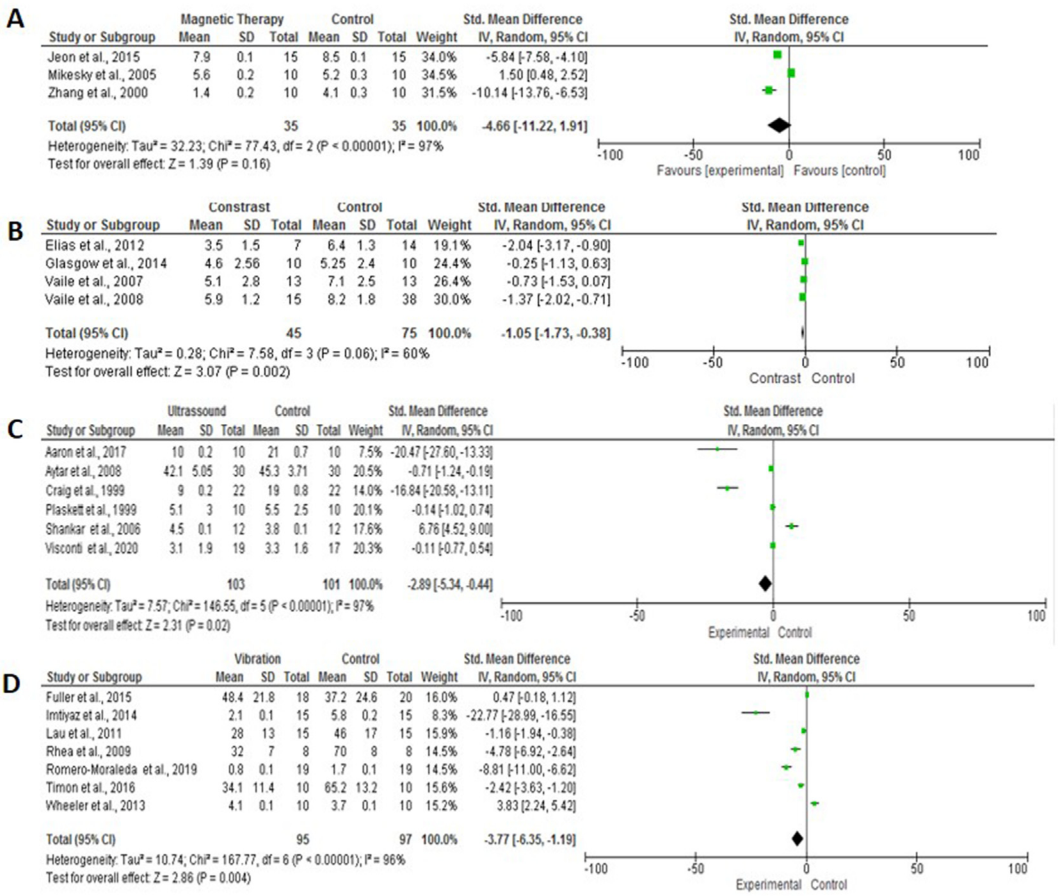

Fig. 2. Forest plot of comparison, Physical methods, outcome: A-Magnetic Therapy. B-Contrast. C- Ultrasound. D- Vibration *versus* no interventionon management of muscle soreness. Legend: SD: standard deviation; Std: standardized; CI: confidence interval.

et al., 1997; Craig et al., 1996a; Jajtner et al., 2015; Lambert et al., 2002; Malmir et al., 2017; Minder et al., 2002; Tourville, Connolly, & Reed, 2006; Vanderthommen et al., 2007; Weber et al., 1994) found no effects. On ultrasound, two studies (Aaron et al., 2017; Hasson et al., 1990) showed significant effects, while five studies (Aytar et al., 2008; Craig et al., 1999a; Parker & Madden, 2014; Plaskett et al., 1999; Shankar et al., 2006) did not observe effects.

The only study that investigated the effectiveness of short waves to improve pain did not observe significant effects on the use of this method (Northey et al., 2016). Phototherapy demonstrated positive effects in three studies (de Paiva et al., 2016; Douris et al., 2006; Glasgow et al., 2001) and no effects in four studies (Craig et al., 1996b, 1999b; Fleckenstein et al., 2016; Vinck et al., 2006). Finally, heat has demonstrated significant effects in four studies (Engel et al., 1996; Hassan, 2011; Petrofsky et al., 2012; Sellwood et al., 2007) and no effects in two other studies (Jayaraman et al., 2004; Vaile et al., 2008).

Fifty-eight studies were included in the meta-analysis comparing the effects of physical methods with the no intervention for DOMS's treatment. An analysis was performed for each type of intervention that can be examined below. The meta-analysis was not performed for heat technique because only two studies were eligible for such analysis.

It was found that magnetic therapy does not have statistical significance superior in relation to no intervention (A: 3 studies, n = 70; SMD = −4.66, 95 % CI [-11.22, 1.91]; p = 0.16 I^2 = 97 %). Contrast, ultrasound and vibration techniques are significantly superior to no intervention conditions (B - Contrast: 4 studies, n = 120; SMD = −1.05, 95 % CI [-1.73, −0. 38]; p = 0.002 I^2 = 60 %; C- Ultrasound: 6 studies, n = 204; SMD = −2.89, IC 95 % [-5.34, −0.44]; p = 0.02 I^2 = 97 %; D- Vibration: 7 studies, n = 192; SMD = −3.77, IC 95 % [-6.35, −1.19]; p = 0.004 I^2 = 96 %). See Fig. 2 for details.

The phototherapy was significantly superior to the no intervention (A: 6 studies, n = 142; SMD = −6.77, IC 95 % [-10.05, −3.49]; p = 0.0001; I^2 = 95 %). Electrotherapy was not significantly superior to control (B: 15 studies, n = 536; SMD = −3.97, IC 95 % [-12.74, 4.80]; p = 0.37; I^2 = 100 %). See Fig. 3 for details.

The use of cryotherapy has demonstrated a significantly superior outcome in relation to the no intervention (24 studies, n = 578; SMD = −4.02, 95 % CI [-6.58, −1.46]; p = 0.002 I^2 = 100 %).

3.2.2. Mechanical methods

It was considered mechanical methods the foam roller, compression, massage, stretching, and active exercise. All five studies that investigated this method found significant effects (Akinci et al., 2020; Macdonald et al., 2014; Naderi et al., 2020; Pearcey et al., 2015; Romero-Moraleda et al., 2019) on the foam roller technique; For compression, four studies demonstrated positive effects (Jakeman et al., 2010a, 2010b; Kraemer et al., 2001; Prill et al., 2019) while five studies did not reveal differences (Carling et al., 1995; Ferguson et al., 2014; Hill et al., 2017; Hoffman et al., 2016; Northey et al., 2016). Regarding massage, 14 studies

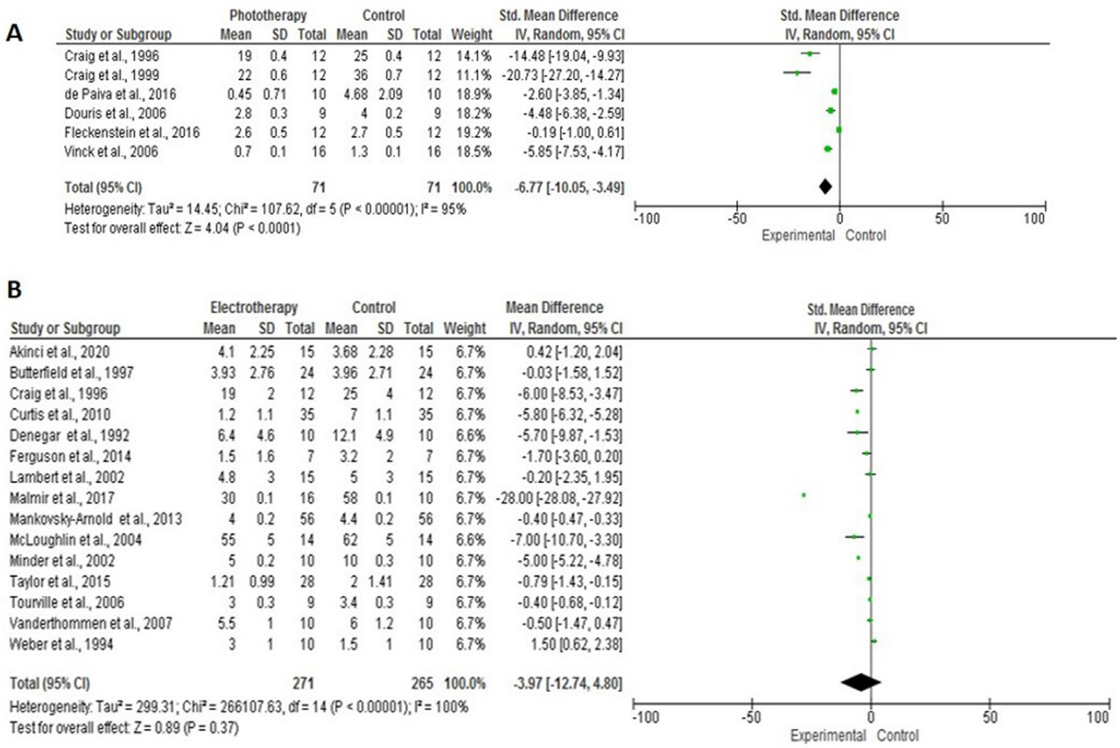

Fig. 3. Meta-analysis of effects of interventions physicals on muscle soreness rating. Outcomes: A-Phototherapy. B-Electrotherapy.Legend: SD: standard deviation; Std: standardized; CI: confidence interval.

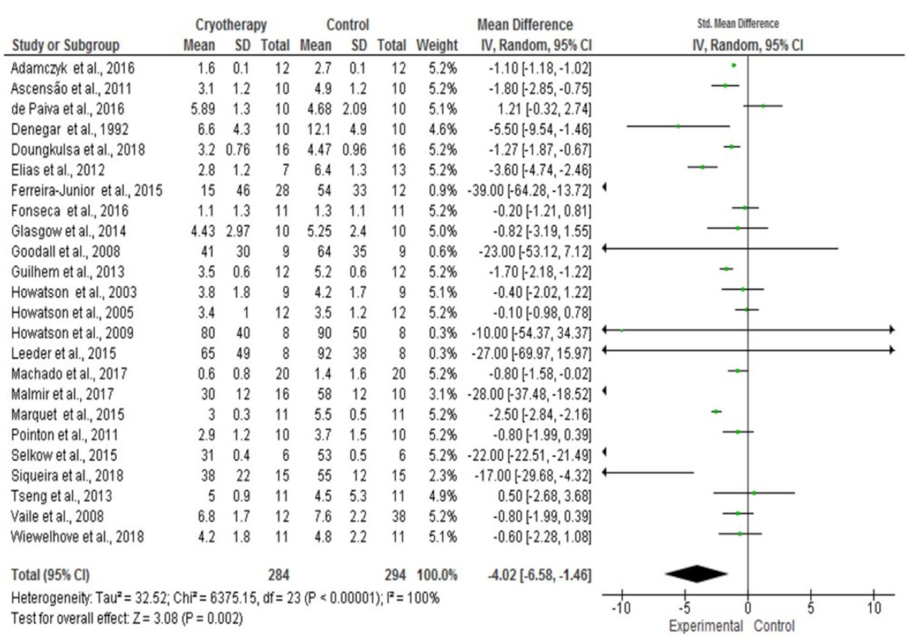

Fig. 4. Meta-analysis of effects of interventions physicals on muscle soreness rating. Outcome: Cryotherapy.Legend: SD: standard deviation; Std: standardized; CI: confidence interval.

reported significant outcomes (Andersen et al., 2013; Frey et al., 2008; Hilbert et al., 2003; Hoffman et al., 2016; Imtiyaz et al., 2014; Jakeman et al., 2010a, 2010b; Jay et al., 2014; Kargarfard et al., 2016; Smith et al., 1994; Tiidus & Shoemaker, 1995; Wiewelhove et al., 2018; Xiong et al., 2009; Zainuddin et al., 2005; Zebrowska et al., 2019), while eight other studies did not observe relevant effects on the use of this technique (Changa et al., 2020; Fuller et al., 2015; Hart et al., 2005; Howatson & Van Someren, 2003; Kong et al., 2018; Lightfoot et al., 1997; Visconti et al., 2020; Weber et al., 1994). For stretching, two studies (Ozmen

Table 2
Summary of the results of interventions presented by the meta-analysis.

Sub-categories	Intervention	Number of studies	Number of participants	I2 (%)	mean difference	95 % CI's
Physical Methods	Magnetic Therapy	3	70	97	−4.66	−11.22, 1.91
	Contrast	4	120	60	−1.05	−1.73, −0.38
	Ultrasound	6	204	97	−2.89	−5.34, −0.44
	Vibration	7	192	96	−3.77	−6.35, −1.19
	Phototherapy	6	142	95	−6.77	−10.05, −3.49
	Electrotherapy	15	536	100	−3.97	−12.74, 4.80
	Cryotherapy	24	578	100	−4.02	−6.58, −1.46
Mechanical Methods	Stretching	6	139	91	0.02	−1.32, 1.37
	Compression	9	224	93	−2.33	−3.76, −0.89
	Foam roller	3	130	91	−0.83	−2.23, 0.57
	Active exercise	13	307	93	−2.03	−3.15, −0.91
	Massage	19	476	94	−2.46	−3.52, −1.41
Other Methods	Kinesiotaping	4	146	74	−0.50	−1.18, 0.17
	Acupuncture	5	109	94	0.70	−1.55, 2.95

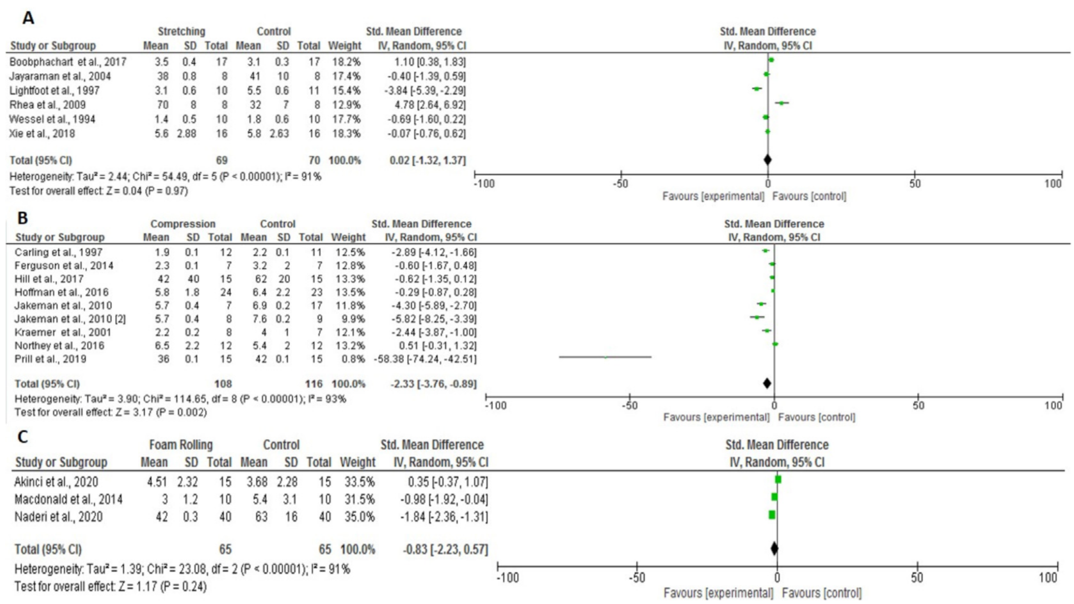

Fig. 5. Meta-analysis of effects of interventions mechanicals on muscle soreness rating. Outcomes: A- Stretching, B- Compression, C- Foam Roller *versus* no interventionon management of muscle soreness. Legend: SD: standard deviation; Std: standardized; CI: confidence interval.

et al., 2017; Wang et al., 2006) demonstrated significant effects while seven studies did not observe effects (Boobphachart et al., 2017; Lightfoot et al., 1997; Rhea et al., 2009; Torres et al., 2013; Wessel & Wan, 1994; Xie et al., 2018). Finally, seven studies (Akinci et al., 2020; Andersen et al., 2013; Hart et al., 2005; Olsen et al., 2012; Ozmen et al., 2017; Rey et al., 2012; Zainuddin et al., 2006) showed significant outcomes regarding active exercise, while nine studies did not observe effects (Changa et al., 2020; Isabell et al., 1992; Law & Herbert, 2007; Marquet et al., 2015; Tufano et al., 2012; Wang et al., 2006; Weber et al., 1994; Wheeler & Jacobson, 2013; Wiewelhove et al., 2018).

Forty-two studies were included in the analysis that examined the effects of mechanical methods compared to the no intervention for DOMS treatment. Also, a meta-analysis was performed for each type of intervention presented below.

Fig. 5 presents analyses resulting from stretching (A), compression (B) and foam roller (C) techniques. In this respect, it was observed that compression was significantly superior to no intervention (B: 9 studies, n = 224; SMD = −2.33, IC 95 % [-3.76, −0.89]; $p = 0.002$ $I^2 = 93$ %). On the contrary, elongation and foam roller are not significantly superior to no intervention for the investigated condition (A: 6 studies, n = 139; SMD = 0.02, IC 95 % [-1.32, 1.37]; $p = 0.97$ $I^2 = 91$ %; C: 3 studies, n = 130; SMD = −0.83, IC 95 % [-2.23, 0.57]; $p = 0.24$ $I^2 = 91$ %).

The active exercise (A) and the massage (B) have demonstrated to be significantly superior to the no intervention, to be improved in the DOMS (A: 13 studies, n = 307; SMD = - 2.03, IC 95 % [-3.15, 0.91]; $p = 0.0004$ $I^2 = 93$ %; B: 19 studies, n = 476; SMD = −2.46, IC 95 % [-3.52, −1.41]; $p < 0.00001$ $I^2 = 94$ %). See Fig. 6 for details.

3.2.3. Other methods

All the studies investigating the effects of kinesiotaping, observed significant results favorable to the use of this technique (Boobphachart et al., 2017; Haksever et al., 2016; Hazar Kanik et al., 2019; Kirmizigil et al., 2019; Ozmen et al., 2017). However, on acupuncture, two studies (Hübscher et al., 2008; Itoh et al., 2008) demonstrated statistically significant effects in relation to the no intervention and/or placebowhereas three studies (Barlas et al., 2000; Fleckenstein et al., 2016; Mikesky & Hayden, 2005; Romero-Moraleda et al., 2019) did not observe superior results.

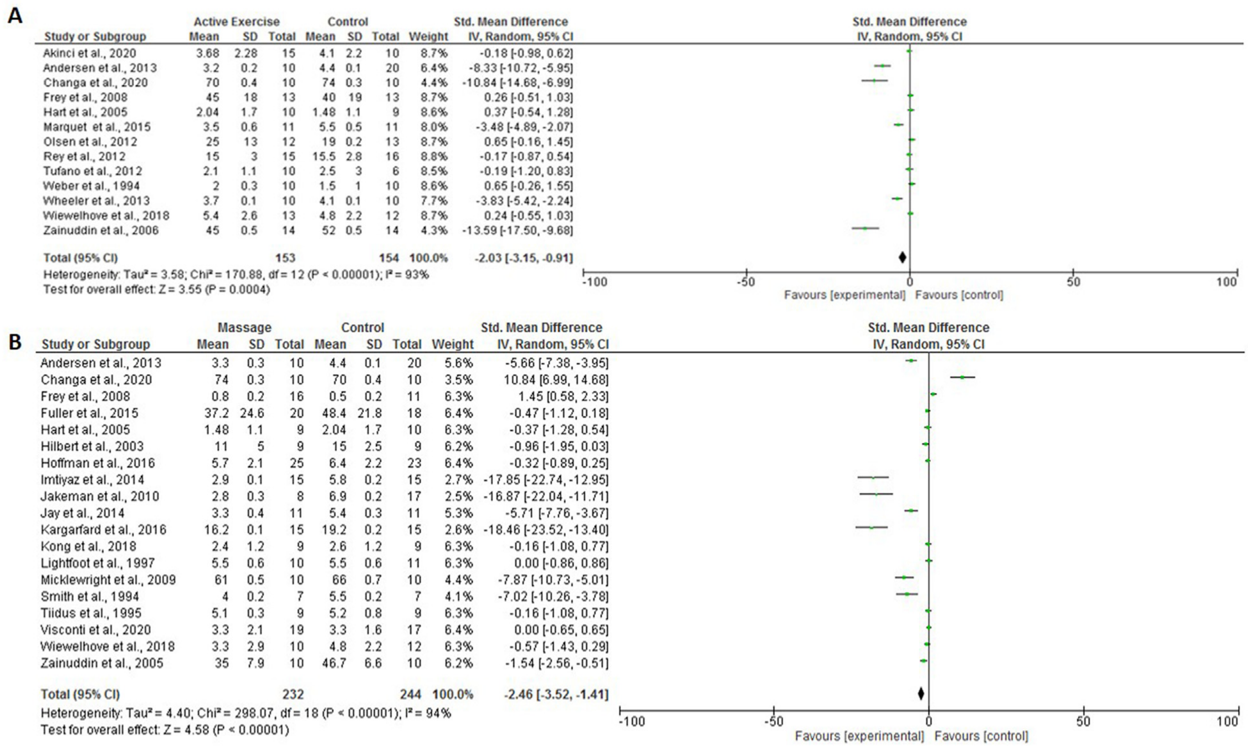

Fig. 6. Meta-analysis of effects of interventions mechanicals on muscle soreness rating. Outcomes: A- Active Exercise, B-Massage. Legend: SD: standard deviation; Std: standardized; CI: confidence interval.

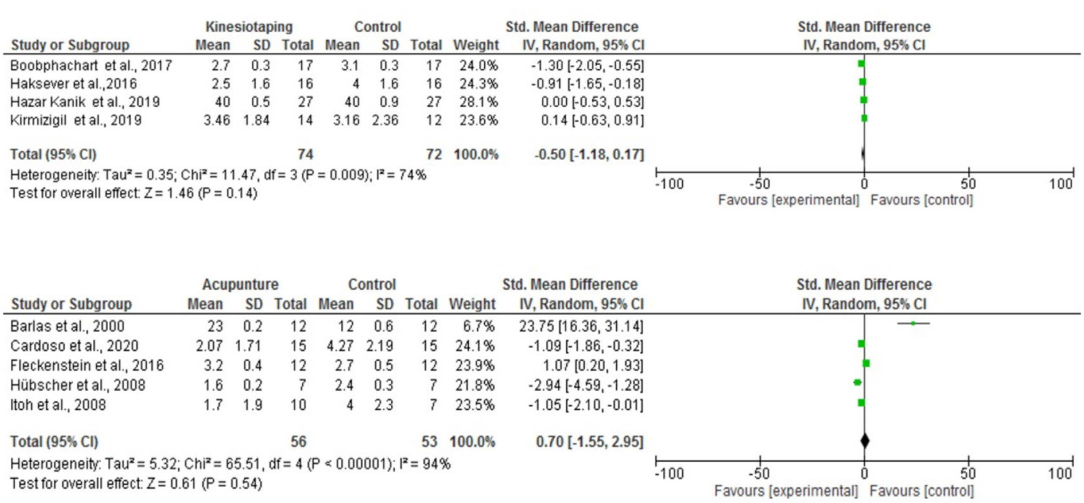

Fig. 7. Meta-analysis of effects of interventions of other methods on muscle soreness rating. Outcomes: A- Kinesiotaping and B – acupuncture. Legend: SD: standard deviation; Std: standardized; CI: confidence interval.

Despite this, the results showed an absence of superiority between the use of these interventions, over the improvement of DOMS, since there were no statistically significant differences for kinesiotaping (4 studies, $n = 146$; $SMD = -0.50$; 95 % CI -1.18, 0.17; $p = 0.14$; $I2 = 74$ %) e acupuncture (5 studies, $n = 109$; $SMD = 0.70$; 95 % CI -1.55, 2.95; $p = 0.54$; $I2 = 94$ %). See Fig. 7 for details.

Table 2 is used to combine the main findings for each modality you have reported in Figs. 2–7. For each modality, we included: the number of studies; the number of participants; I2; the mean difference and 95 % CI's to compare the relative information for each modality within a single figure.

3.3. Methodological quality assessment

The methodological evaluation of the quality of the studies has yielded an average of 4.7 points on the PEDro scale. Sixteen studies were considered “high quality” (Aaron et al., 2017; Aytar et al., 2008; Chang et al., 2019; Craig et al., 1999b; de Paiva et al., 2016; Ferreira-Junior et al., 2015; Fleckenstein et al., 2016, 2017; Frey et al., 2008; Fuller et al., 2015; Glasgow et al., 2014; Lambert et al., 2002; Mikesky & Hayden, 2005; Selkow et al., 2015; Sellwood et al., 2007; Vinck et al., 2006); 42 studies were considered "moderate quality" (Adamczyk et al., 2016; Andersen et al., 2013; Butterfield et al., 1997; Changa et al., 2020; Craig et al., 1996b; Curtis et al., 2010; Doungkulsa et al., 2018; Elias et al., 2012; Glasgow et al., 2014; Guilhem et al., 2013; Hart et al., 2005; Hasson et al., 1990; Hazar Kanik et al., 2019; Hoffman et al., 2016; Howatson et al., 2008; Jayaraman et al., 2004; Jeon et al., 2015; Johar et al., 2012; Kirmizigil et al., 2019; Kong et al., 2018; Law & Herbert, 2007; Leeder et al., 2015; Macdonald et al., 2014; Machado et al., 2017; Malmir et al., 2017; McLoughlin et al., 2004; Micheletti et al., 2019; Naderi et al., 2020; Paddon-Jones & Quigley, 1997; Rey et al., 2012; Rocha et al., 2012; Romero-Moraleda et al., 2019; Siqueira et al., 2018; Smith et al., 1994; Tourville et al., 2006; Wang et al., 2006; Weber et al., 1994; Wiewelhove et al., 2018; Xie et al., 2018; Zebrowska et al., 2019; Zhang et al., 2000) and 63 studies were considered "low quality" (Akinci et al., 2020; Behringer et al., 2018; Boobphachart et al., 2017; Carling et al., 1995; Ferguson et al., 2014; Haksever et al., 2016; Hill et al., 2017; Imtiyaz et al., 2014; Jakeman et al., 2010a, 2010b; Kraemer et al., 2001; Lau & Nosaka, 2011; Northey et al., 2016; Ozmen et al., 2017; Pearcey et al., 2015; Prill et al., 2019; Rhea et al., 2009; Timon et al., 2016; Vaile et al., 2007, 2008; Visconti et al., 2020; Wheeler & Jacobson, 2013)' (Ascensão et al., 2011; Hassan, 2011; Hilbert et al., 2003; Howatson & Van Someren, 2003; Jajtner et al., 2015; Kargarfard et al., 2016; Lightfoot et al., 1997; Marquet et al., 2015; Micklewright, 2009; Tiidus & Shoemaker, 1995; Torres et al., 2013; Weber et al., 1994; Wessel & Wan, 1994; Xiong et al., 2009; Zainuddin et al., 2005)' (Abaïdia et al., 2017; Barlas et al., 2000; Cardoso et al., 2020; Craig et al., 1996a, 1999a; Howatson et al., 2005; Itoh et al., 2008; Mankovsky-Arnold et al., 2013; Minder et al., 2002; Parker & Madden, 2014; Petrofsky et al., 2012; Plaskett et al., 1999; Shankar et al., 2006; Taylor et al., 2015; Tseng et al., 2013; Tufano et al., 2012; Vanderthommen et al., 2007; Zainuddin et al., 2006) (See details in Appendix 3). The overall analysis results showed that there was "low quality evidence" (according to GRADE classification).

4. Discussion

The results of the meta analysis of interventions to improve pain associated with DOMS, demonstrated a statistically significant improvement for the modalities of contrast, cryotherapy, phototherapy, vibration, ultrasound, massage, active exercises and compression when compared with no intervention. In counterpart, acupuncture, kinesiotaping, foam roller, elongation, and electrostimulation techniques have not demonstrate effects statistically significant.Review study by Dupuy et al. (Dupuy et al., 2018) has investigated similar techniques to those studied in the present trial to treat DOMS's symptoms. This study concluded that the technique with the most significant effect on pain was massage. Similarly, a meta-analysis that has investigated such a technique showed positive effects after the exercise (Guo et al., 2017). In comparison to no intervention, massage showed a more significant improvement in VAS scores for pain than the other interventions investigated. It is assumed that, this expressive effect on pain is basically based on massage's ability to increase local blood flow. In addition, the clinical popularity of massage is associated with the logistic practicality, low cost, and personal preference of athletes inherent to the application of this technique (Fleckenstein et al., 2016).

Regarding the active recovery, we verified significantly effects superior when compared to the no intervention. These data agree with the previous data (Dupuy et al., 2018) and can be justified by increasing the blood flow, understood as responsible for removing metabolic residues and better recovery conditions. In relation to the compression, the data from the meta-analysis showed significant effects. A possible explanation that justifies such findings refers to the potential reduction of interstitial space, which causes changes in osmotic pressure and reduces fluid diffusion, with improved venous return (Dupuy et al., 2018). Thus, clinically, there is a limitation of bump and edema and less long-term pain.

Among the physical methods analyzed, phototherapy has demonstrated the best effect. The effects of phototherapy on functional and biochemical recovery are well described in the literature. We believe that the same arguments contribute to the effect on pain verified in this study. In this sense, phototherapy has its recuperative effects (Leal-Junior et al., 2015) attributed to increased mitochondrial activity and ATP synthesis, accelerating the inflammatory process. In addition, the production of aerobic ATP seems to assist in the removal and oxidation of lactic acid, stimulated by phototherapy (Leal-Junior et al., 2015).

Contrast and cryotherapy demonstrated the same significant effect in this study. In relation to cryotherapy, the previous meta-analysis verified the same outcome (Leeder et al., 2012). The explanation for this result is based on vasoconstriction caused by low temperatures, which results in less interstitial fluid diffusion and a lower magnitude of the inflammatory response, which would justify a reduction in the sensation of pain (Fleckenstein et al., 2016; Leeder et al., 2012). In addition, theories defend the analgesic effect of cold. In contrast, previous qualitative review (Hing et al., 2008) has shown positive effects on this method, as well as those verified in this study. Probable grounds for such outcomes are related to the mechanism triggered by successive periods of vasoconstriction and vasodilatation, which sequentially generates less formation for edema, with the potential to influence inflammatory pathways and reduce the sensation of pain (Hing et al., 2008).

Acupuncture, kinesiotaping, foam roller, elongation, and electro-stimulation techniques have not demonstrated significant effects. Such data converge with data presented in qualitative studies (Fleckenstein et al., 2016; Ko & Clarkson, 2020) and are based on a greater magnitude of placebo effects related to such techniques, which so far do not seem to support outcomes capable of sustaining the proposed physiological theories on each of these methods (Ko & Clarkson, 2020). Additionally, the application protocols on such methods were very different, which may justify, in parts, the discrepancy identified.

Specifically, the outcomes presented combine data, which identify the scope and magnitude of the effects of clinical therapeutic techniques used in the management of DOMS, with intrinsic potential capable of guiding practical conduct based on scientific evidence in a field, clinical and scientific context. In addition, results have been observed in an athletic and healthy population from realizing the techniques described. However, it is essential to highlight that the lack of standardization on the protocols used, including different dose-response descriptions, may make it difficult to compare the same nature results and limit in-depth discussions. In this sense, future studies need to be attentive to the best definition and description of the parameters used regarding each technique used.

The present study has some limitations that deserve to be presented. Thus, although the literature on the subject is vast, the clinical trials are of low quality and present important gaps in standardization of protocols and description of the methodology used mainly on the empirical fragility regarding the dose responses used. Secondly, the present study only evaluated the pain parameter, not verifying other important functional variables such as sensitivity, range of motion, stiffness, strength and cell injury markers. Thus, some techniques may not significantly affect the improvement of DOMS, but improve the mentioned parameters. Future studies must answer this question. Moreover, we do not specifically address the best dose-response for each technique. Therefore, prospective review and meta-analysis studies must investigate the best parameters on the techniques with significantly superior effects presented in this study.

On the other hand, strong points are associated with the broad search strategy used, without restrictions on the sample's condition such as athletic level, age, sex, year, or publication language. The PEDro scale was also used to assess the studies' methodological quality and use the GRADE system to classify the quality of the evidence. The results have important implications for clinical practice, optimizing the use of the resources provided in specific populations.

5. Conclusions

The findings of this study demonstrated that contrast techniques, cryotherapy, phototherapy, vibration, ultrasound, massage, active exercise, and compression clothing are more effective than no intervention for DOMS treatment. The low quality of the included studies should be considered. In addition, several modalities were found to be potentially beneficial and that clinicians can make choices based on their individual circumstances. In this meta-analysis, different protocols were considered, which must be considered and not extrapolated to different population profiles.

Declaration of competing interest

None declared. The authors declare that the research was conducted with no features that could be construed as a potential conflict of interest.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ptsp.2021.07.005.

Ethical information

As this is a systematic review study, ethical approval is not required. However, this study was registered in PROSPERO (suitable for this type of study), under registration number: CRD42020179798.

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